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2022 Ranger Mine Closure Plan

Executive Summary

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Cover: Magpie Geese (*Anseranas semipalmata*)

1 PREAMBLE

Energy Resources of Australia Ltd (ERA) produced uranium oxide for the global nuclear energy market for more than 40 years. The Ranger ore body, located on Mirarr country in the Alligator Rivers Region of the Northern Territory, was first discovered in 1969. ERA was established in February 1980, and when floated on the Australian Stock Exchange (ASX) in July 1980 was at that time the largest ever public float in Australian history.

After considerable exploration and site preparation activity, mining started from Pit 1 (Plate ES1), processing soon followed with the plant commissioned in July 1981, and the first drum of uranium oxide was produced on 13 August 1981.

Mining from Pit 1 finished in December 1994 and finished from Pit 3 in November 2012. The last processing of stockpiled ore and the final drum of uranium oxide was produced on 8 January 2021 (Plate ES2), completing the mine's operational stage after producing a total of 132,000 tonnes of uranium oxide.

As the mine transitions to its final stage, ERA's focus is to create a positive legacy and achieve world class, sustainable rehabilitation and closure of its former mine assets.

The first Ranger Mine Closure Plan (MCP) was submitted in May 2018 to the Commonwealth Minister for Resources and Northern Australia, and the Northern Territory Minister for Primary Industry and Resources. The MCP is a live document that is updated annually.

Plate ES1 Pit 1 in 1981

Plate ES2 Final drum of Uranium Oxide

The environmental protection conditions within which ERA has operated and must now close the mine are set out in the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (ERs). These ERs are attached to the Ranger Authority issued under Section 41 of the Atomic Energy Act 1953 (S41). The ERs are also given effect through the Ranger Authorisation issued under the Northern Territory Mining Management Act 2001. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation.

The ultimate objective for closing the mine is to prevent impacts to people and the environment, and to rehabilitate the site to a standard that would allow its incorporation into Kakadu National Park.

ERA has worked in close collaboration with many stakeholders over the last 40 years, generating a significant amount of information from research and monitoring. This ongoing information collection and analysis is guiding the rehabilitation activities towards a successful mine closure (Plate ES3 and ES4).

The MCP is ERA's primary mechanism to describe, and seek approval for, the mine's rehabilitation strategy and closure activities. The MCP seeks to consolidate the relevant information from the last 40 years and demonstrate how the current and planned rehabilitation activities will achieve the ERs. To ensure its currency, and to incorporate lessons learnt from ongoing modelling and monitoring studies, it is updated and submitted for approval annually.

Standalone applications for the closure of certain aspects of the mine (e.g. Pit 1, Pit 3, Tailings Storage Facility and Final Landform) are also required. Once approved, key information from these applications is incorporated into the relevant annual update of the MCP.

ERA was exempt from providing a 2021 MCP. As such, the 2022 MCP includes updates from 1 July 2020 to 30 June 2022.

This Executive Summary does not strictly follow the structure of the 2022 MCP main document. Rather, it seeks to inform the reader of the key aspects for this final stage in the journey of the Ranger mine. Figure ES1 shows a simplified approach of how ERA are achieving successful closure.

Plate ES3 Seedlings in ERA's nursery

Plate ES4 Early successful revegetation on Pit 1

Environmental Requirements (S41) →	Risks to achieving Environmental Requirements →	Information required to manage impacts and risks →	Closure implementation →	Monitoring and maintenance
Primary Objectives: • Self-sustaining ecosystem • Stable radiological conditions • Stable landform	• Closure risk assessment workshops (2008 – present) • ERA Closure Risk Management Plan • Ranger Rehabilitation and Closure Risk Assessment (CSIRO 2013)	• Key Knowledge Needs (KKNs) • Best Practicable Technologies (BPTs) to achieve As Low As Reasonably Achievable (ALARA) • Engineering and environmental studies	• Description of the activities being undertaken to achieve the final landform	• Closure research studies • Monitoring, maintenance and adaptive management • Achieving completion criteria
MCP: Executive Summary – S3 Main Document – S3	MCP: Executive Summary – S5 Main Document – S7	MCP: Executive Summary – S5 Main Document – S5 & 6	MCP: Executive Summary – S6 Main Document – S9	MCP: Executive Summary – S7 Main Document – S8 & 10

Stakeholder Engagement

MCP:
Executive Summary – S4
Main Document – S4

Figure ES1: Simplified approach to delivering successful rehabilitation and closure of the Ranger mine

2 MINE CLOSURE PLAN UPDATES

The 2022 MCP includes both minor and substantial updates to several sections of the document. Sections that have undergone substantial update since the 2020 MCP are listed in Table ES1. The remainder of the 2022 MCP received minor updates, or the information from the 2020 MCP were carried forward as it remains relevant.

Each MCP is subject to stakeholder review and detailed feedback. Feedback is considered and included in the 2022 MCP where possible. On occasions, some feedback requests for specific details that will be understood better when current and future studies are completed. Where this occurs, the requested details will be incorporated into future MCPs as the information becomes available or has been assessed and approved through future standalone activity-specific applications.

Figures ES2 and ES3 provide an indicative sequence of the major closure activities and primary standalone applications respectively to help inform the reader of when certain information is likely to be available, and therefore the corresponding MCP where this information would be discussed in detail. It is emphasised that the timing provided in Figure ES2 is subject to change and indicative only as of 30 June 2022. Appendix A to the main document outlines the stakeholder feedback that was received on the 2020 MCP, as well as the relevant sections within the 2022 MCP where the feedback is addressed.

Table ES1 Substantial Updates from 2020 MCP

Chapter	Description of update
Chapter 1 – Scope and Purpose	In July 2021, ERA commenced a major reforecast of cost and schedule after risks materialised post-completion of the 2019 Feasibility Study. The preliminary findings by ERA from its reforecast exercise based on the Ranger rehabilitation project being completed in accordance with the methodology set out in the 2020 Mine Closure Plan indicates that: (i) the revised total cost of completing the Ranger Project Area rehabilitation, including incurred spend from 1 January 2019, is forecast to be approximately between $1.6 billion and $2.2 billion (undiscounted nominal terms); and (ii) the revised date for completing the Ranger Project Area rehabilitation is forecast to be between Quarter 4, 2027 and Quarter 4, 2028. In May 2022, ERA commenced a feasibility study update in connection with a lower technical risk rehabilitation methodology (primarily relating to the subaerial capping of Pit 3) and to further refine the Ranger Project Area rehabilitation execution scope, risks, cost and schedule. The 2022 Feasibility Study is expected to take approximately 12 months to complete. The 2022 MCP update provides an indicative sequence of major closure activities and estimates of future milestones, with an indicative closure sequence out to Quarter 4, 2028 provided.

Chapter	Description of update
Chapter 1 – Scope and Purpose	Chapter 1 notes that the relevant aspects of the Mining Management Plan (MMP) have been incorporated within the Mine Closure Plan (MCP).
Chapter 5 – Key Knowledge Needs (KKN) Supporting Studies	Substantial updates have been provided for the KKNs that have materially advanced since the submission of the 2020 MCP.
Chapter 6 – Best Practicable Technologies (BPTs)	In response to stakeholder feedback on the 2020 MCP, detailed descriptions of completed BPTs have been removed from the chapter and included as Appendix 6.1. The chapter now focuses on the currently active, yet to be approved, BPT (Pit 3 backfill and capping).
Chapter 7 – Risk Assessment and Management	Risk assessments and updates to the closure risk register occur on a regular and ongoing basis. The chapter and accompanying appendix have been updated to reflect the latest risk updates.
Chapter 8 - Post-mining land use, closure objectives and closure criteria	The ecosystem restoration closure criteria have undergone significant review and stakeholder engagement, and the agreed criteria are included in this chapter.
Chapter 9 – Closure Implementation	Substantial updates have been provided for those aspects of closure implementation that have materially advanced since the submission of the 2020 MCP.
Chapter 10 – Closure Monitoring and Maintenance	Substantial updates have been provided for those aspects that have materially advanced since the submission of the 2020 MCP.
Chapter 11 – Financial Provision for Closure	This chapter has been updated to reflect recent announcements.
Appendix A – Stakeholder Feedback	This appendix has been simplified to remove duplication and provide a cross-reference to the relevant section/s of the 2022 MCP that address the stakeholder feedback on the 2020 MCP, as opposed to including in the appendix a summary of the often complex and lengthy response.

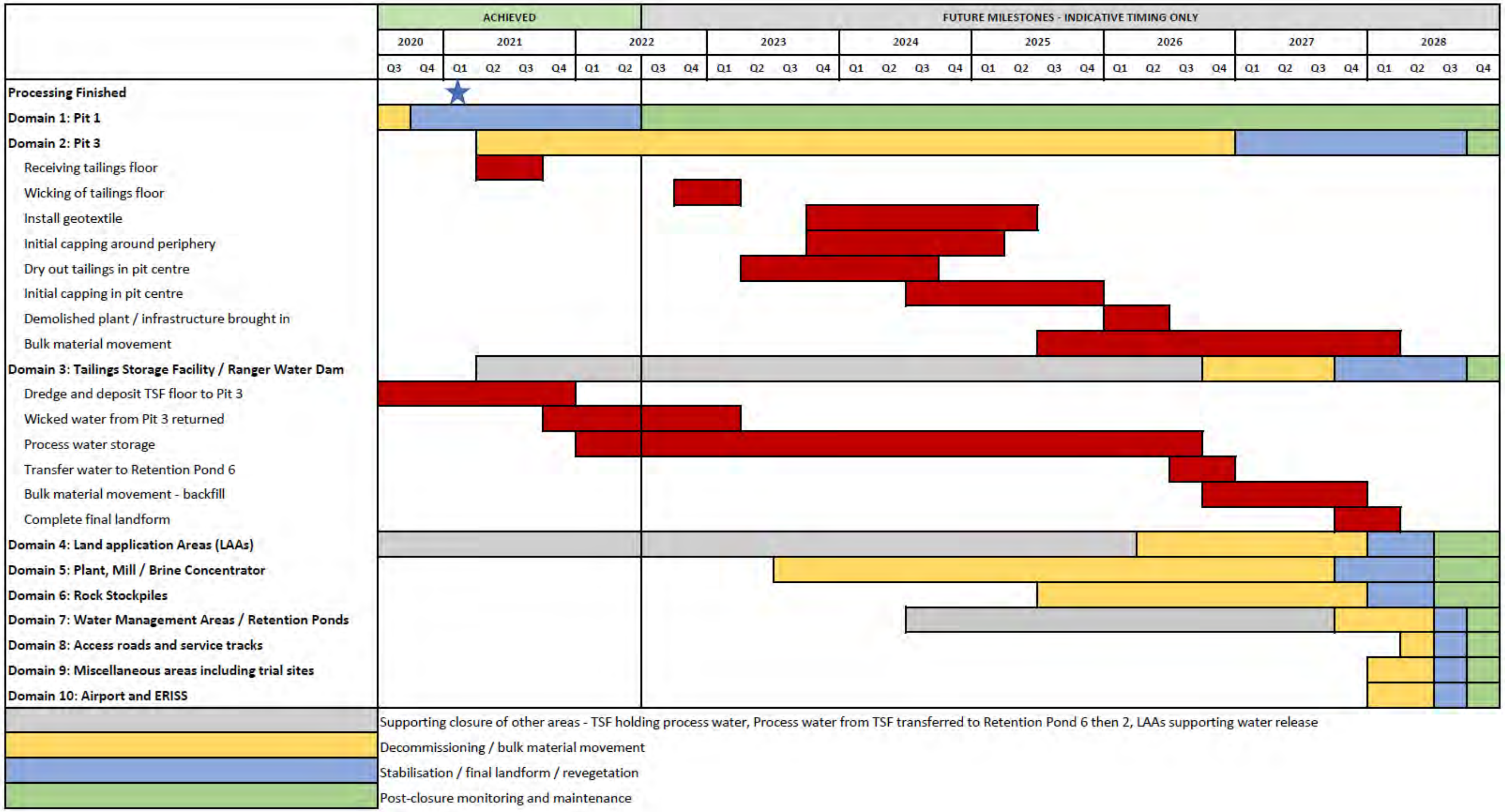

Figure ES2 Indicative sequence of major closure activities - as of 30 June 2022

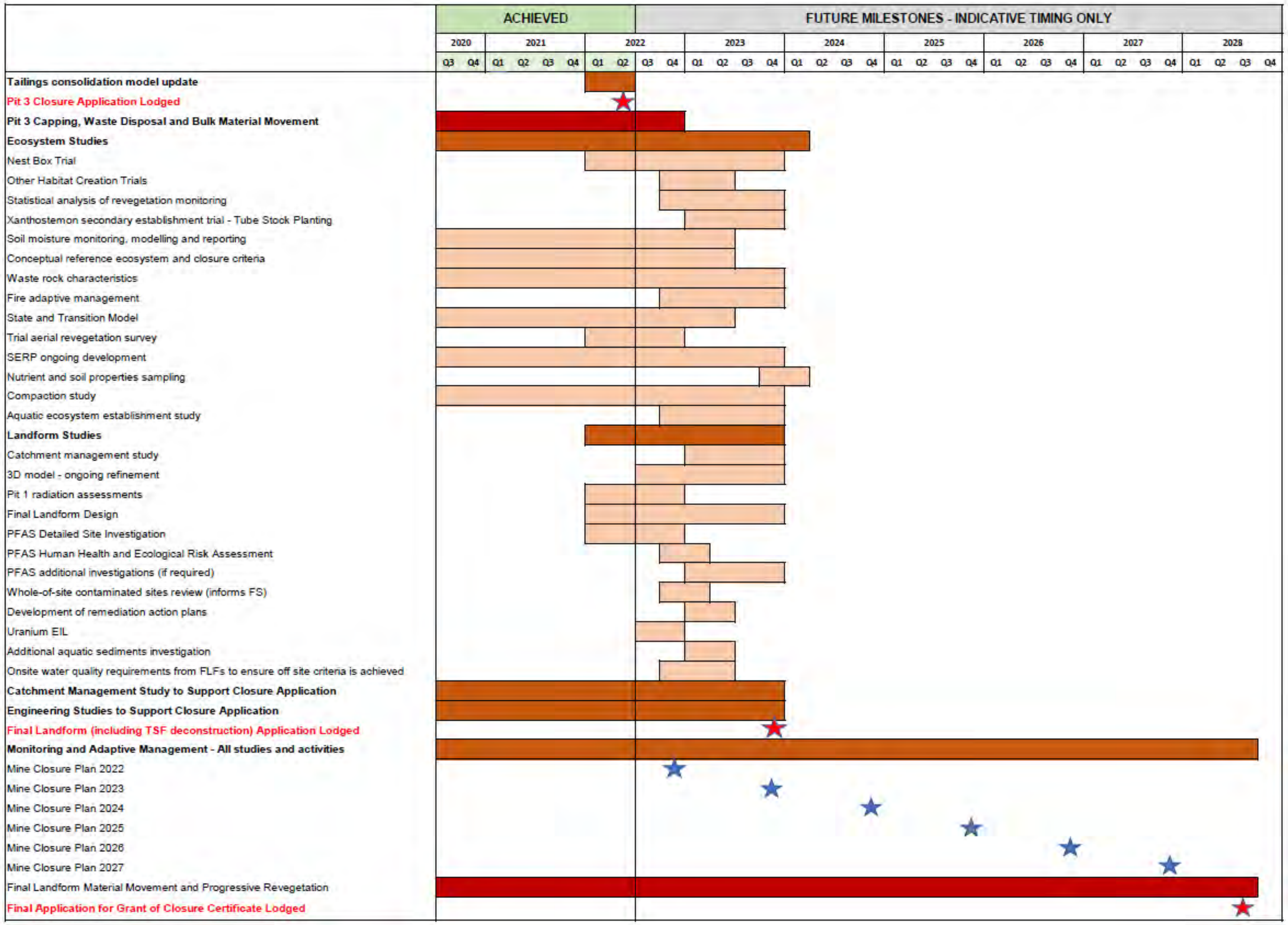

Figure ES3 Indicative timing of key studies and approvals

3 OVERVIEW OF THE MINE AND CLOSURE DOMAINS

The Ranger uranium mine (Ranger Mine) is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 km east of Darwin on Mirarr country in the Alligator Rivers Region of the Northern Territory (Figure ES4). The RPA is surrounded by Kakadu National Park and is bounded on the east and north by Magela Creek and its tributaries, and on the west by Gulungul Creek and its tributaries. Access to the mine is via the Arnhem Highway (Figure ES5).

The Commonwealth Government announced approval of the project under the, now repealed, Commonwealth *Environmental Protection (Impact of Proposal) Act 1974* (*EPIP Act*) in August 1977, following submission of an Environmental Impact Statement (EIS) and associated supplements under this Act. Construction of the Ranger Mine began in 1979 and the mine came into full production in 1981.

During the same period, much of the Alligator Rivers Region was declared a National Park and Aboriginal people were given a major role in the management of Kakadu National Park. 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* (*Aboriginal Land Rights Act*) and the Commonwealth Government entered an agreement with the Northern Land Council (NLC) to permit mining to proceed.

The Mirarr people are the Traditional Owners of the lands on which the Ranger mine operates. Mirarr country encompasses the RPA, the Jabiluka Mineral Lease, the town of Jabiru, and parts of Kakadu National Park including the wetlands of the Jabiluka billabong country. In 1995, the Mirarr established the Gundjeihmi Aboriginal Corporation (GAC), an incorporated body, to assist them to manage a balance between sustainable development and traditional practice on their land. The GAC represents the Mirarr Traditional Owners in discussions and negotiations with ERA.

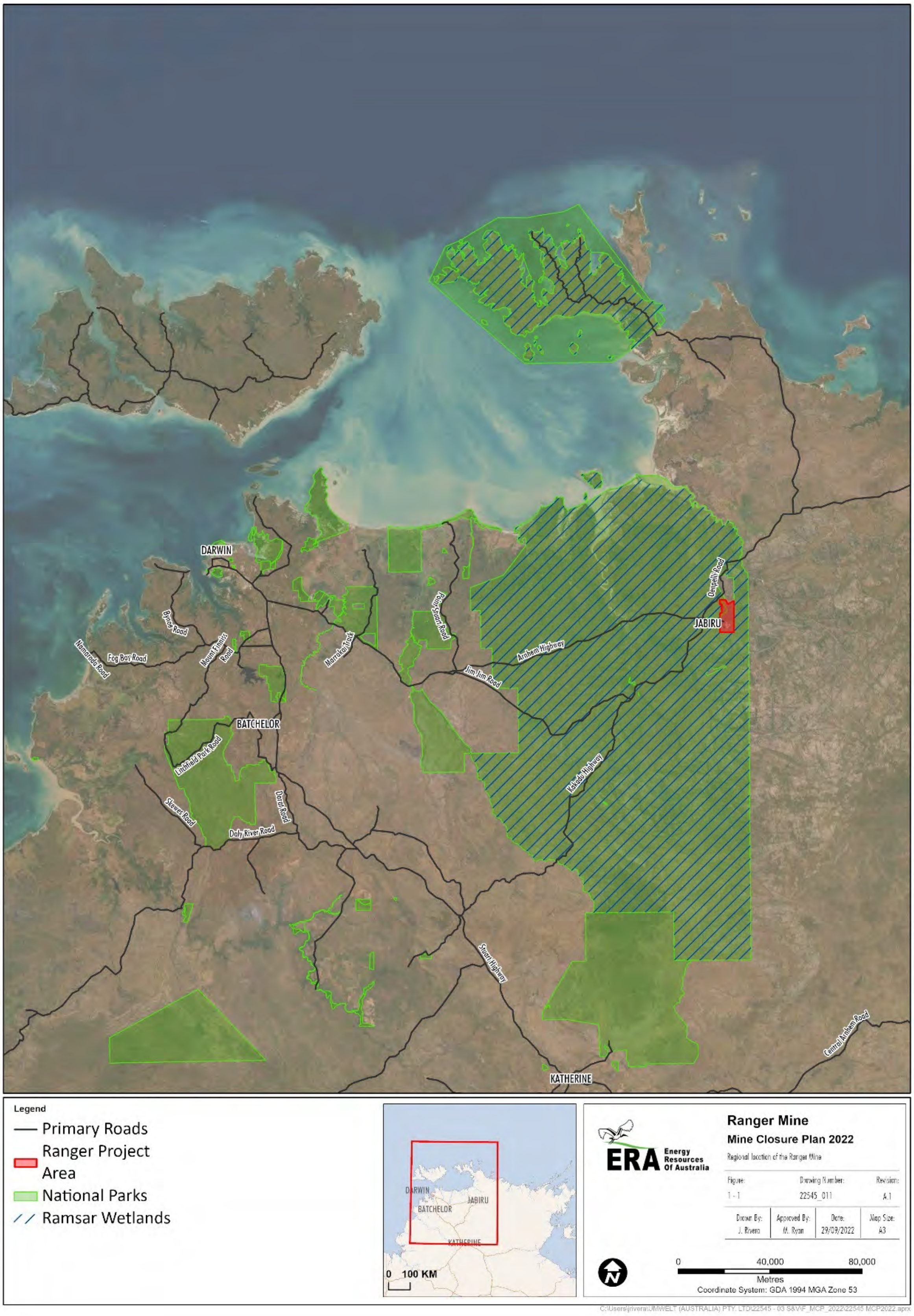

Figure ES4: Regional location of Ranger Project Area

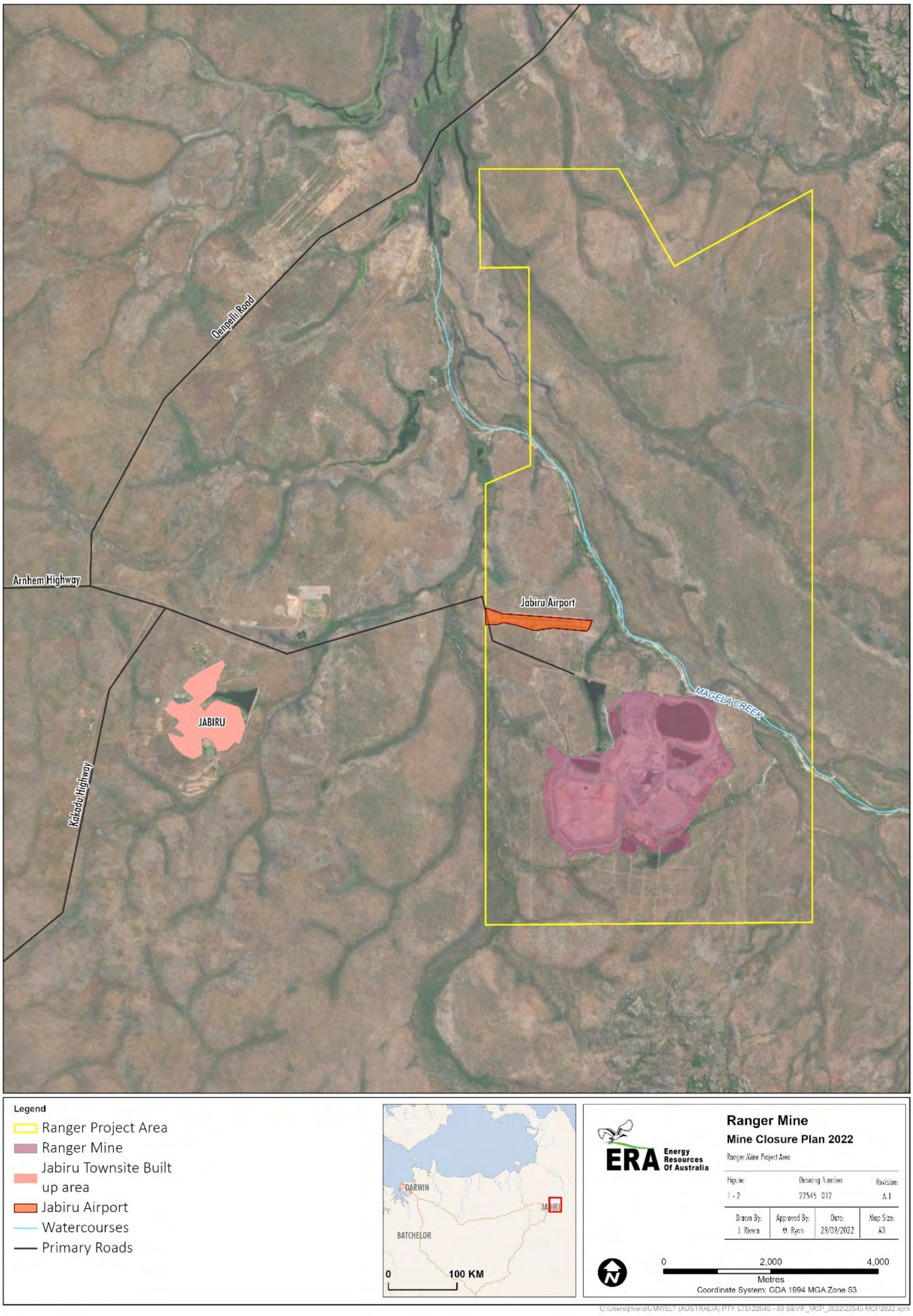

Figure ES5: Ranger Mine Project Area and nearby Jabiru Township

With the completion of on-site processing, ERA's primary focus is now the successful rehabilitation and closure of the mine. Areas of the mine site that have similar features, decommissioning and/or rehabilitation requirements for closure have been grouped into Closure Domains. These Domains are shown on Figure ES6 and comprise the following:

- Domain 1: Pit 1
- Domain 2: Pit 3
- Domain 3: Tailings storage facility (TSF) / raw water dam (RWD)
- Domain 4: Land application areas – these areas are used for irrigation of treated water during the dry season
- Domain 5: Processing plant, water treatment plant, power station, administration and maintenance facilities
- Domain 6: Rock stockpiles
- Domain 7: Water retention ponds, water storage structures and constructed wetlands
- Domain 8: Linear infrastructure corridors supporting access roads and service tracks
- Domain 9: Miscellaneous areas that include trial sites
- Domain 10: Jabiru Airport and offices of the Environmental Research Institute of the Supervising Scientist (ERISS)
- Domain 11: Residual Ranger Project Area (RPA). This area encompasses the balance of the RPA (i.e. all areas not included in another closure domain). It is largely undisturbed but was subject to exploration activities (e.g. historic exploration drill holes, access tracks). It also contains monitoring wells and sampling stations. Parts of this domain will be the first areas that ERA seeks progressive relinquishment under the *Mining Management Act* (section 46).

Figure ES2 provides a high-level sequence for the main stages of closure for each of these domains.

Figure ES6: Location and extent of Closure Domains

4 STAKEHOLDER ENGAGEMENT

The ERA approach to stakeholder engagement is centered on maintaining our relationships based on mutual respect, active partnership, transparency and long-term commitment. ERA will continue to connect with and respect Mirarr culture and the aspirations of local communities as we create a positive legacy and achieve world class, sustainable rehabilitation of the Ranger mine.

Our approach to stakeholder engagement has fostered collaboration and cooperation with a diverse range of stakeholders on the following key aspects of closure and rehabilitation:

- the overall planning process and schedule
- engineering and design criteria for technical aspects of closure such as water treatment, tailings transfer, backfilling of mine pits and the final landform design
- post-mining land use, closure objectives and closure completion criteria
- legal requirements and obligations associated with the various agreements for the mine and Jabiru township
- land tenure and governance.

Figure ES7 illustrates the matrix of stakeholders engaged in two-way conversations regarding the closure of the Ranger mine. These discussions are coordinated through the forums listed in Table ES2.

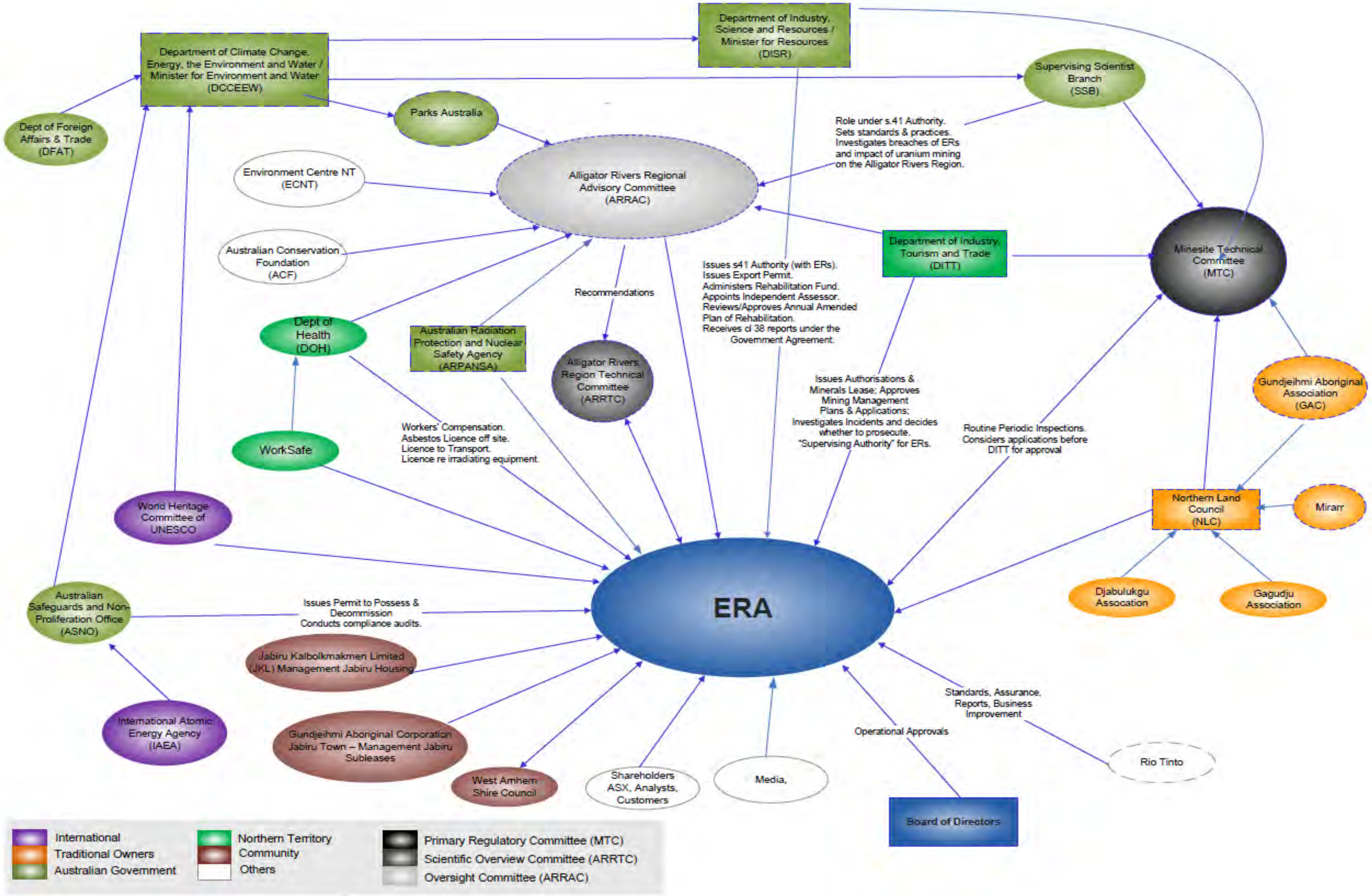

Figure ES6 Ranger Mine Stakeholder Matrix

Table ES2 Stakeholder Engagement Forums

Engagement forum	Frequency	Comment
Minesite Technical Committee (MTC)	Bi-annually (additional meetings held as required)	The MTC is the formal forum for key advisory and stakeholder groups to discuss and resolve technical environmental management matters relating to the closure of the Ranger Mine, regulatory functions of the NT Government, functions of the Supervisory Scientist, and the views of the Mirarr and other affected Aboriginal people. It includes representatives of the Northern Territory Department of Industry, Tourism and Trade (DITT) (Chair), Commonwealth Department of the Climate Change, Energy, the Environment and Water (DCCEEW), Supervising Scientific Branch (SSB), Energy Resources of Australia Ltd (ERA), Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC) (the Commonwealth Department of Industry, Science & Resources (DISR) are invited as an observer).
Ranger Closure Consultative Forum (RCCF)	Monthly	The RCCF is a forum for ERA to discuss progress and matters relating to the closure of the Ranger Mine with the key stakeholder group representatives from the DISR, SSB, DITT, and the NLC/GAC. The purpose of the forum is to provide ongoing updates of closure activities, confidence in the closure strategy for achieving environmental requirements, information on upcoming approvals, and to receive feedback from stakeholders on studies, applications and the close-out progress of Key Knowledge Needs (KKN).
Alligator Rivers Region Technical Committee (ARRTC)	Bi-annually	The ARRTC was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* and reviews the appropriateness and quality of scientific research conducted by Northern Territory and Commonwealth Government agencies, ERA and others relating to protection of the environment from the potential impacts of uranium mining in the Alligator Rivers Region. Members include an independent Chairperson, the Supervising Scientist, independent scientific members, a member representing the NLC and a member representing environmental non-government organisations. http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrtc
Alligator Rivers Region Advisory Committee (ARRAC)	Bi-annually	The ARRAC was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* and facilitates communication between Government, industry and community stakeholders on environmental issues associated with uranium mining in the Alligator Rivers Region. Members include an independent Chairperson, the Supervising Scientist, representatives from several Northern Territory Government departments, Office of the Administrator of the Northern Territory, several Commonwealth Government departments, non-government organisations (NGOs), ERA and other uranium mining/exploration companies that operate in the region. http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrac.
Ecosystem Restoration Forum	Fortnightly	Communication and consultation with stakeholders focusing on ecosystem restoration closure criteria and KKNs.
Investor briefings	Bi-annually	Briefings provided by the ERA Chief Executive regarding ERA operations to all company shareholders.

Engagement forum	Frequency	Comment
Relationship Committee	Quarterly	The Relationship Committee was established under the Ranger Mining Agreement between ERA and the NLC in 2013 to review processes and ensure effective information sharing between ERA and the Mirarr Traditional Owners and their representatives.
Ministerial briefings	Regularly as required	Briefings are provided to both Federal and Northern Territory Ministers and senior advisors on operations of the Ranger Mine, including aspects of closure.
Kakadu Board of Management	Quarterly, ERA update provided bi-annually	Kakadu National Park (NP) is a park jointly managed by Parks Australia and the Traditional Owners of Kakadu. A board of management has been established as part of the governance structure for the NP and consists of Commonwealth Government representatives, Park Management and Traditional Owners from each region in the NP. ERA provides a regular operations update, including mine closure status, and consults with the broader Indigenous population through this forum.
State of the Nation	Quarterly	Presentations and question and answer sessions provided to all ERA personnel and contractors on ERA operations by either the Chief Executive or General Manager Operations including aspects of closure, Jabiru and stakeholder engagement.
Closure Criteria Working Group	No longer required	The Closure Criteria Working Group was established by the MTC for the purpose of developing the closure criteria for the rehabilitation of the Ranger Mine. The Closure Criteria Working Group also had sub-groups responsible for the development of the technical criteria for each of the following elements: landform, radiation, water and sediment, flora and fauna, soils and cultural. The MTC decided that closure criteria had progressed enough that this working group was no longer required. Rather, the specific technical groups would continue to develop criteria and report directly into the MTC.
Water and Sediment Working Group (WASWG)	No longer required	Communication and consultation with stakeholders focusing on surface water and sediment closure criteria and KKNs. These discussions now occur in each of the above-mentioned relevant forums.
Monitoring Evaluation and Research Review Group (MERRG)	No longer required	MERRG was formed in response to the submission of the application to progress Pit 1 final landform, in order to further communicate and consult with stakeholders regarding Pit 1 revegetation monitoring activities. Pit 1 has now undergone initial rehabilitation and monitoring success is reported in the above-mentioned relevant forums.

5 RISK ASSESSMENTS, KNOWLEDGE BASE AND SUPPORTING STUDIES

The benefit of operating a mine, collaborating with stakeholders, and conducting research and monitoring for over 40 years, is an in-depth understanding and substantial base of knowledge on which closure activities, rehabilitation and supporting studies can be guided.

Having said that, ERA understand that risks to an operating mine are considerably different to successfully rehabilitating and closing a mine. To facilitate successful closure, ERA has held regular risk assessment workshops since 2008 to identify key risks specific to the closure of the Ranger mine. Of note:

- CSIRO led ERA and key stakeholders through the Ranger Rehabilitation and Closure Risk Assessment in 2013. This risk assessment, along with the significant knowledge base gained from operating the mine for 40 years, helped to inform ERA and the Supervising Scientist Branch (SSB) of the environmental research programs to be undertaken to better understand and manage the impacts and risks associated with mine closure. The various studies identified through this process were captured in a list of Key Knowledge Needs (KKNs). Table ES3 in Section 5.1 provides a summary of the KKNs.

- A risk workshop held in August 2016 identified a range of assessments that would further the understanding of Best Practicable Technology (BPT). BPT may be interpreted as the technology that is consistent with achieving the ERs and ranks highest when considering world's best practice, cost-effectiveness, proven effectiveness, Ranger's location, the age of equipment, and social factors. Table ES4 in Section 5.2 provides a summary of the completed and active BPTs.

- During 2018, several assessments were undertaken as part of the Ranger closure Feasibility Study, with the outcomes presented in the form of a risk register in the 2018 Mine Closure Plan (MCP). The risk register was updated in the 2020 MCP to incorporate comments received from stakeholders (it is noted that the Feasibility Study itself was not subject to stakeholder review) and continues to be regularly reviewed and updated. Section 5.3 provides a summary of the current risk register.

5.1 Key Knowledge Needs (KKNs)

A total of 35 KKNs were identified and grouped under the following five themes:

- Landform
- Water and sediment
- Radiation
- Ecosystem rehabilitation
- Cross-theme matters such as cumulative risk.

The 35 KKNs were then further divided into 63 specific questions and responsibility to answer the questions was assigned to ERA, the SSB, or to both, as follows:

- 22 questions have been addressed / completed
- 41 questions remain and are the subject of studies being undertaken by:
  - ERA: 18 questions
  - Both: 12 questions
  - SSB: 11 questions.

Section 5 of the 2022 MCP main document details the existing environmental conditions of the RPA and surrounds, and describes each of the studies being undertaken by ERA (either solely or in collaboration with SSB) to address the KKNs and outstanding questions.

Table ES3 provides a summary of the KNNs, and the 30 active questions and associated studies being undertaken by ERA (either solely or in collaboration with SSB).

Table ES3 Summary of the KNNs, outstanding questions and ERA supporting studies

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
Landform Theme				
LAN2	Understanding the landscape-scale processes and extreme events affecting landform stability	LAN2B. How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?	Both	A likelihood and consequence assessment was undertaken and is being carried through into the site's environmental risk assessment.
LAN3	Predicting erosion of the rehabilitated landform	LAN3A. What is the optimal landform shape and surface (e.g. rip lines, substrate characteristics) that will minimise erosion?	Both	The final landform shape was initially developed in 2003 and is subject to ongoing refinement as results from studies become available (e.g. completed trial landforms and current studies targeting Pit 1 and Stage 52 (the area between Pit 1 and the services corridor on the southern wall of Pit 3)).
		LAN3B. Where, when and how much consolidation will occur on the landform?	ERA	Landform evolution modelling (LEM) to assess the stability of the final landform, erosion and surface water runoff has been undertaken by the SSB since 2015. ERA engaged resources in mid-2019 and added in-house modelling capacity in 2021 to support the SSB in the ongoing refinement of key model inputs to provide increased confidence in the model predictions out to 10,000 years post closure. The LEM incorporates findings from other relevant modelling studies, including the Pit 1 tailings consolidation models undertaken from 2003 to 2017. Tailings consolidation modelling for Pit 3 started in 2014 and is currently being updated and refined as closure activities in the pit continue and additional monitoring information is available.
		LAN3E. How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?	Both	This question is also being addressed by the LEM, which is being strengthened by ERA studies on particle size distribution, sediment runoff and vegetation cover.

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
Water and Sediment Theme				
WS1	Characterising contaminant sources on the RPA	WS1A. What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?	ERA	These are collectively termed Constituents of Potential Concern (COPC) and the following 20 are relevant: aluminium (Al), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), nitrate (NO3-N), lead (Pb), total phosphorus (P total), polonium-210 (210Po), radium-226 (226Ra), selenium (Se), sulfate (SO4), total ammoniacal nitrogen (TAN), uranium (U), vanadium (V), and zinc (Zn).
		WS1B. What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?	ERA	The capacity of these COPC to be dissolved in surface water and groundwater (i.e. their solubility) is the primary mechanism and pathway for mobilisation from their source.
WS2	Predicting transport of contaminants in groundwater	WS2B. What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?	ERA	Local groundwater movement and solute transport can be influenced by geological, groundwater flow and transport characteristics. Local groundwater movement at the site is well understood via a calibrated numerical groundwater flow model that covers 29 km2 and 800 m vertically and comprising 612,940 active cells. The model can simulate groundwater pathways through 19 hydrolithologic units (HLUs), each representing a different geological, groundwater flow and transport characteristic within the three main regional groundwater zones (alluvial, weathered and bedrock).

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
WS3	Predicting transport of contaminants in surface water	WS3F. What are the predicted concentrations of suspended sediment and contaminants (including nutrients) bound to suspended sediments in surface waters over time?	Both	Understanding surface water, and the interaction between groundwater and surface water, are critical for mine closure because these are the main pathways for COPC to enter the receiving environment. This modelling is well underway and being informed by over 40 years of surface water monitoring. From the perspective of groundwater to surface water catchments, the mine site is divided into the catchments of Corridor Creek (principally Pit 1), Coonjimba Creek (principally the TSF/RWD), Magela Creek (principally Pit 3 and the northern side of Magela Creek) and Gulungul Creek (some land application areas but largely undisturbed areas to the west of the TSF). Each of these is the subject of detailed modelling studies to address the questions raised in WS3. Aquatic sediments at the mine site and the Magela catchment have been studied since the late 1970s. This includes research projects as well as routine monitoring to understand metal concentrations and bio-geochemical pathways, spatial distribution (vertically and within and between catchments), changes over time, and potential bioavailability.
		WS3H. Where and when will suspended sediments and associated contaminants accumulate downstream?	ERA	
WS5	Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health	WS5A. Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?	Both	Concentrations of metals has not increased in sediments in the offsite billabongs in the Magela catchment, with concentrations within natural variation (at the low end of the range). There are three key constituents that contribute to the potential formation of acid sulfate soils (ASS): the potential water-logged conditions, elevated sulfate concentration (≥10 mg/L), and sufficient organic matter to establish the chemically reducing environment. Although considerable historical studies of ASS exist from the Magela Plain and lowland areas surrounding the mine, a few studies are continuing to fully understand the ASS conditions as they relate to closure.

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
WS6	Determining the impact of nutrients in surface water on aquatic biodiversity and ecosystem health	WS6C. Will the total loads of nutrients (N and P) to surface waters cause eutrophication?	ERA	The primary sources of nutrients to the water system at the mine are from waste rock, ammonia and phosphate (in lime) added to the mill process circuit, residual nitrates from blast residue in waste rock, and fertiliser application. The risk of nutrient loading has been low during the operational phase as waters are segregated and treated before release. Concentrations of ammonia, nitrate and phosphate entering the surface water environment post closure are being assessed through solute transport modelling. The risk of eutrophication is being addressed through this modelling.
WS7	Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health	WS7B. What is the risk associated with emerging contaminants?	Both	Closure risks have been identified and continue to be revisited as information from studies becomes available. ERA will be undertaking another environmental risk assessment in 2023 to ensure exposure pathways and potential effects to human and ecosystem health are informed by the latest study results.
WS9	Optimisation of water quality monitoring programs and assessment methods	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?	ERA	Ongoing review and innovation are being applied to ensure that the methods used in the water quality monitoring program are providing useful and reliable information and are cost-effective. This includes data collection, data management practices and analytical techniques. Ensuring the use of proven state-of-the-art technologies for equipment, instruments and methods is a key requirement for optimisation.

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
Health Impacts of Radiation Theme				
RAD1	Radionuclides in the rehabilitated site	RAD1A. What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and land application areas?	ERA	Baseline radiological conditions for eleven areas of the mine, seven groundwater units and nine local bush foods are provided in Section 5 of the MCP main document. As expected, the pre-mining radiological baseline over the orebodies that led to Pits 1 and 3 was much higher than the surrounding area. The impact assessment required to assess the radiological impact to members of public and terrestrial and aquatic wildlife is largely dependent on the outcomes of other studies such as the groundwater/surface water solute transport modelling. These studies are now well advanced and will be informing the radiation assessment.
RAD6	Radiation dose to wildlife	RAD6E. What is the sensitivity of model parameters on the assessed radiation doses to wildlife?	ERA	
RAD7	Radiation dose to the public	RAD7A. What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?	ERA	
		RAD7B. What is the sensitivity of model parameters on the assessed doses to the public?	ERA	
RAD8	Impacts of contaminants on wildlife	RAD8A. Will contaminant concentrations in surface water (including creeks, billabongs and seeps) pose a risk of chronic or acute impacts to terrestrial wildlife?	ERA	
RAD9	Impacts of contaminants on human health	RAD9D. What is the dietary exposure of, and toxicity risk to, a member of the public associated with all contaminant sources, and is this within relevant Australian and/or international guidelines?	ERA	

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
Ecosystem Restoration Theme				
ESR1	Determining the requirements and characteristics of terrestrial vegetation in natural ecosystems adjacent to the mine site, including Kakadu National Park.	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally inundated savanna) in natural ecosystems adjacent to the mine site, how do they vary spatially and temporally, and what are the factors that contribute to this variation?	ERA	The RPA and surrounds are primarily within the Pine Creek Bioregion, which comprises hilly ridges with undulating plains within the foothills of the Arnhem Land Massif. Vegetation types consist of tall eucalypt woodlands, dominated by Darwin woollybutt (*Eucalyptus miniata*) and Darwin stringybark (*E. tetrodonta*) with patches of monsoon forests, riparian vegetation and tussock grasslands. Section 5 of the MCP main document details and maps the location of the four vegetation types specific to the RPA and the characteristics that define these types.
ESR2	Determining the requirements and characteristics of a terrestrial faunal community similar to natural ecosystems adjacent to the mine site, including Kakadu National Park	ESR2A. What faunal community structure (composition, relative abundance, functional groups) is present in natural ecosystems adjacent to the mine site, and what factors influence variation in these community parameters?	Both	Kakadu National Park contains over one third of Australia's bird species (271), one quarter of Australia's land mammals (77), 132 reptile species, 27 frog species and over 246 fish species recorded in tidal and freshwater areas. Vegetation types and the tropical monsoon weather pattern influence the distribution of fauna throughout the area. Approximately 90% of the average annual rainfall (1,565 mm/a) occurs in the wet season from November to March.
		ESR2B. What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?	ERA	One objective of the final landform rehabilitation is to provide habitats that support fauna assemblages similar to the surrounding Kakadu National Park and that contain culturally important bush foods. Fauna refuge areas in the form of a boulder pile have been included in the Pit 1 landform and nest box trials are underway.
		ESR2C. What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?	ERA	Feral cats and cane toads have contributed to the decline of mammals in Kakadu National Park and populations of these introduced animals, along with dogs, may influence faunal colonisation of the final landform.
ESR3	Understanding how to establish native terrestrial vegetation, including understory species.	ESR3A. How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?	ERA	Considerable success has already been seen in the trial landform areas and more recently on Pit 1. The Trail Landform (TLF) and Pit 1 are two of ERA's key ecosystem research programs and are critical components of the Species Establishment Research Program (SERP).

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
ESR5	Develop a restoration trajectory for Ranger mine	ESR5A. What are the key sustainability indicators that should be used to measure restoration success?	Both	Ecosystem restoration closure criteria is now being finalised with key stakeholders.
		ESR5B. What are possible/agreed restoration trajectories (flora and fauna) across the Ranger mine site; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the mine site, including Kakadu National Park?	Both	State and transition (S&T) models are non-linear conceptual models that organise information about ecosystem change. A S&T model describing desirable and undesirable transitions along possible rehabilitation trajectories at Ranger mine was developed by scientific, industry and local ecology experts at a workshop in April 2019. Another key element of S&T models is the development of adaptive management plans for ecosystem rehabilitation that is linked to and guides monitoring and maintenance activities. Ecosystem attributes related to structure, composition, function, abiotic and landscape characteristics are have been modelled and will continue to be studied to deliver a final landform that contains a self-sustaining ecosystem.
ESR6	Understanding the impact of contaminants on vegetation establishment and sustainability	ESR6A. What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants?	Both	The groundwater/surface water solute transport modelling discussed in WS1-WS3 will inform this KKN. Also, studies on plant establishment and growth rates for specific species may inform future management practices that could mitigate nutrient and toxicity effects. These studies are currently being undertaken by SSB in collaboration with the National Environmental Science Program (NESP) and Charles Darwin University.
		ESR6B. Based on the structure and health of vegetation on the Land Application Areas, what species appear tolerant to the cumulative impacts of contaminants and other stressors over time?	ERA	Groundwater solute plumes at the land application areas (LAAs) developed from application of RP2 pond water is being assessed to inform COPCs in this area. ERA presented to ARRTC (May 2018) results of vegetation growing in areas exposed to pond water, with observations and studies of the LAAs, irrigated with pond water for over a decade, indicating no observed negative effects on vegetation from waste rock contaminants.

KKN	KNN Title	Question	Responsibility	Supporting study being undertaken
ESR7	Understanding the effect of waste rock properties on ecosystem establishment and sustainability	ESR7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?	Both	Developing waste rock ‘soil’ to a level able to sustain native vegetation is a result of complex interactions between the waste rock, plant roots, leaf litter, a range of microbial organisms and other environmental and climatic factors. Production of rock fines through weathering forms an important component of this process, as does generation and infiltration of organic matter. Weathering of the waste rock over time increases both the proportion of fines in the soil profile as well as water holding capacity. Observations indicate the waste rock used on the trial landform has been breaking down since its initial placement as a consequence of physical, chemical and biological weathering processes, vegetation establishment and litter accumulation, and decomposition by microbial activity in the substrate. The increased proportion of fines will provide a suitable substrate to support understorey development. Some natural establishment of understorey species in the waste-rock-only section of the trial landform has been observed 4-5 years after revegetation supporting the theory. Monitoring and studies on waste rock properties and rehabilitation success are ongoing.
ESR8	Understanding fire resilience and management in ecosystem restoration	ESR8A. What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?	Both	Fire is a major exogenous feature of Australian eucalypt-dominated ecosystems, especially subtropical savanna woodlands. The fire management plan for Kakadu National Park from 2016 to 2026 aims to reduce the area impacted by large fires and the risk of wildfires entering, spreading, or leaving the park; it also plans for reduced frequency of large severe fires and reduced average fire patch size. The management plan also identifies the importance of maintaining long-unburnt patches for vegetation regeneration and wildlife habitat. Frequent fires tend to simplify vegetation structure leading to the presence of a dominant tree layer and an understorey of grasses and resprouting shrubs and trees. By contrast, a regime of less frequent fires will provide greater opportunities for saplings to escape the flame zone and for a mid-stratum to develop.

5.2 Best Practicable Technology (BPT)

A BPT is a process of analysing currently available technologies against specified criteria to identify the preferred option or approach for undertaking major closure activities at the mine.

The identification and use of BPTs are a key component of the legal framework for the closure of the Ranger Mine supporting applications to the Minesite Technical Committee (MTC) and demonstrating that impacts on the RPA are as low as reasonably achievable (ALARA).

A BPT score is generated for each technology option assessed. The score is calculated using the rank against each applicable criterion, whereby:

- an option that achieves the highest possible rating for all criteria would score 100
- an option that meets standards for all criteria would score 0
- an option that achieves the lowest possible rating for all criteria would score -100.

The criteria applied to BPT assessments is provided in Table ES4, and Table ES5 provides a summary of the selected option for each BPT.

Table ES4 Criteria applied in a Best Practicable Technology assessment

Aspect	Criteria applied to the assessment
Traditional Owner culture and heritage	• Would the adoption of the option have adverse impacts on the cultural practices, traditions and customs of the local Aboriginal communities? • Would the option threaten, in any way, the integrity of sacred sites, rock art or any other aspect of the cultural heritage of the region?
Protection of people and the environment	• Would the option give rise to adverse impacts on the health and safety of Aboriginal or non-Aboriginal members of the local community? • Would the option have any adverse socio-economic impacts on the communities in the town of Jabiru or in the broader Kakadu region? • Would the option achieve protection of the natural World Heritage and Ramsar status of Kakadu NP? • While disturbance and environmental impact is inevitable on the project area, would adoption of the option minimise such onsite impacts?
Fit for Purpose	• Does the option use proven technology? (proven and demonstrated technology would be ranked higher than very new, unproven or theoretical technology). • How effective is the technology used in the option in meeting its desired output objective? (effective, highly robust options would rank highly). • How robust or sensitive is the option to variation in external factors such as weather and relevant factors (e.g. expected ground strengths, result of predecessor activities, higher or lower flows)? • Does the standard of environmental protection achieved by the option meet the highest standards achieved in uranium mining elsewhere in the world?
Operational Adequacy	• Would adoption of the practice ensure the ongoing health and safety of the workforce? • Would the option require extensive control and support effort to construct? • Is the process operationally reliable? That is, will it have high availability, or will it have features whose inherent sensitivity may impact availability? • Would the option be difficult to maintain? • Would the complexity of construction create cost risks arising from schedule uncertainty?

Aspect	Criteria applied to the assessment
Rehabilitation and Closure	• Would the option promote or detract from the ability to: ○ Revegetate the mine site with local native species and resulting in a low maintenance regime? ○ Establish stable radiological conditions that will ensure health risks to the public from the principal exposure pathways are ALARA? ○ Establish erosion characteristics on the site that, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas? ○ Meet agreed water quality criteria in creeks draining the mine site and achieve appropriate ecosystem restoration standards for water bodies on the rehabilitated landform? ○ Ensure that for 10,000 years all tailings produced at the Ranger site are physically isolated from the environment and contaminants arising from the tailings do not result in any detrimental environmental impact off the RPA? ○ Meet operational deadlines to achieve closure within a period that meets stakeholder expectations any legal requirements? • Would adoption of the option result in closure costs that significantly detract from overall project value?

Table ES5 Summary of Best Practicable Technology option assessments

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
Completed BPTs					
Integrated tailings, water and closure (ITWC)	9 – PFS1 8 – PFS2 (Stage 1) 4 - PFS2 (Stage 2) 8 – Supp ITWC	Dredging 1B/1C 1B A3	Tailings reclamation via Dredging Two options carried forward for brine injection Brine injection, thickened tailings and milling until 2020 Unthickened tailings with wicks to accelerate consolidation	41.3	2013-2016
Salt treatment and disposal	10	1B	8 options were assessed in Stage 1, the top 2 options plus 2 additional options were assessed in Stage 2. The preferred option is brine injection to the underfill without rock screening.	19	October 2018
Brine Squeezer	27	BM2	Addition of the Osmoflo Brine Squeezer to treat Water Treatment Plant (WTP) brines to minimise additions to the pond water and process water inventory, and to optimise pond and process water treatment and disposal mechanisms.	23	April 2019
Closure of ranger 3 Deeps	7 - Decline 3 - Portal 9 - Ventilation Shaft	A7 B2 C9	A7 Decline: waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m). B2 Portal: Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock. C9 Ventilation Shaft: Crushed waste rock up to weathered zone, then 10 m cemented rock fill and then 10 m of crushed rock to surface; concrete collar removed.	41.7 30.8 39.5	April 2019

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
Progress Pit 1 to final landform	Multiple	NA	Requirement to maintain pre-mining drainage and catchment areas and to ensure that it does not degrade unduly as a result of climate change. Each version of the landform undergoes landform evolution and erosion modelling by the SSB and is peer reviewed by ARRTC. The studies, reviews and subsequent modelling done to address landform design and backfill planning are consistent with the general practice of BPT assessment.	NA	May 2019
Tailings deposition into Pit 3 for Mill tailings and dredge tailings	3 Mill 4 Dredge	M2 D2	M1: Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing) D1: Dredge 1 and 2 subaerial	35.4 16.7	July 2019
Remnant tailings transfer – TSF to Pit 3	10	3	Scrape clean TSF floor and walls, transfer by truck, and deposit into Pit 3 south west end via a constructed tip head.	17	Included within tailings transfer approval
High density sludge (HDS) plant recommissioning	12	11	No change to the method approved by DITT in February 2020. That is, indirect treatment by releasing HDS product into the pond water inventory (i.e. RP2), for subsequent treatment through any of the pond water treatment plants (WTPs).	44.4	February 2020
TSF North Notch Stage 3	6	A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) and construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0	June 2020
TSF subfloor material management	14	1a	Leave material *in situ.* TSF subfloor material left undisturbed in situ. All visible tailings removed. TSF is then used for process water storage.	38.2	August 2020

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
Blackjack (gear oil) waste disposal	5	A1	Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise contaminants prior to disposal in a bed of low permeability clay.	50	NA
Active BPTs					
Pit 3 Capping	7	D	Hybrid + East platform - Wicking completed sub-aqueously in Zone 1, 2, & 3 only. Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method in Zone 4 and perimeter. Sub-Aerial (passive dry out) Capping Method to cap Zone 1,2,3 after wicking.	23	Application lodged April 2022

5.3 Risk assessment and management

Risk assessments for the closure of the RPA have been held since 2008 and will continue to be undertaken throughout closure as results of monitoring and technical studies become available and are used to refine ERA's understanding of risk. ERA developed the Hazard Identification and Risk Management Standard (ERS003) to ensure that strategies are developed to identify and manage hazards and risks. This standard is integrated within the ERA Health, Safety and Environmental Management System, which has been certified to meet the requirements of the AS/NZ ISO14001:2015 and AS4801 national standards.

A risk matrix is used to determine the overarching risk classification for each identified risk event or threat. The risk classification is a function of the consequence and likelihood ratings determined by subject matter experts within risk workshops. The overarching risk classification is determined to be either Class I (Low), Class II (Moderate), Class III (High) or Class IV (Critical) as per the risk matrix shown in Table ES6. The risk classification identifies the level of management action that must be taken to mitigate the risk as shown in Table ES7.

Table ES6 - Risk Classification Determination

Likelihood	Consequence Severity				
	Very low	Low	Moderate	High	Very high
Almost certain	Class II	Class III	Class IV	Class IV	Class IV
Likely	Class II	Class III	Class III	Class IV	Class IV
Possible	Class I	Class II	Class III	Class IV	Class IV
Unlikely	Class I	Class I	Class II	Class III	Class IV
Rare	Class I	Class I	Class II	Class III	Class III

Table ES7 - Management response

Risk Class	Response
Class I	Risks are acceptable and do not require active management
Class II	Risks are on the threshold of acceptance and require active monitoring
Class III	Risks exceed the risk acceptance threshold and require proactive management
Class IV	Risks significantly exceed the risk acceptance threshold and require urgent and immediate attention

At the time of writing this 2022 MCP, there are 45 environmental and technical risks related to mine closure. The number of risks per class are:

- 5 Class IV (Critical) risks
- 21 Class III (High) risks
- 14 Class II (Moderate) risks
- 5 Class I (Low) risks.

Table ES8 provides a summary of the current risk register for the Class IV and Class III risk events.

Considerable attention and work have been placed on the identification and management of closure risks for the Ranger mine since 2008. ERA acknowledges that this work is not finished, it is continuing and will be subject to ongoing reviews and updates as more information becomes available from the KKN studies and from monitoring activities. ERA will undertake another significant review of the environmental risks (including controls, planned activities and contingency measures) in 2023.

With specific regard to risk management, the current risk register provided in Appendix 7.1 of the main document shows that for the 45 risks:

- 351 existing controls are in place
- the effectiveness of the control currently in place is identified for one (1) risk as ‘weak’, twelve (12) risks as ‘marginal’, nineteen (19) risks as ‘satisfactory’, ten (10) risks as ‘good’, and three (3) risks are currently unrated
- two (2) risks have an ‘increasing’ risk trend (i.e. risk classification has increased over time), thirty-nine (39) risks have a ‘stable’ trend (i.e. have retained the same risk classification), and four (4) risks has a ‘decreasing’ trend (i.e. risk classification has improved)
- with regards to those risk events that are in a class that requires further management action (i.e. Class IV and Class III risks):
    - for the five (5) Class IV risks, 9 actions, additional to the ongoing successful implementation of the existing controls, are identified
    - for the twenty-two (22) Class III risks, 65 actions, additional to the ongoing successful implementation of the existing controls, are identified.

Table ES7 – Summary of the risk register for Class IV (Critical) and III (High) risks

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Class IV (Critical)			
Extraction of process water from pit 3 takes longer than planned	• Assurance of consolidation model being completed by stakeholders (2 independent reviews). [504190] • Continued stakeholder engagement via ongoing presentations to stakeholders through MTC and RCCF. [1083233] • CPT Testing to inform consolidation model and wick design. [504194] • Ongoing monitoring and modelling of tailings during deposition phase. [602110] • Pit 1 actual consolidation rates known and model adjusted to suit; ongoing monitoring. [504193] • Pit 3 design is based on the learning of Pit 1. [602105] • Placement of bulk backfill will be undertaken to lead to timely completion of consolidation. [602107] • Prefabricated vertical drains (wicks) installed to maximise consolidation. [602106] • Specialist consultant employed on consolidation modelling. [504189]	Satisfactory	• Monitoring the success of existing decant towers, pumping systems, and the number and distribution of the settlement towers, which may also be equipped with pumps. • Beyond the use of the settlement towers, risk contingency is installation of additional extraction and/or monitoring bores, following completion of capping and backfill works.
Inadequate pond water storage availability	• Continuous monitoring of pond water level and volumes [700068] • Developing catchment conversion plan for BMM operations [1047332] • OPSIM Water Balance model and forecast. [597533] • RWMP001 Ranger Water Management Plan. [700052] • Water model validated throughout operations [1047331] • Weekly water treatment plant operational coordination meeting [1047329]	Marginal	• Develop detailed plan for catchment management (inc. catchment conversion). Develop a water management plan for bulked and final landform construction, and a post closure sediment management plan. • Plan and execute wet season preparation activities for 2022-2023 wet season.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Unable to inject brine into underfill	• Ability to directionally drill additional steel-cased bores, with accessible headworks and positive-displacement pump injection capability. [504877] • Additional pipe available on-site to allow faster installation of replacement. [504880] • Assurance Plan with production metrics developed. . [504878] • Conductivity meter on the under-drain water flow. [602390] • Contingency plan for blocked well head [936477] • Data gathering plan for performance of brine injection. [504882] • Delivery lines (to manifold with original system, to headworks with replacement bores) able to be pigged and flushed. [1047291] • Full pump replacement held on-site as critical spare. [504881] • HDS plant incorporated into water model, removes salt from circuit. [602389] • Once Pit 3 capping and backfill is complete, ability to vertically drill additional bores through capping and tailings into underfill [1047293] • Pigging strategy. [504883] • Underfill engineered with a 20% contingency for brine storage (based on 100% of process water treated via BC) [602387] • Underfill volume review of as-built undertaken (Mark Goghill Nov. 2016) and determined contingency of 20% [602388] • Water model capable of forecasting TDS. [504879]	Marginal	• Brine storage options study • Contingency plan for brine injection system development
Failure to contain and/or eradicate *Spigelia* weed from the operations area causing infestation in Kakadu NP	• Clear procedures around vehicle hygiene (e.g. washdowns)Dedicated resources to manage treatment [616678] • External Stakeholder monitoring, managing and regular consultation [616681] • Mini ipads for weed monitoring [936385] • Monthly reporting to weeds Branch of Gov [597593] • Polaris ATV used for weed management [607791] • Regular monitoring and surveys of *Spigela* weed [597592] • Weed Management Plan [597591] • Weed specific training (exclusive to *Spigela*) [597594]	Marginal	• Investigate the opportunity for partial coverage of *Spigelia* through final landform development

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Rainfall is greater than planned in the Water Model (P50) increasing the process water inventory to manage/treat leading to later completion of process water treatment than planned	• Industry established tool used (water model) with model assured. [504167] • OBS upgrade for process water treatment[936453] • Process water volume tracked against water model prediction [602101] • Regular Water Model update. [504171] • Scenario of extreme weather event late in the closure schedule assessed during feasibility study and included in water management plans. [504174] • Water inventory sensitivity to rainfall is well understood via model based on significant data base (>100 years of data). [504168] • Water Model uses significant historical data records from local monitoring location. [504169]	Satisfactory	• Complete a concept level study to determine a suitable location and design for RP7, including in TSF options as contingency • Confirm the P50 values that are to be taken into the Feasibility Reforecast.
Class III (High)			
Solutes and sediments from surface runoff from final rehabilitated site enters off-site water bodies at greater than closure criteria. (surface water)	• Bathymetry and I-site scanning of billabongs [936473] • Characterisation of LAA and billabong sediments (partially complete). [504627] • Historic and ongoing studies into erosion. [504625] • Landform flood study informs sedimentation controls design. [504624] • Post-closure Management Plan. [504628] • Ranger Conceptual Model (RCM) and solute transport modelling completed. [504623] • Source term review. [936474] • Surface water pathways risk assessment [936475] • TSF solute transfer study completed by Intera. [504626]	Currently Unrated	• Conduct study to review the confidence and suitability of TSS sensors. • Consider reactive transport for Manganese, Ammonia, Uranium and Radium in Solute Transport Model

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Over time climate change causes a significant shift to the expected environmental baseline of the RPA restricting ERA in meeting its environmental requirements	• Current groundwater modelling incorporates considerations for climate change [936484] • Early understorey growth and survival will be monitored and remediated as required during the management period. [936483] • Irrigation strategy creates cyclone resistance (encourage deep root development). [1069939] • Landform Evolution Model (LEM) has climate change scenarios and a synthetic rainfall data set for 10,000 years. [1092045] • Monitor climate projections and ensure that new information is accounted for when selecting plant species for revegetation. [936482] • Monitor performance of revegetation actions and make adjustments as required. [936481] • Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [1092052] • Ongoing review of climate risk assessment following IPCC updates. [1047337] • Revegetation Adaptive Management Plan [1047336] • Revegetation management plan draft. [1092066] • Revegetation strategy designed to meet closure criteria for resilience (e.g. species mix, irrigation, weed monitoring) [1092069] • State and Transition model for revegetation [1047335] • Weed management plan [1092077] • YFM001 Fire Management Plan [1092080]	Weak	• Develop agreed scenario for climate change, with Stakeholders, so unknowns or reduced and appropriately considered. • Revegetation Adaptive Management Plan to improve Revegetation Management Plan. • Review climate risk assessment for Ranger in light of the 2022 IPCC report.
Planned active process water treatment tactics (i.e. plant capacity) do not meet the assumed productivities modelled for site inventory reduction.	• BC evaporator vessel scaling issue understood and addressed. [504649] • BC fan upgrade completed . [504652] • BC operation reached a sustained rate of 115% with no fan upgrade. [504651] • BC seed cyclones upgraded. [504650] • Brine squeezer being implemented - schedule in Water Model. [504653] • Regular review and update of the water model [1092057] • Performance guarantees from vendor for BC upgrade. [1093480] • Sensitivity analysis on current water model complete. [504658]	Marginal	• Develop a compendium of past water treatment plans and current status. • Develop Brine Concentrator Recovery Execution Plan. • Develop/revise Asset Management Plan • Feasibility Reforecast to review planned performance of water treatment tactics. • Installation of the Brine Squeezer upgrade.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Elevated levels of contaminants (metals) in bush tucker.	• Alligator Rivers Region Technical Committee (ARRTC) process and key knowledge needs developed. [500616] • Bush food consumption restrictions to particular areas of the RPA may apply post closure. [694655] • Bush food monitoring program [1047356] • Closure criteria working group [507828] • Diet confirmed through consultation [1047354] • Singular RP1 additional sediments investigation. [988328] • Site specific concentrations factors (BRUCE database) [1047355] • Site specific research undertaken against identified knowledge gaps. [499956] • Stakeholder communication strategy and management e.g. Traditional Owners (TOs), Minesite Technical Committee (MTC), Alligator Rivers Region Advisory Committee (ARRAC), Alligators Rivers Region Technical Committee (ARRTC), technical working groups, community engagement. [693662] • Stakeholder engagement. [518282] • Water Pathways Risk Assessment to inform additional contamination knowledge gaps [988327]	Marginal	• Review diet assumptions and concentration factors for manganese - consider peer assessment • Determine an appropriate uranium environmental investigation level (EIL). • Undertake additional sediment sampling at RP1 and Coonjimba billabong. • Undertake aquatic vegetation investigation as a part of the Bushtucker Investigation & Assessment study. • Undertake faunal bushtucker investigation as a part of the Bushtucker Investigation & Assessment study. • Undertake flora assessment of on-site fruit as a part of the Bushtucker Investigation & Assessment study.
Tailings consolidation is slower than expected.	• Assurance of completion of consolidation model to stakeholders (2 independent reviews). [1105989] • CPTu, sampling and test work to inform consolidation model and wick design. [1105992] • Norwegian Geotechnical Institute separate 2D consolidation model. [1105990] • Ongoing presentations to stakeholders through MTC and RCCF platforms. [1105993] • Pit 1 actual consolidation rates understood with adjustment to model; ongoing monitoring. [1105991] • Specialist consultant employed for consolidation modelling. [1105988]	Marginal	• Continue to monitor and update model as required.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Insufficient volume or quality of trees from nursery for revegetation.	• 20% allowance for infill. [505250] • Alternative off site nursery available if required. [602401] • CDM.03-0000-NH-PLN-00002 Ranger Closure Revegetation Plan (Final Landform). [694601] • Disease control activities in nursery. [505254] • Expert propagation knowledge and implementation provided by existing contractor. [602399] • Interative allowances for unviable seeds per species is factored into seed collection requirements. [505251] • Learnings from Pit 1 will be taken into remaining work - lead time for additional seeds & seedlings. [505256] • Management of combustables in nursery area. [505253] • Nursery secured. [505252] • Planting and propogation trials successfully completed. [505255] • Primary nursery (expansion) [829839] • Primary nursery (fit for purpose). [693556] • Primary nursery constructed on site [602400] • Revegetation handover checklist [1092063]	Marginal	• Consider accelerating revegetation packages for LAAs and final landform.
Process water exceeds Maximum Operating Limit (MOL) in Pit 3.	• Approved MOL based on surrounding head data to ensure Pit 3 remains a sink. [504642] • Monitoring of water levels in Pit 3 [1047327] • Pumps in pit 3 maintained through the wet season to allow pump back. [973177] • Regular bathymetric surveys to determine process water inventory. [504644] • Tailings quantities well understood - production data and Fugro survey. [504643] • Significant capacity in the Ranger Water Dam (converted from TSF)	Marginal	• Continue to monitor (risk trending down now Ranger Water Dam operational)
Uncertain terms of access to RPA from 9th January 2026, including Traditional Owner Access to significant areas.	• General agreement to proposed amendment (i.e. GAC, Traditional Owners, cross government, DISER) [1046045] • Multiple mechanisms for stakeholder discussion (i.e. MTC, ARRTC, ARRAC, Relationship Committee). [1046048] • Supportive letter from Minister received [1046046] • Atomic Energy Act amendment bill	Marginal	• Continued engagement with Commonwealth, GAC and NLC on term sheets for section 41, section 44 and mining agreement.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Insufficient volume or quality of viable seed stock available for whole of site revegetation.	• Backup air-conditioning in seed storage room. [504584] • Current seed collection permit with Kakadu National Park with KNPS [504576] • Dedicated equipment for collecting grass seed [557230] • Dedicated equipment for collection of seed i.e. EWP, brush harvester. [693553] • ERA conducts annual and opportunistic seed collection on the Ranger Project Area (RPA). [504585] • Main planting for shrubs and trees will be planted via tube-stock rather than direct seeding (significantly less seed required) [602122] • MTO and schedule of seed requirements complete (including by species). [504586] • Nursery expansion including seed storage facility. [504583] • Ongoing collection and storage of seed stock by third party. [504575] • Ongoing review and update of seed collection and propagation plan regarding seed viability (including storage, handling, duration of viability). [797817] • Primary fit for purpose seed storage facility including climate control, security etc. [693557] • Quality assurance process applied to see management (viability testing regime). [693559] • Secondary fit for purpose seed storage facility. [726843] • Secure Contract in place with third party seed and plant provider [936388] • Seed management database, collection schedule and metric to manage performance. [504578] • Stakeholder agreed tree and shrub species list. [504580] • Emergency management / security plans and fire protection in place for seed storage • Seed collection and management procedures	Marginal	• Ongoing review and update of Species Establishment and Research Plan to inform seed requirements.
Slope failure in Pit 3 or stockpiles.	• Bi-annual geotechnical inspection, assessment and review of the slope stability in Pit 3 and stockpiles. [592105] • Prism monitoring of Pit 3. [927855] • Slope dump management plan updated annually through geotechnical consultant. [505719] • Vehicle standards. [505721]	Satisfactory	• Conduct risk assessment for upcoming wicking works. • Geotechnical investigation, assessment and review of the slope stability in Pit 3 and stockpiles.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Damage occurs to cultural heritage site during rehabilitation works.	• Aboriginal Areas Protection Authority (AAPA) certificate. [505865] • Access restricted to sites through signage and / or fencing. [505868] • Cultural Heritage Management Plan includes corrective actions for unplanned solute or sediment load at sacred site. [1045954] • Cultural Heritage Management system including general induction and heritage induction, mitigation measures, incident process and additional security of sensitive sites [505864] • Database of cultural heritage sites. [505867] • Land Disturbance Permit system. [505866] • Maintain multiple ERA representatives with relationships to specific stakeholders i.e. GAC [696045] • Solute transport modelling to understand issue and design controls. [1045956]	Satisfactory	• Complete all actions from 2019 CH audit. • Develop sediment and water quality control plan • Ensure that Feasibility Reforecast reflects the final landform design to address stakeholder recommendations. • Land disturbance process to be reviewed against CH requirements and rehabilitation process. • Undertake role review for the Cultural Heritage training matrix.
Unplanned contaminated materials found on RPA.	• Asbestos Register available for consultation. [1101007] • FS generated Contaminated Sites Management Plan. [989604] • PFAS is no longer used on the RPA. [989600] • Resources available to manage circumstance. [989602] • RT PFAS specific E15 Guidance note. [989601]	Satisfactory	• Consultant undertaking PFAS Assessment
Closure of Ranger Mine impacts on local economics causing reputational damage.	• Engagement with stakeholders on future state. [504049] • SIA (social impact assessment) [504048] • Stakeholder Engagement and Communications Plan [1033370]	Satisfactory	• Complete SIA review and communicate any changes to the relevant stakeholders. • Continue local employment programs to build a future employable workforce.
Inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), leads to inadequate water treatment tactics.	• Consolidation model. [506949] • Regular bathymetric surveys of free process water inventory used to validate model. [504368] • Water Model validation (external assurance). [504369]	Satisfactory	• Assurance plan to be developed for water model for FR. • Complete a concept level study to determine a suitable location and design for RP7, including in TSF options for contingency • Stage and/or phasing plans to better detail catchments and simplifications for input into the water model.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), leads to inadequate water treatment tactics.	• Consolidation model. [506949] • Regular bathymetric surveys of free process water inventory used to validate model. [504368] • Water Model validation (external assurance). [504369]	Satisfactory	• Assurance plan to be developed for water model for FR. • Complete a concept level study to determine a suitable location and design for RP7, including in TSF options for contingency • FR to document, in an auditable form, the basis of water model, setting out the inputs, constraints and assumptions for water model. • Stage and/or phasing plans to better detail catchments and simplifications for input into the water model.
Large scale fire or natural disaster (e.g. cyclone) destroys immature vegetation.	• Deep rooting of trees [607821] • Delayed introduction of high biomass grasses, reduces fire risk. [602392] • Fire breaks and access tracks. [505242] • Introduction of cool burns 5-10 years post planting. [602394] • Irrigation strategy creates cyclone resistance (encourages deep root development). [505241] • LAAs have planned annual burn if not prevented. [505244] • Ongoing active management of revegetation [505243] • Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [1092051] • Ongoing review and update of seed collection and propagation plan regarding seed viability (including storage, handling, duration of viability). [1092053] • Restricted access to revegetation areas [607816] • Revegetation strategy designed to meet closure criteria for resilience (e.g. species mix, irrigation, weed monitoring) [1092068] • State and Transition Model [936391] • Waste rock surface has low fire risk for 5-7 years post-planting. [505240] • Weed Management Plan [1049161]	Satisfactory	• Develop weed hygiene package to address prevention and management of weed spread on the RPA. • Integration of weed management plan.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Site condition does not meet Stakeholder expectations resulting in rework.	• Site specific recognised scientific research undertaken against identified knowledge gaps. [500615] • 3D printed physical model of final landform used to demonstrate final landform topography. [693665] • Alligator Rivers Region Technical Committee (ARRTC) process and Key Knowledge Needs developed. [1092006] • Application of BPT processes [1092007] • BPT and approvals process. [500625] • Agreed closure criteria • Closure Plan updates to incorporate stakeholder recommendations [500630] • Communication fora (e.g. ARRTC, ARRAC, MTC, stakeholder workshops). [1092016] • Continued stakeholder engagement via ongoing presentations to stakeholders through MTC and RCCF. [504195] • Early engagement with stakeholders [602094] • GIS study undertaken to model the potential view lines which has been approved by stakeholders. [602100, 693666] • Iterations of the Mine Closure Plan with updated closure criteria are submitted to Minister for approval annually. [936465] • Landform design cultural closure criteria. [693663] • Physical site visits undertaken by stakeholders i.e. Pit 1, Trial landform [936464] • Rehabilitation Animation [608175] • Socio-economic impact assessment [602098] • Stakeholder communication strategy and management e.g. Traditional Owners (TOs), Minesite Technical Committee (MTC), Alligator Rivers Region Advisory Committee (ARRAC), Alligators Rivers Region Technical Committee (ARRTC), technical working groups, community engagement. [1092073] • Stakeholder engagement has occurred to understand their needs and the ability to meet these needs [602099] • Stakeholder Engagement Plan developed. [500621] • Tiered assessment framework. [500628] • Trial landform established and results transparent to TO's. Jabiluka rehabilitation provides precedent. [500622]	Satisfactory	• Continue to engage with TOs on site conditions post closure. • Investigate opportunities to demonstrate the construction of a stable landform to stakeholders.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Groundwater solute transport outcomes are not as expected.	• Closure execution and post closure groundwater monitoring to inform model validation and updates. [1105980] • Detailed assessment via Water Pathway Receptors Risk Assessment and Vulnerability Assessment Framework (VAF). [1105968] • Groundwater and Surface Water interaction Study. [1105972] • Monitoring of bores / site groundwater during closure to to track the performance of the model. [1105967] • Non conservative assessments available for certain Constituents of Potential Concern (COPCs), including reactive transport and bioavailability modelling. [1105976] • Ongoing engagement/peer review with stakeholders through presentation of water studies at RCCF and ARRTC forums. [1105979] • Review source term for magnesium, manganese, ammonia, uranium and radium. [1105977] • Short term deviations (approx. 5 years) can be handled by decant operations. [1105966] • Significant database of site hydrogeological characteristics. [1105961] • Tailings consolidation model updates to improve predictive capability of the model. [1105962] • Uncertainty analysis of Intera Model. [1105960] • Update of Solute Source Terms Conceptual Models. [1105981] • Validation of ground water model through monitored real data informing the update of Ranger Conceptual Model and Groundwater Uncertainty Analysis. [1105978] • Verified the tailings consolidation model from geotechnical and geophysical investigations. [1105963]	Satisfactory	• Review and verify tailings consolidation model. • Consider reactive transport for Manganese, Ammonia, Uranium and Radium in Solute Transport Model

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Requirement for more extensive remediation / removal of contaminated plumes than planned.	• Application of BPT processes [602095] • Closure Contaminated sites management plan. [504381] • Engagement underway with regulator on remediation plan. Contaminated sites management plan. [504421] • Existing audits of LAA, wetland filters provide an accurate indication of potential scope and contamination level. [504420] • Ground water monitoring program for mill and fuel farm has provided specific information. [504410] • Initial TSF plume characterisation and impact assessment completed (Intera). [504412] • Ranger conceptual model developed and accepted by stakeholders. (Confirms Mill plume can stay in situ, TSF plume needs further investigation) [504411] • Surface water pathway risk assessment [936463]	Good	• Characterise contamination of wetland filters and billabongs • Conduct an Independent Assurance Audit on TSF deconstruction methodology (post-FR). • Conduct stakeholder engagement and obtain stakeholder acceptance on plume remediation plan. • Develop the TSF deconstruction methodology/plan. • Ensure this risk is reviewed in detail under the Feasibility Reforecast. • Following a risk based approach determine remediation required for PFAS contamination.
Tailings Storage Facility wall breached during deconstruction works or while still in use.	• Additional monitoring and instrumentation for drawdown [602112] • Advanced notice through bore monitoring. [504392] • Compliance and auditing against compliance to RT D5 Standard. [504391] • Dedicated dam engineer oversiting and approving all plans (Coffey). [504386] • Downstream raise dam constructed with clay core [602113] • Engineering supervision of construction works. [1092028] • Independent review of all engineering. [504387] • Interception trenches installed around west wall of the TSF. [504390] • Maintain appropriate MOL. [504395] • Modelling to understand impact [602114] • Process safety CCMP's include TSF failure which references drawdown rates on facility. [504389] • Process safety controls for dredging. [504393] • Successful completion of Eastern wall notch. [504394] • Technical review complete for use of TSF as a water storage facility. [504396]	Good	• Conduct an Independent Assurance Audit on TSF deconstruction methodology (post-FR). • Develop the TSF deconstruction methodology/plan.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Excessive erosion impacts landform stability and revegetation success.	• Access tracks designed to minimise erosion and/or not cause erosion. [602120] • Compaction of waste rock on Pit 1/Stage 13 results incorporated into Material Movement Plan. [971916] • Contour ripping in high erosion areas. [602119] • Controls on Material Movement to ensure built landform matches design. [504478] • Final designed landform does not contain slopes > 4%. [504480] • Flood study informs erosion control design. [504482] • Landform Evolution Model (LEM) has climate change scenarios and a synthetic rainfall data set for 10,000 years. [504477] • Landform Evolution Model (LEM) model has informed both landform design, erosion controls and sediment traps. [504476] • Monitoring of backfill during landform construction [1047338] • Revegetation handover checklist [1092062] • Revegetation plan updated with outcomes of Pit 1 and Stage 13 trails [1047339] • Revegetation strategy tailored to landform elements (e.g slopes, gullies, etc). [602118] • Ripping Management Plan. [971917] • Scheduling of landform to decrease erosion output and landform design includes no gully formation over tailings. [971915] • Traffic and logistics management plan [1047340] • Updated consolidated model with Pit 1 validation from monitoring data and CPT testing. Ongoing updates. [504481] • Validation of consolidation models. [504479]	Good	• Develop detailed plan for catchment management (inc. catchment conversion). Develop a water management plan for bulked and final landform construction, and a post closure sediment management plan. • Ensure components are in line with BMM schedule. • Ensure revegetation strategy tailored to landform elements (e.g slopes, gullies, etc). • Incorporate stage 13 results into revegetation plan • Update final landform to include concave slopes and first order drainage lines. • Update MNP126 Specification for Design and Construction of Mine Roads Procedure to ensure erosion is highlighted. • Update scarification/ripping plan to incorporate contour ripping in high erosion areas and pit 1 learnings.

Description of risk event	Current controls [ERA Reference Number]	Control Effectiveness	Actions
Perception amongst local community of downstream contamination from Ranger closure impacting ability to engage in traditional activities. Includes radiation, contamination.	• ARRAC meeting discussed and presented by DITT and SSB. [1101057] • Community and Stakeholder Engagement plan. [1092018] • Cultural reconnection steering committee [1046097] • Management Actions included in the Communities and Stakeholder Engagement Plan. [1069955] • Relationship committee meetings. [503405] • Water monitoring program. External Relations team is on mailing list for enviro water monitoring to proactively manage media. [503404]	Good	• Develop and implement internal communications to address perceptions on Ranger Mine's potential impact to the environment. • Include water quality model in 3D landform model • Undertake aquatic vegetation investigation as a part of the Bushtucker Investigation & Assessment study. • Undertake faunal bushtucker investigation as a part of the Bushtucker Investigation & Assessment study. • Undertake flora assessment of on-site fruit as a part of the Bushtucker Investigation & Assessment study.

Class II (Moderate) risks – 14 risks – see Chapter 7 of MCP main document

Class I (Low) risks – 5 risks – see Chapter 7 of MCP main document

6 CLOSURE IMPLEMENTATION

Throughout the 40+ years of operation, the Ranger mine has disturbed 1,062 hectares of land. ERA recognises that indirect impacts may have also occurred in areas surrounding the mine's disturbance footprint. Figure ES4 shows the location and spatial extent of each of the closure domains and Figure ES1 provided an indicative timeline for their progressive closure.

Table ES8 summarises the completed, current and future activities being undertaken within each of the closure domains as they progress towards final landform (noting that ongoing monitoring and weed management as required are common to all domains and is not included in the table). The table also identifies which of the activities are new to a MCP. This information is important as the MCP is the mechanism by which most activities are considered and approved by the Australian and Northern Territory governments. On this basis, those activities that are highlighted as being new to an MCP are described in further detail in Section 9 of the MCP main document. The exceptions to this process are the significant activities that are subject to a standalone application and approval (i.e. Pit 1 backfill, Pit 3 backfill, and TSF deconstruction/Final Landform).

Table ES8: Closure implementation work program

Domain	Completed Activity	Current Activity	Future Activity
1: Pit 1 (~41 ha)	• Mining of Pit 1 ended in December 1994 (Plate ES5) • Underdrain installed in preparation to receive tailings • Tailings deposition began in August 1996 and ended Q4 2008 (Plate ES6) • Wicking to assist dewatering and consolidation of tailings • Installation of geotextile layer and initial capping in 2013-14 • Full backfill started in May 2019 and final landform achieved in August 2020 (Plate ES7) • Scarification of the landform started in November 2020 and rehabilitation plantings started in 2021 (Plate ES8) • Creation of habitat via rock/boulder features (Plate ES9)	• Removal of pit tailings flux (process water) via decant wells • Monitoring, maintenance and adaptive management activities to inform surface water runoff and ecosystem re-establishment. This work will enable ERA to apply lessons learnt to other landforms as they are progressively established	• Remove/relocate associated infrastructure from Pit 1 (e.g. decant wells, asbestos, laydown yard, Orica yard, transfer station, Omega pump) into Pit 3 • Contour perimeter drain to final landform • Removal of corridor creek road, associated bund and high voltage (HV) power • Relocation of central services corridor
2: Pit 3 (~107 ha)	• Mining started in 1997 and ended in November 2012 (Plate ES11) • Underfill, underdrain and dewatering systems completed 2012-2014 (Plate ES12) • Brine injection bores installed into the underfill zone in 2015 and injection started in 2016 • Tailings deposition from mill processing started in 2015 and ended 2021 • Tailings transfer from TSF started in 2016 and ended 2021 • Tailings floor transferred via truck and dozer • Wicking to assist dewatering and consolidation of tailings	• Brine injection into the underfill zone via pit wall directional drilling (Plate ES13) • Ongoing wicking followed by dewatering and drainage	• Installation of geotextile and initial backfill • Placement of demolished plant and other infrastructure / materials • Progressive capping, waste disposal and bulk backfill (standalone approval Pit 3 application lodged April 2022) • Final 6m of landform (standalone approval application for Final Landform) • Revegetation of final landform

Domain	Completed Activity	Current Activity	Future Activity
3: TSF / RWD (~185 ha)	• Tailings transfer into Pit 1 ended 2008 and into Pit 3 in 2021 • Cleaning of remnant tailings from walls in 2019-21 (Plate ES14) • Approval in 2020 to leave subfloor material in-situ • Dredging floor ended February 2021 (Plate ES15) • RWD wall notches installed and process water received from Pit 3 in 2022 • One dredge removed, decontaminated and removed off-site	• Process water storage and evaporation	• Progressively remove HV power supply and telemetry • TSF deconstruction and dredge disposal (standalone approval application for TSF deconstruction / Final Landform) • Final landform (standalone approval application for Final Landform) • Revegetation of final landform
4: Land Application Areas (~158 ha)	• These areas support ongoing disposal of release water	• Ongoing disposal of release water	• Progressive removal of infrastructure • Progressive remediation of any contamination • Progressive revegetation
5: Process plant, water treatment plants & other infrastructure (~39 ha)	• Decommissioning of infrastructure associated with the leaching and solvent extraction circuits and areas of calcination, drying and product packing	• Progressive contaminated material recovery • Ongoing use of water treatment facilities (including brine concentrator, brine squeezer, high density sludge plant, reverse osmosis plant.0), fuel storage, power station and administration buildings	• Demolition of plant / crusher • Treatment of water - progressively transfer sections from process water to pond water • Remediation of contamination sites • Revegetation
6: Stockpiles (~268 ha)	• Stockpiled waste rock used to backfill Pit 1 in 2020 • Progressive rehabilitation of Areas A (0.6 ha) and C (2.4 ha)	• Stockpiled waste rock being used to create Stage 52 final landform	• Initial capping and bulk material movement for Pit 3 backfill (standalone approval Pit 3 application lodged April 2022) • Bulk material movement for RPA final landform (standalone approval application for TSF deconstruction / Final Landform)

Domain	Completed Activity	Current Activity	Future Activity
7: Water management areas (~125 ha)	• These areas are supporting ongoing water storage, dust suppression and management	• These areas are supporting ongoing water storage, dust suppression and management, including authorised release of treated (pond) water during the wet season	• Progressive remediation, backfill, rehabilitation of retention ponds, water storages, wetland filters and on-site billabongs
8: Linear infrastructure (~40 ha)	• Two redundant tracks (3.6 ha) and six drill pads (0.8 ha) have been rehabilitated • Bulk of this domain is supporting ongoing activities	• None - these areas are supporting ongoing activities	• Progressive removal and rehabilitation as aspects of this domain are no longer required
9: Miscellaneous areas (~55 ha)	• Trail landform constructed in 2009 to investigate rehabilitation success into Ranger waste rock (Plate ES16) • Closure of the Ranger 3 Deeps (R3D) approved April 2019. Ventilation shaft backfilled and decline allowed to flood naturally to -20mRL. Decline backfilled 350 m from ground level in 2021. • Ranger mine village contractor camp and adjacent workshop (1.4 ha) rehabilitated in 2020 • Several old domestic landfills to the north of Pit 1 were covered with waste rock in 2020 as part of the Pit 1 backfill • All explosives have been removed from the magazine area and the site has been de-registered	• Ongoing use of the plant nursery, trial landforms (Plate ES17), Magela Creek levee and some landfill sites	• Relocating office space/gate house to maximise demolition efficiency • Plant nursery expansion/core yard decommissioned and rehabilitated • R3D decline, ventilation shaft pad and associated infrastructure progressively removed/rehabilitated for final landform (within standalone approval application for TSF deconstruction / Final Landform) • Progressive decommissioning, remediation, backfill and rehabilitation of miscellaneous areas

Domain	Completed Activity	Current Activity	Future Activity
10: Airport and Environmental Institute for the Supervising Scientist (ERISS) (~44 ha)	• Ongoing use	• Ongoing use	• Final decommissioning and closure to be determined via the socio-economic assessment
11. Residual RPA	• Largely undisturbed	• Water monitoring	• Progressive relinquishment of undisturbed areas • Progressive rehabilitation of disturbed areas

Plate ES5: Pit 1 (1992)

ES6: Pit 1 after tailings deposition (2008)

Plate ES7: Pit 1 being backfilled (2014)

Plate ES8: Pit 1 backfilled (2022)

Plate ES9: Pit 1 fauna habitat features added as boulder piles (2021)

Plate ES10: Pit 1 perimeter drain (2021)

Plate ES10: Pit 1 perimeter drain (2021)

Plate ES12: Pit 3 underfill (2014)

Plate ES13: Pit 3 tailings deposition (2016)

Plate ES13 Directional drilling for brine injection into Pit 3 underfill (2022)

Plate ES14 Cleaning remnant tailings from walls of tailings storage facility (2020)

Plate ES15: Ranger Water Dam in final stages of remnant tailings removal from floor (2021)

Plate ES16: Trial landform constructed (2009)

Plate ES17: Trial landform as of March 2022

7 COMPLETION CRITERIA, MONITORING AND MAINTENANCE

This is arguably the most important aspect of successfully closing the Ranger mine. It is critically important to:

- agree with the Traditional Owners and all other relevant stakeholders the post-mining land use and criteria against which the material aspects of closure and rehabilitation will be measured
- undertake regular monitoring so that:
  - the previously acquired monitoring results and those to be collected over the next few years can be used to test the accuracy of current predictions and influence the closure and rehabilitation activities up until the creation of the final landform
  - monitoring undertaken after the creation of the final landform can be used to test the progress/achievement of the closure criteria and trigger adaptive management and/or contingency measures if required
- implement maintenance activities to ensure, and where possible accelerate:
  - the return of useful land to the Mirarr people
  - the achievement of closure criteria
  - a positive legacy for ERA.

Chapters 8 and 10 of the MCP main document provide extensive discussion on the closure criteria, research, monitoring and adaptive management relevant to the following themes: Landform; Radiation; Water and sediment; Soil; Ecosystem; Cultural.

Table ES9 provides a summary of the closure criteria and the relevant studies that are being undertaken to inform and address these criteria.

Table ES9: Summary of completion criteria and monitoring

Completion Criteria Objective	Relevant Study / Monitoring (refer Table ES3 for KKN numbering)
Landform (criteria finalised – approved 30 September 2021)	
The tailings are physically isolated from the environment for at least 10,000 years	• Landform evolution modelling (LEM) to assess the stability of the final landform, erosion and surface water runoff (LAN3)
Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	• Erosion and sediment transport sampling from Pit 1 and Stage 52 area (LAN1) • Landscape-scale processes and extreme events (LAN2) • Land evolution modelling to assess the stability of the final landform (LAN3)
Radiation (criteria finalised – approved 30 September 2021)	
Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area.	• Radiation dose assessment (RAD6 and RAD7)
The company must ensure that operations at the Ranger do not result in: • change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	• Assessment of radionuclides in the rehabilitated site (RAD1, RAD9), aquatic ecosystems (RAD2), drinking water (RAD9) and bushfoods including wildlife (RAD3, RAD8, RAD9) • Radon progeny in air (RAD3)

Completion Criteria Objective	Relevant Study / Monitoring (refer Table ES3 for KKN numbering)
Water and Sediment (criteria to be finalised)	
• The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objective: 1.1(c) Protect the health of Aboriginals and other members of the regional community • The company must ensure that operations at Ranger do not result in: 1.2(c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	• Assessments that characterise the constituents of potential concern (COPC) in the rehabilitated site (WS1), groundwater (WS2) and surface water (WS3) • Assessments of radionuclides and radiation dose assessment noted above
• The company must ensure that operations at Ranger are undertaken is such a way as to: maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes • The company must ensure that operations at Ranger do not result in: change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. • Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	• Studies that characterise the baseline aquatic biodiversity (WS4) and impacts on this diversity (WS5) • Studies that assess the impact of COPCs in surface water and groundwater on biodiversity values (WS6 and WS7) • Groundwater/surface water interaction, and fate and transport modelling, to determine the concentrations of constituents of concern (COPC) entering the receiving environment (WS2)
• The company must ensure that operations at Ranger do not result in: environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. • 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.	• These are addressed by the options analysis completed for the Best Practicable Technology (BPT)(Table ES4) and many of the KKNs listed above • Cumulative assessments of the site and surrounds conducted for CT1 and CT2

Completion Criteria Objective	Relevant Study / Monitoring (refer Table ES3 for KKN numbering)
Soil (criteria finalised – approved 30 September 2021)	
The company must ensure that operations at Ranger do not result in: environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	• These are addressed by the options analysis completed for the Best Practicable Technology (BPT)(Table ES4) and many of the KKNs listed above
Ecosystem (criteria finalised August 2022 – yet to be approved)	
Revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.	• All of the studies conducted for the ecosystem restoration theme address this objective (ESR1-8)
Cultural (developed with GAC and NLC)	
• The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list • 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.	• Genuine engagement with the Mirarr people, Gundjeihmi Aboriginal Corporation (GAC) and Northern Land Council (NLC) • Cumulative assessments of the site and surrounds conducted for CT1 and CT2

1 Scope and purpose

Issued Date: October 2022

Revision number: 1.22.0

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APPENDICES

Appendix 1.1: Ranger 2022 Mine Closure Plan stakeholder feedback form

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary 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.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
APR	Annual Plan of Rehabilitation
ASX	Australian Securities Exchange
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
GAC	Gundjeihmi Aboriginal Corporation
MCP	Mine Closure Plan
MMP	Mining Management Plan
MTC	Minesite Technical Committee
NLC	Northern Land Council
NT	Northern Territory
RPA	Ranger Project Area
RWD	Ranger Water Dam formerly referred to as the Tailings Storage Facility (TSF)

1 SCOPE AND PURPOSE

This Mine Closure Plan (MCP) is prepared by Energy Resources of Australia Limited (ERA) to describe the plan for the Ranger Mine closure as at 30 June 2022 and meet its regulatory obligations and conditions under Annex B.2 of the Ranger Authorisation 0108-18 (*Section 3 Closure Obligations and Commitments*). The MCP is submitted to both the Commonwealth Minister for Resources and for Northern Australia, and the Northern Territory Minister for Mining and Industry for approval.

This MCP also appropriately addresses the requirements of the annual Mining Management Plan (MMP) for the Ranger Mine, as defined in Section 40(2) and 41 of the *Mining Management Act 2001 (NT)*, and is submitted for the approval of the NT Minister for Mining and Industry under Section 35 of that Act.

1.1 Operator Details

Energy Resources of Australia Limited (ERA) is Australia's longest continually operating uranium producer. Rio Tinto owns 86.3 per cent of ERA shares with the balance of the shares publicly held and traded on the Australian Securities Exchange (ASX). Information about ERA and a business overview can be found at www.energyres.com.au.

Production at the Ranger Mine ceased, in accordance with the Ranger Authority, on 8 January 2021. This concluded the processing activity on the Ranger Project Area (RPA) after 40 years of operation. The current and future priority of ERA is now the successful rehabilitation and closure of the RPA.

Contact details for the General Manager Closure and the Health, Safety, Environment and Communities Manager are provided in Table 1-1.

Table 1-1 Ranger Mine operator details

Name of Operator	Energy Resources of Australia Limited
Name of Mining Site	Ranger Mine
Address	Locked Bag 1
	Jabiru NT 0886
ABN	71 008 550 865
ACN	008 550 865
Address for service documents	GPO Box 2394 Darwin NT
Principal Place of Business	Level 8, 24 Mitchell Street Darwin NT 0800
Phone	1800 778 056
Fax	08 8938 1622
General Manager Ranger Closure	Forrest Egerton
Manager HSE	Josh Curran
Commodity	Uranium
Product	Uranium Oxide (U_3O_8)

The General Manager Ranger Closure has responsibility for maintaining the Ranger Mine Closure Plan.

1.2 Title Details

Table 1-2 summarises the holder details associated with the Ranger Mine.

Table 1-2 Ranger Mine title holder details

Name of mining site	Ranger Mine
Mineral Title	Ranger Project Area (RPA)
Mining interests	Uranium mining
Administration act	*Atomic Energy Act 1953 (Cth)*
Authorisation number	0108-18
Operator to whom Authorisation was granted	Energy Resources of Australia Ltd

1.3 Location

The Ranger Mine is located in the Alligator Rivers Region of the Northern Territory (NT), approximately 260 km east of Darwin (Figure 1-1). The RPA is surrounded by, but separate to, Kakadu National Park. It is bounded to the north and east by Magela Creek and its tributaries, to the west by Gulungul Creek and its tributaries, and to the south by Corridor Creek shown in Figure 1-3.

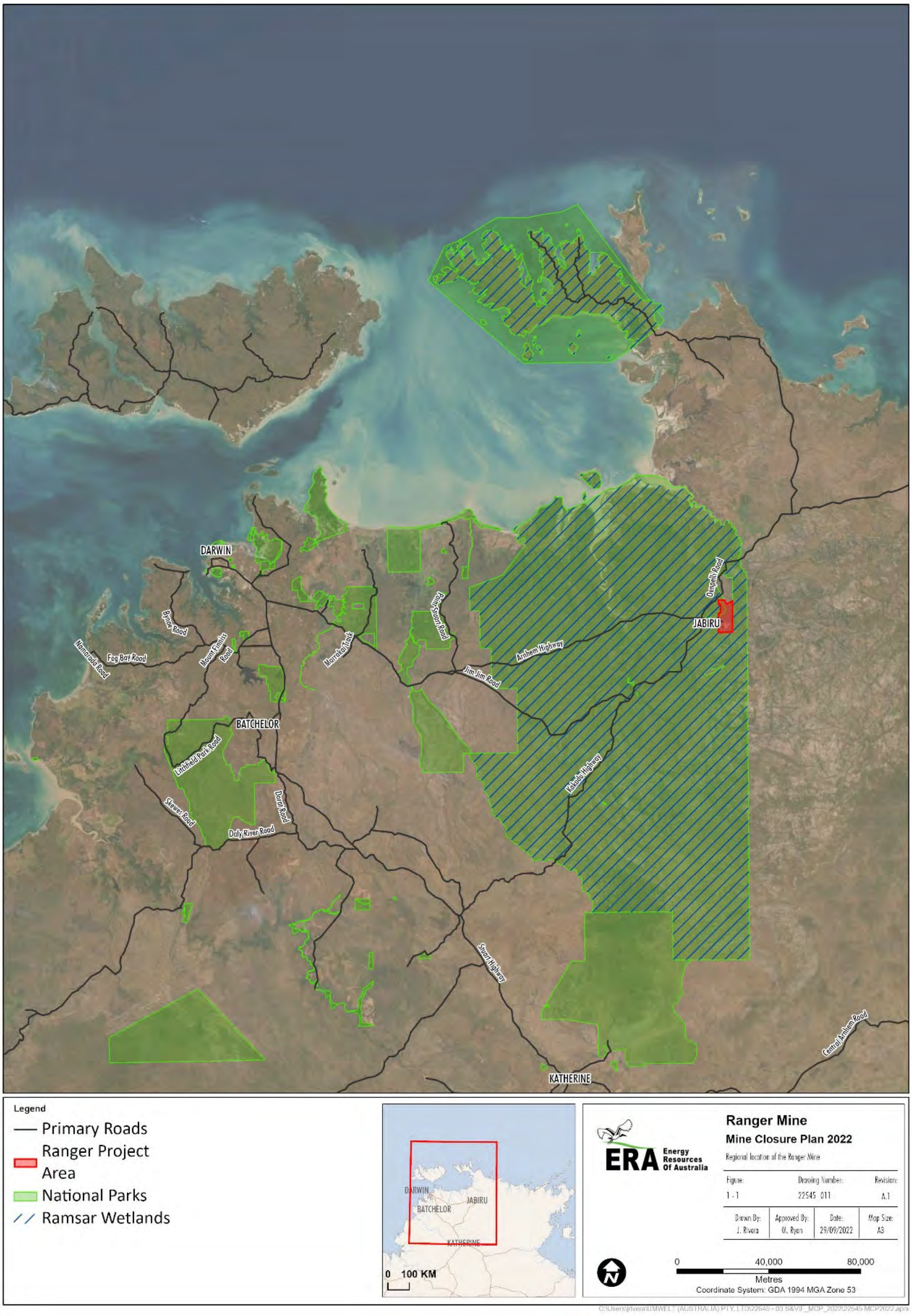

Figure 1-1 Regional location of Ranger Project Area

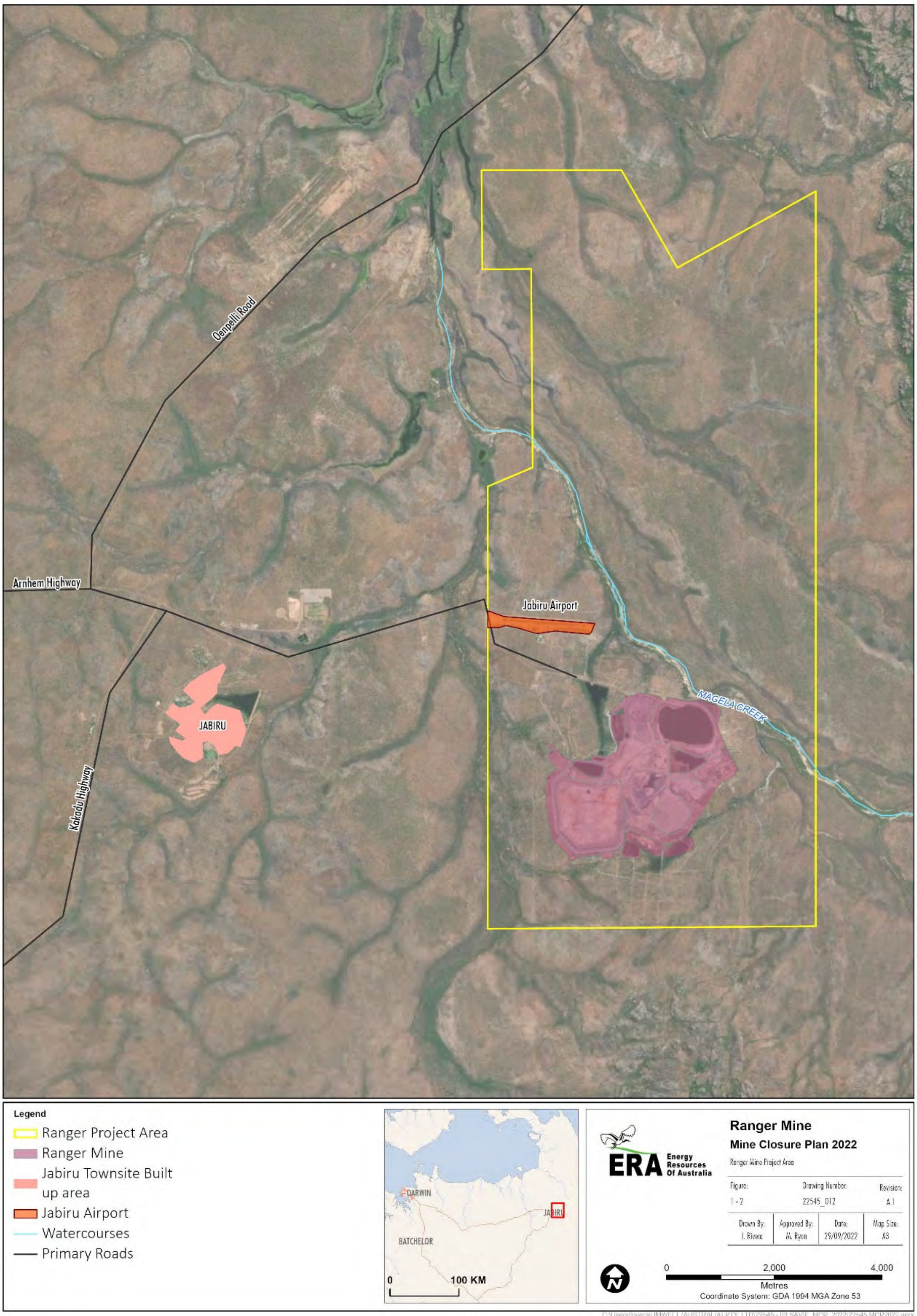

Figure 1-2 Ranger Mine Project Area

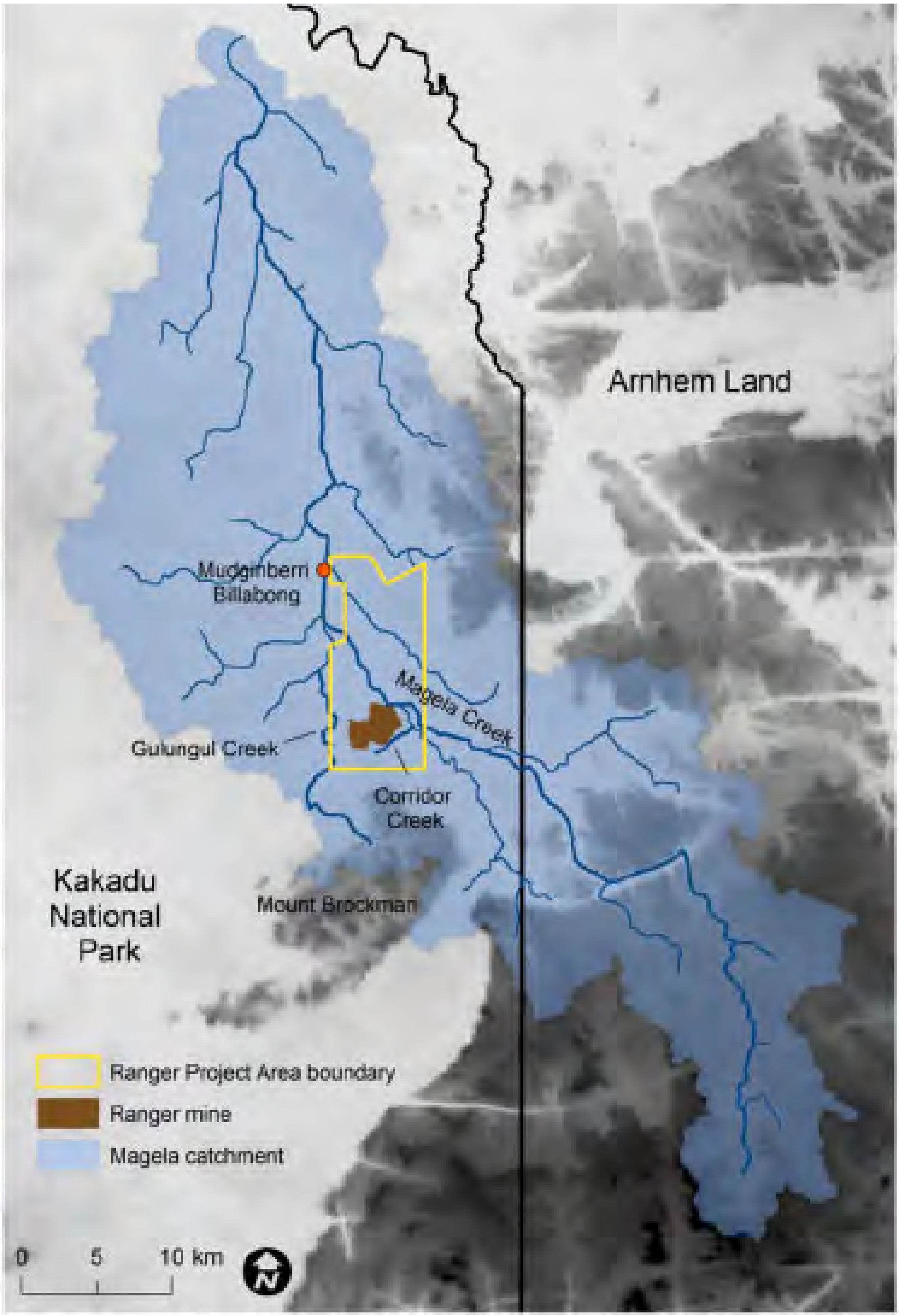

Figure 1-3 Proximity of Ranger Mine to natural topographic features

1.4 Background

ERA has operated the Ranger Mine since the commencement of operations in 1980. ERA has provided international customers with a reliable supply of uranium oxide (U_3O_8) in the 40 years since production began. The Ranger Mine has produced more than 132,000 tonnes of uranium (ERA, 2021) to meet the global uranium demand for fuelling nuclear power plants. ERA product is supplied to power utilities in Asia, Europe and North America in accordance with strict international and Australian safeguards.

Closure and rehabilitation of the Ranger Mine is governed by both Australian and Northern Territory legislation and regulations. The key instrument that governs operations at the Ranger Mine on a day-to-day basis is the Ranger Authorisation 0108-18 (the Authorisation) issued under the Northern Territory's *Mining Management Act 2018* (Mining Management Act). The main Commonwealth authority issued under Section 41 of the *Atomic Energy Act 1953 (Cth)* (Atomic Energy Act), provides the key tenure and land access approval required for the mine (S41 Authority).

The Ranger Environmental Requirements (ERs) are attached to the S41 Authority and set out environmental objectives which establish the principles by which the Ranger mining operation is to be conducted, closed, and rehabilitated and the standards that are to be achieved. The Mining Management Act also requires the Authorisation to incorporate, by reference, the ERs. A current view of the mine is shown in Figure 1-4.

Figure 1-4: Oblique view of Ranger Mine 2019

1.5 Purpose of this MCP

This MCP has been prepared as part of the ERA obligations under the Ranger Authorisation. It describes the ERA mine closure plan for the Ranger Mine as at 30 June 2022. ERA were exempt from providing a 2021 MCP. As such, the 2022 MCP includes updates from 1 July 2020 to 30 June 2022.

This MCP is the result of the past 40 plus years of extensive scientific research, engineering design and stakeholder consultation. It is an updated version of previous iterations presented to stakeholders (e.g. McGovern, 2006, Puhalovich & Pugh, 2007, ERA, 2019 and ERA, 2020). It is noted that further studies and works are ongoing, and that the outcomes of these studies will be presented in the annual updates of the MCP.

The MCP has been developed in line with the overall goal for the final land use, as 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.*

1.5.1 Implications of Ranger project reforecast process

In July 2021, ERA commenced a major reforecast of cost and schedule after risks materialised post-completion of the 2019 Feasibility Study. The reforecast continued into early 2022, including an external evaluation by Bechtel of the preliminary findings. The preliminary findings by ERA from its reforecast exercise based on the Ranger rehabilitation project being completed in accordance with the methodology set out in the 2020 Mine Closure Plan indicates that:

(i) the revised total cost of completing the Ranger Project Area rehabilitation, including incurred spend from 1 January 2019, is forecast to be approximately between $1.6 billion and $2.2 billion (undiscounted nominal terms). The previously announced closure estimate, which was based on the Ranger Project Area closure Feasibility Study finalised in 2019 ("Feasibility Study"), was $973 million (undiscounted nominal terms); and

(ii) the revised date for completing the Ranger Project Area rehabilitation is forecast to be between Quarter 4, 2027 and Quarter 4, 2028.

ERA notes that the above revised estimates, as to both cost and schedule, are based on the Ranger rehabilitation project being completed in accordance with the methodology set out in the 2020 Mine Closure Plan.

In May 2022, ERA commenced a feasibility study update in connection with a lower technical risk rehabilitation methodology (primarily relating to the subaerial capping of Pit 3) and to further refine the Ranger Project Area rehabilitation execution scope, risks, cost and schedule. Subaerial capping, previously adopted for Pit 1, is a more traditional method and it is currently ERA's preferred methodology. The 2022 Feasibility Study is expected to take approximately 12 months to complete.

This 2022 MCP update provides an indicative sequence of major closure activities and estimates of future milestones. A conservative approach to timing has been taken, with an indicative closure sequence out to Q4, 2028 provided.

1.5.2 Ranger Authorisation and *Mining Management Act*

A variation of the Authorisation was issued on 22 June 2018 and included Annex B, which details the process for submission and assessment of the MCP (also referred to as a 'rehabilitation plan') as agreed in accordance with S34 of the Mining Management Act. The MCP is required to be reviewed and updated annually, with submission to the Commonwealth Minister and the Northern Territory Minister on or before 1 October each year for approval. The MCP must demonstrate that closure activities will achieve the relevant ERs including:

- identification and management of closure issues, in particular, environmental and regulatory risks;
- key closure and monitoring activities with indicative timing; and
- a summary of closure works undertaken in the previous 12 months.

Once the MCP has been received by the Ministers, it is subject to review by the Supervising Scientist, Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) with advice provided by these stakeholders to both Ministers.

1.5.3 Section 41 Authority and ERs

The ERs are appended to the S41 Authority. Clause 9.1 of the ERs requires ERA to prepare a 'rehabilitation plan' which 'provides for progressive rehabilitation' and achieves the overall goal of rehabilitation outlined in clause 2.1 and the 'major objectives of rehabilitation' outlined in clause 2.2.

2.1 Subject to subclauses 2.2 and 2.3, 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.

2.2 The major objectives of rehabilitation are:

revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park;

stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including traditional owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area;

erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas.

The ERs also provide for infrastructure to remain on the RPA post closure if all stakeholders agree:

2.3 *Where all the major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in subclauses 2.1, 2.2 and 3.1.*

The requirements for the rehabilitation plan within the S41 Authority are more broadly based than those of the Authorisation (*Section 8 Post Closure Land Use*, *Closure Objectives and Closure Criteria*).

All progressive rehabilitation must also be approved by the Supervising Authority on the advice of the Supervising Scientist and is also subject to the NLC agreeing that the aim and objectives for rehabilitation have been met. The Supervising Authority is the person responsible under an applicable law (with relevance to *Atomic Energy Act 1953, Environment Protection (Alligator Rivers Region) Act 1978, Uranium Mining (Environment Control) Act 1979* etc.) or, where no law applies, the Supervising Scientist.

The parallel NT and Commonwealth legislative approvals processes that relate to mine closure activities at the Ranger Mine are complex. *Section 3 Closure obligations and commitments* and appendices provide further details on the complexities of the legislative framework.

1.5.4 Government agreement

Separate to this MCP, ERA is required to maintain the Ranger Rehabilitation Special Account (Trust Fund) with the Commonwealth Government. The Trust Fund is intended to provide security against the estimated costs of closing and rehabilitating the Ranger mine immediately. Each year, the Company is required to prepare and submit to the Commonwealth Government an Annual Plan of Rehabilitation (Annual Plan). Once accepted by the Commonwealth Government, the Annual Plan is then independently assessed and costed and the amount to be provided by the Company into the Trust Fund is then determined. *Section 11 Financial Provision for Closure* provides further details of this agreement.

1.6 Scope of this MCP

The MCP covers the RPA shown in Figure 1-2, specifically referring to the following areas and assets:

- Ranger Mine infrastructure, former mine pit voids, Ranger Water Dam (RWD) formerly known as the Tailings Storage Facility (TSF), the exploration decline and all associated utilities within the operational area of the Ranger Mine;
- Land application areas, wetland filters and other infrastructure associated with the Ranger Mine; and

- Jabiru Airport and associated infrastructure and utilities: noting that discussions are progressing between ERA, Traditional Owner representatives and relevant government agencies regarding the potential future use of the airport. These discussions will include rehabilitation obligations.

The following areas and assets are not considered in this MCP:

- The town of Jabiru.
- 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.

ERA has defined the closure and rehabilitation activities in the phases outlined in Table 1-3. Table 1-3 must be read subject to the qualifications in Section 11.

Table 1-3 Timelines of the operations and closure phases of the Ranger Mine

Phase	Timeline	Closure Related Activities
Operations	Period prior to 8 January 2021	Progressive rehabilitation and monitoring (operational and closure related research and monitoring activities).
Closure	Period between 8 January 2021 and the completion of final landform and rehabilitation (indicative estimate Q4, 2028 for the purpose of this MCP)	Decommissioning, bulk material movement to achieve final landform, rehabilitation and monitoring.
Monitoring and maintenance	Currently estimated to be 25 years after Closure Phase	Completion criteria monitoring (and maintenance rehabilitation works if required) [note – arrangements under which ERA has access to the RPA for this period are yet to be finalised].
Relinquishment	Issue of close-out-certificate(s), relinquishment of RPA	Progressive close-out certificates may be obtained for areas rather than a single area for the entire RPA.

1.7 Review and updates

To ensure its currency, and to incorporate lessons learnt from ongoing modelling and monitoring studies, the MCP is updated and submitted for approval annually. Having said that, the 2021 MCP was exempt from submission and therefore this 2022 MCP provides updates to closure activities from the period of 1 July 2020 to 30 June 2022.

Subsequent to the distribution of a draft of the MCP to stakeholders in December 2016, several aspects of rehabilitation/closure activities were identified for standalone assessment via the Minesite Technical Committee2 (MTC) and the Commonwealth Minister[3]. These activities were identified during the stakeholder workshop held in May 2017. The remaining commonwealth applications for assessment and approval are listed Table 1-4. Other minor applications may be required to provide further clarification on technical aspects of closure activities or for minor changes. These will be submitted for MTC approval as required. Ideally, for ERA, such clarification would be provided and approved within the MCP rather than a separate minor approval application.

The 2020 MCP was subject to stakeholder review and detailed feedback was provided and has been considered in the preparation of this document (refer to Appendix A). Stakeholders are requested to utilise the form provided in Appendix 1.1 to provide feedback on this 2022 MCP.

[2] The functions of the MTC and other ERA key stakeholders are described in *Section 4 Stakeholder Engagement.*

[3] Matters requiring Commonwealth ministerial consultation according to the update sent from the Department of Industry, Science and Resources & Department of Industry, Tourism and Trade (April 2017)

Table 1-4 Future Commonwealth applications to be submitted

APPLICATION TITLE	APPLICATION TYPE	PLANNED SUBMISSION DATE	SCHEDULED APPROVAL DATE	CONTENT
Pit 3 Capping, Bulk Backfill and Waste Disposal	Commonwealth Ministerial approval required	Draft April 2022 Q4 2022	Q1 2023	Details of Pit 3 capping and bulk backfill activities that include the co-disposal of site demolition and other waste.
TSF (RWD) Deconstruction and Final landform	Commonwealth Ministerial approval required	Q1 2024	Q3 2024	The detailed plan of deconstruction of TSF (RWD) and the final landform application will be combined and submitted as a stand-alone application.
Completed closure works report	Commonwealth Ministerial approval required	6 months after completion of rehabilitation works	N/A	Final report detailing all completed closure activities.

1.8 Content and structure of this MCP

Clause B6 of the Authorisation requires that the MCP must be prepared in accordance with mine closure guidelines accepted by the Commonwealth Minister as well as addressing the Mine Management Plan requirements. The currently adopted guidelines are the Western Australian mine closure guidelines. These guidelines were reviewed and updated in March 2020 (DMIRS, 2020) and have been used for reference in the preparation of this MCP. The guidelines provide for a preferred structure, which has been used as the basis for the MCP (with some minor adjustments to suit the unique circumstances of the Ranger Mine). The structure of this MCP, along with an overview of the content of each section, is provided in Table 1-5.

Table 1-5 Structure and content of this MCP

Section	Content
1. Scope and purpose	Introduction to the Ranger Mine, including its location and history, purpose of the document, overview of relevant regulatory requirements of the document and scope of this MCP. Includes details on future standalone closure applications.
2. Project overview	A historical overview of the Ranger Mine ore deposits and mine development, including a description of the historical mining operations and major mine components/infrastructure. Future closure related Land disturbances are provided in *Section 9: Closure Implementation*.
3. Closure obligations and commitments	Presents the legal obligations, commitments, standards and guidelines relevant to the Ranger Mine closure.
4. Stakeholder engagement	Description of the stakeholder engagement process and details of the stakeholder engagement for matters relating to rehabilitation and closure, with the stakeholder engagement register provided as an appendix to this section.
5. KKN Supporting Studies	Overview of the existing environment of the RPA in relation to the local and regional setting, including nearby sensitive receptors. Discussion of the Key Knowledge Needs relevant to ERAs key studies informing the overarching closure strategy, design and closure criteria. Summaries of the substantial knowledge base accumulated by ERA over 40 years of monitoring and research investigations of the site and surrounding environment.
6. Best practicable technology	Description of the process and identification of the best practicable technology for the Ranger Mine rehabilitation and closure. Includes details on best practicable technology assessments already undertaken on closure related works.
7. Risk assessment and management	Description and outcomes of the closure risk assessments.
8. Post Closure land use, closure objectives and closure criteria	Description of the agreed post-mining land use and closure objectives. Description of the closure criteria that will be used to measure rehabilitation success and demonstrate the closure objectives have been met. This section includes an overview of the current status of closure criteria at 30 June 2022.

Section	Content
9. Closure implementation	Description of the proposed closure strategy and is aligned with closure domains. Includes details on what has been completed and the proposed schedule for future works.
10. Closure monitoring and maintenance	Description of the monitoring programs currently being undertaken or proposed. Also describes what maintenance will be required.
11. Financial Provision for closure	Provides the rehabilitation provision based on estimates of costs and their timing to rehabilitate and restore disturbed land to agreed criteria.
12. Management of information and data	Description of management strategies, including systems and processes, for the retention of mine records relevant to mine closure.
Appendix A:	Responses to stakeholder comments on the 2020 MCP.

REFERENCES

Department of Mines, Industry Regulation and Safety (DMIRS), 2020. Statutory Guidelines for Mine Closure Plans, Government of Western Australia, March 2020, p 14 http://www.dmp.wa.gov.au/Documents/Environment/REC-EC-111D.pdf

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McGovern, E. 2006. *Energy Resources of Australia Ltd Ranger Mine Closure Model- First Pass. (Prepared June 2005 & revised March 2006)*. EWL Sciences Pty Ltd. March 2006, p 220.

Puhalovich, A & Pugh, L. 2007. *ERA Ranger Closure Model 2007*. Report by Energy Resources of Australia Ltd, Commercial in Confidence. November 2007, p 137.

APPENDIX 1.1 RANGER 2022 MINE CLOSURE PLAN STAKEHOLDER FEEDBACK FORM

2022 Ranger Mine Closure Plan Stakeholder Feedback

STAKEHOLDER: *Insert stakeholder details e.g. Supervising Scientist Branch*

MCP Section/subsection	**MCP page No.**	**Query/comment**
e.g. S1, 1.3.2	*1-13*	*More information is requested regarding …...*

2 Project overview

Issued Date: October 2022

Revision#: 1.22.0

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GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary 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.
Water management technology	Refer Appendix 2.1 for the definitions for common terms used in water management.
Reference Level	Reference Level abbreviated to RL. Denotes a specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the RWD or depth of Pit 3
Release Plan Calculator	Basic mass balance equation model used to assist with the prediction of changes in water quality between upstream (MCUS) and downstream (MG009) monitoring points. The RPC is used to determine when it is appropriate to actively release water from the minesite
Water Management System	The infrastructure, operations and procedures required to manage water at Ranger which includes capturing, storing, transferring, treating and disposing volumes of water.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
AAEC	Australian Atomic Energy Commission
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
BC	Brine Concentrator
CB2	Collection Basin 2 – also denotes other collection basins on site – e.g. CB7
CCLAA	Corridor Creek Land Application Area
CCWLF	Corridor Creek Wetland Filter
DJKPS12	Djalkmarra Pump Station 12
DJKRP	Djalkmarra Release Point
DLAA	Djalkmarra Land Application Area
EIS	Environmental Impact Statement
EPIP Act	*Environmental Protection (Impact of Proposal) Act 1974*
ER	Environmental Requirements

Abbreviation/ Acronym	Description
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
EZ	Electrolytic Zinc Company of Australasia Ltd
FLV 7	Final Landform Design Model Version 7
GC2	Georgetown Creek 2
GCMBL	Georgetown Creek Median Bund Leveline
ha	hectare
HDS	High Density Sludge
JELAA	Jabiru East Land Application Area
LAA	Land Application Area
M t	Million Tonnes
NLC	Northern Land Council
NT	Northern Territory
NP	National Park
OBS	Osmoflow Brine Squeezer
Peko	Peko-Wallsend Operations Ltd
Pit 1	Walem Madjawulu 1
PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances
R3 Deep	Ranger 3 Deep
RL	Reference Level
RP1	Retention Pond 1 - also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RP1Ext	Retention Pond 1 Extension
RPA	Ranger Project Area
RPC	Release Plan Calculator
RWD	Ranger Water Dam formerly the Tailings Storage Facility (TSF)
RWMP	Ranger Water Management Plan
S41	Section 41 Authority
SSB	Supervising Scientist Branch
TSF	Former Tailings Storage Facility now Ranger Water Dam (RWD)
WTP	Water Treatment Plant

2 PROJECT OVERVIEW

The purpose of this section is to provide background information on the history and status of the Ranger Mine project, and current mine site activities. Table 2-1 provides a timeline of events and key milestones for the mine.

Table 2-1 Ranger Mine timeline

Date	Description of Event / Milestone
1969	Ranger orebodies discovered by joint ventures Electrolytic Zinc Company of Australasia Ltd (EZ) and Peko-Wallsend Operations Limited (Peko).
1974	The Australian Government, through the Australian Atomic Energy Commission, agrees to finance 72.5 per cent of the project and sell the uranium, with 50 percent of the net proceeds distributed to the joint ventures.
1974	February: Submission of Environmental Impact Statement (and supporting material) under the Australian Government's *Environmental Protection (Impact of Proposal) Act 1974*.
1975	May: Submission of Supplements 1 and 2 to Environmental Impact Statement (EIS).
1975	The Ranger Uranium Environmental Inquiry (Fox *et al.* 1976) is established.
1977	Final Fox report (Fox *et al.* 1976, 1977) recommends that uranium mining proceed.
1977	Much of the Alligator Rivers Region (ARR) was declared a National Park (NP) and Aboriginal people were given a major role in the management of Kakadu NP.
1978	Title to the Ranger Project Area (RPA) was granted to the Kakadu Aboriginal Land Trust, in accordance with the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* (Aboriginal Land Rights Act) and the Commonwealth Government entered an agreement with the Northern Land Council (NLC) to permit mining to proceed. The Supervising Scientist position is established under the *Environment Protection (Alligator Rivers Region) Act 1978*.
1979	S41 Authority under the Australian *Atomic Energy Act 1953* is issued. Construction at Ranger commences.
1980	Energy Resources of Australia Limited is established as a public company. It was the largest public float in Australian history at the time. Using open cut methods, mining of Ranger Pit 1 orebody commences in May 1980.
1981	The first drum of uranium oxide is produced on 13 August 1981.
1994	Mining of Ranger Pit 1 orebody is completed in December, after recovering 19.78 million tonnes (M t) of ore.
1996	Final approval to mine Ranger Pit 3 orebody is received from the Northern Territory Government in May.
1997	Open cut mining of orebody 3 commences in July 1997, with mining expected to continue until at least 2009.
2000	Rio Tinto acquires North Limited, the previous major shareholder in ERA.

Date	Description of Event / Milestone
2006	October: ERA announces an increase in Ranger Mine's reserves as a result of a reduction in cut-off grade of stockpiled and yet to be mined ores for processing, adding approximately six years to the predicted life of processing at Ranger to 2020.
2007	September: ERA announces an extension to the Ranger operating Pit 3, extending mining at Ranger until 2021. ERA also announces expenditure for a pre-feasibility study to examine options to extend the mine further and to increase production from the processing plant.
2008	November: ERA announces a significant mineral exploration target defined at Ranger 3 Deeps of 15 to 20 million tonnes with a potential for 30,000 to 40,000 tonnes of contained uranium oxide.
2009	April: The laterite treatment plant was commissioned to extract uranium from weathered ores (referred to as laterite ores) that are unable to be processed through the existing processing plant.
2011	August: The ERA Board approves the construction of an exploration decline to conduct underground exploration drilling of Ranger 3 Deeps and to explore areas adjacent to the Ranger 3 Deeps resource.
2011	October: The ERA Board announced an accelerated renounceable entitlement offer (Entitlement Offer) of new ERA ordinary shares to all eligible shareholders at an offer price of $1.53 per new share. The Entitlement Offer was successfully completed on 15 November 2011 with ERA raising its target amount of $500 million. The funds to be used to progress the implementation of ERA’s strategic initiatives including the construction of a brine concentrator, construction of an exploration decline for the Ranger 3 Deeps resource and an expanded surface exploration on the Ranger Project Area.
2012	ERA approved the design, construction, and commissioning of a Brine Concentrator facility at Ranger.
2012	Works began on the construction of Phase 1 of the Ranger 3 Deeps exploration decline. ERA engaged MacMahon Holdings Limited to construct the 2.2-kilometre decline.
2012	June: The ERA Board approved expenditure to conduct a prefeasibility study on the potential Ranger 3 Deeps mine. The study to be conducted from 2012 until 2014 inclusive.
2012	Onsite water management was boosted to expand capacity beyond potential flood levels, with the completion of Retention Pond 6 and Ranger Water Dam (RWD) formerly Tailings Storage Facility (TSF) wall lift.
2012	Construction of a new levee to guard Pit 3 from Magela Creek in the event of a large flood event.
2012	Cessation of open cut mining in Pit 3. Commencement of Pit 3 backfill activities.
2013	Finalised the Ranger Mining Agreement with Mirarr Traditional Owners and implementation of a Relationship Committee.
2013	The operation submitted a referral for the Ranger 3 Deeps mine under the *Environment Protection and Biodiversity Conservation Act 1999.*

Date	Description of Event / Milestone
2013	Placement of waste rock over Pit 1 tailings to assist in ongoing dewatering of Pit 1. Approximately 70 per cent of the pre-load of waste rock was completed in 2013.
2013	Construction of the Brine Concentrator was completed. Commissioning tests and verification phase commenced.
2013	Backfill of 22.8 M t of waste material into Pit 3 in preparation for the planned transfer of tailing from the RWD and processing plant and storage of brines from the Brine Concentrator (BC).
2013	Phase 1 of the Ranger 3 (R3) Deep exploration decline continued with 1,900 metres of tunnel development and 13.9 kilometres of underground exploration drilling completed.
2014	Pit 3 under fill drainage layer and extraction pumping system installed.
2014	Construction of the tailings dredge completed.
2015	Pit 3 brine injection piping and infrastructure installed and commissioned.
2015	Tailings dredge, tailings transfer and water recovery/pumping infrastructure commissioned.
2016	All production tailings directed to Pit 3.
2017	April: Regulatory approval permitting ERA to begin the final stages of backfill in Pit 1 was obtained and this work has commenced.
2018	Laterite plant ceased operation due to exhaustion of laterite ore. Laterite plant placed under care and awaiting demolition as part of the site closure project.
2019	Ministerial approval to commence decommissioning of the R3 Deeps exploration decline.
2020	The High Density Sludge (HDS) plant application was submitted in October 2019 to gain approval for the release of partially treated process water into the pond water circuit. Approval was received on 19 February 2020.
2020	The application to utilise the Osmoflow Brine Squeezer (OBS) for the treatment of process water (as well as pond water for which the OBS is already approved to treat) was submitted on 5 May 2020. Approval to commence trialling the treatment of pond water through the OBS was received on 22 June 2020.
2020	The application to leave the subfloor of the RWD *in situ,* rather than to remove and transfer into Pit 3, was submitted on 16 March 2020. An updated version following stakeholder comments was submitted on 15 June 2020.
2020	Approval received July 2020 to leave the subfloor of the RWD *in-situ*.
2021	Production at the Ranger Mine ceased on 8 January 2021. This concluded processing activities on the RPA after 40 years of operation.
2021	Completion of dredging for tailing transfer from the RWD to Pit 3.
2021	Decommissioning of Processing Plant.
2021	Commenced planting on the backfilled surface of Pit 1 (Walem Madjawulu 1).

Date	Description of Event / Milestone
2022	Completion of final tailings from RWD to Pit 3 transfer via truck from remnant tailings.
2022	Commencement of ranger closure feasibility study refresh.
2022	Final drum of uranium oxide product sold on 31 May 2022.

2.1 Overview of completed operations and exploration

Mining activity at the Ranger Mine involved a conventional open cut process, commencing with drilling and blasting. Two open-cut pits were mined during the life of the Ranger Mine, Pit 1 and Pit 3 (Figure 2-1; Figure 2-3). Prior to the completion of mining in the pit's, mined material was categorised by a discriminator, measuring the uranium grade designated for either stockpiling or processing (Table 2-2; Figure 2-2; Figure 2-3). Low-grade ore and non-mineralised rock were stockpiled near pits 1 and 3 so it could be used in the future as backfill in the pits and to create the final landform.

Table 2-2: Indicative ore grades and mineral type

<table>
<tr><th rowspan="2">Grade</th><th colspan="3">Grade (% U_3O_8)</th><th rowspan="2">Material type</th></tr>
<tr><th>1980-1997</th><th>1998-2009</th><th>2010-Current</th></tr>
<tr><td>1</td><td><0.02</td><td><0.02</td><td><0.02</td><td>Non-mineralised rock</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">0.02-0.05</td><td rowspan="2">0.02-0.08</td><td>Low 2
0.02-0.06</td><td>Very low-grade ore</td></tr>
<tr><td>High 20.06-0.08</td><td>Low-grade ore</td></tr>
<tr><td>3</td><td>0.05-0.10</td><td>0.08-0.12</td><td>0.08-0.12</td><td>ore</td></tr>
<tr><td>4</td><td>0.10-0.20</td><td>0.12-0.20</td><td>0.12-0.20</td><td>ore</td></tr>
<tr><td>5</td><td>0.20-0.35</td><td>0.20-0.35</td><td>0.20-0.35</td><td>ore</td></tr>
<tr><td>6</td><td>0.35-0.50</td><td>0.35-0.50</td><td>0.35-0.50</td><td>ore</td></tr>
<tr><td>7</td><td>>0.50</td><td>>0.50</td><td>>0.50</td><td>ore</td></tr>
</table>

Figure 2-1: Ranger Mine site

Figure 2-2: Ranger Mine plant layout

Legend

1. Car Park
2. Security
3. Bulk Fuel
4. Shellsol
5. Simon Carves Yard
6. Water Management Yard
7. Ammonia Handling
8. Emergency Dump Tank
9. Calciner & Product Packing
10. Solvent Extraction
11. Sand Filters
12. Administration
13. Water Management and Environmental Services
14. Engineering & Supply
15. Ranger 3 Deeps Portal
16. Decline Laydown Area
17. Closure Projects office
18. Sub Station
19. Demineralisation Plant
20. Power Station
21. Plant Services
22. Grinding
23. Counter-Current Decantation
24. Tailings Neutralisation & Process Water Header Tank
25. Corridor Road

26A. A - WTP 1

26B. B - WTP 2

27. Septic Transpiration Area
28. Acid Leach
29. Laterite Treatment Plant
30. Coarse Ore Stockpile
31. Fine Crushing
32. Secondary Crushing
33. BC Power Station & Control Room
34. Acid Storage
35. Brine Concentrator
36. Water Treatment Plant 3
37. Radiometric Sorting
38. Primary Crushing
39. Pond Water Tank
40. HDS Plant
41. Brine Squeezer
42. Lime Mill & Silos
43. Mine Wash Down
44. Retention Pond 2
45. Retention Pond 3
46. Mines Office
47. Old Orica Yard
48. Trial Evaporation Channels
49. Pit 1
50. Georgetown Creek Medium Bund Level (GCMBL)
51. Corridor Creek Land Application Area
52. Retention Pond 5
53. Corridor Creek Wetland Filter
54. Tailings Dam
55. Retention Pond 6
56. Trial Landform
57. Magazine
58. Retention Pond 1 Land Application Area
59. Retention Pond 1
60. Retention Pond 1 Wetland Filter
61. Retention Pond 1 Land Area Extension
62. Accommodation Camp
63. Workshop (Gagadju)
64. Jabiru East Land Application Area
65. Office of the Supervising Scientist
66. Telstra
67. Airport
68. Exploration Storage Yard
69. Jabiru East Potable Water Supply
70. Exploration Core Yard
71. Djalkmarra Land Application Area
72. Djalkmarra Land Application Area Extension
73. Pit 3
74. Levee
75. Magela Land Application Area
76. Borrow Pit
77. Djalkmarra Pumping Sump 12 (DJKPS12)
78. Exploration decline vent shaft

Energy Resources Of Australia

Ranger Mine

Mine Closure Plan 2022

Index for Site Layout Figures - Ranger Mine

Figure:	Drawing Number:	Revision:
2 - 3	22545_023	A1

Drawn By:	Approved By:	Date:	Map Size:
J. Rivero	W. Ryan	29/09/2022	A3

0 675 1,350

Metres

Coordinate System: GDA 1994 MGA Zone 53

Figure 2-3 Legend to Figure 2-1 and Figure 2-2

2.1.1 Pit 1 (Walem Madjawulu 1)

Construction of Pit 1 began in 1979. Mining of the orebody commenced in 1980 producing approximately 18 M t of ore between May 1980 and December 1994. The mined-out pit, generally circular in plan view, had a surface area of 41.1 ha and an approximate diameter of 750 m at the widest point. The benches were designed to be approximately 7 m high, except the first bench cut at 14 m. The final pit shell had the shape of an inverted cone, with a depth of -150 mRL[2].

Following the completion of mining, activities for the closure and rehabilitation of Pit 1 commenced. Closure and rehabilitation have been completed on Pit 1 with monitoring and adaptive management now being undertaken.

For information on Pit 1 tailings consolidation and solute egress modelling, refer to *Section 5 KKN supporting Studies*.

2.1.2 Pit 3

Approval for the construction of Pit 3 was received in May 1996. Open-cut mining commenced in July 1997. In 2008 ERA progressed with the Shell 50 pit expansion enabling mining of Pit 3 to continue until November 2012. The final pit shell had a base (floor) elevation of -265 mRL at its deepest point. At is its maximum surface extent, Pit 3 is approximately 1,750 m long and 970 m wide. The mine site is located within the Cahill Formation containing significant areas of uranium mineralisation within Lower Cahill metasediments.

In order to use the pit for tailings storage and to achieve a good rate of rise and consolidation of the tailings, the pit was backfilled with 33.7 Mt of low-grade ore and non-mineralised rock (termed underfill) to an approximate elevation of -100 mRL. The void within the underfill is being used for the storage of waste residue produced by the Brine Concentrator. An underdrain system comprising a 2 m layer of waste rock and a sump was constructed over the underfill to facilitate tailings consolidation and allow for the injection of brine.

A separate application has been submitted for Pit 3 closure activities.

2.1.3 Stockpiles

Several stockpiles comprising of low-grade ore and waste rock are situated within the vicinity of the mined pits and the RWD. As shown on Figure 2-1, the area covered by the stockpiles is approximately 2 km at its longest extent and 0.5 km in width. Approximately 21 M t of low-grade ore was processed from these stockpiles, and 104 M t of waste rock was stored for future use in backfilling both pits and to shape the final landform.

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[2] Reference Level abbreviated to RL denoting specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the RWD or depth of Pit 1.

Throughout the mine life, the stockpiles have been segregated according to both grade and material type (Table 2-2).

There are three main stockpile material types: primary, weathered and laterite. Primary material consists of unweathered host rock, comprised mainly of altered quartz-feldspar schists and to a lesser extent, cherts and carbonaceous materials. Weathered material consists of friable rock (usually quartz-feldspar schist) with altered mineral assemblages but generally still low in clay content. Laterite is a near-surface, highly weathered and sometimes reconsolidated material, typically high in iron and aluminium clays and other gangue minerals that have made it difficult to process conventionally. Early in the mine life, improved processing performance led to the combination of the weathered and the primary material being fed to the processing plant. In more recent years, a separate laterite processing circuit was constructed to process the weathered material.

2.1.4 Ranger 3 deeps exploration decline

The Ranger 3 (R3) Deeps orebody was discovered during surface drilling exploration in 2008. To better define the resource ERA constructed an exploration decline at the Ranger Mine adjacent to the south-eastern rim of Pit 3, from early May 2012 to December 2014 (Figure 2-4). This enabled an underground exploration and infill drilling program to increase orebody knowledge and provide geological, hydrogeological, geotechnical and radiological data.

The decline was extended, and the ventilation shaft was constructed between October 2013 and October 2014. Exploration diamond drilling began in May 2013. Preliminary drilling results were announced in August 2013, and the third drill rig was mobilised in November 2013. Drilling ceased in September 2014. In 2015 the decision was made to not progress, and the project was placed into care and maintenance.

The decline extends 2,700 m in length and 450 m below the ground surface, above and parallel to the target mineralised zone. The decline was intended to provide access to the mineral resource and subsequent underground mine known as 'Ranger 3 Deeps' (R3 Deeps).

In April 2019 ERA received approval from both the Commonwealth and Northern Territory Ministers to commence rehabilitation and closure of Ranger 3 Deeps. Details of the closure and rehabilitation of the decline are provided in Chapter 9.3.9 of *Section 9 Closure Implementation*.

Figure 2-4: Spatial extent of the Ranger 3 Deeps exploration decline

2.1.5 Processing

The major ore processing stages are described below.

- Uranium ore is crushed and ground, then the fine ore is mixed with water to produce a slurry;
- The ore slurry is pumped to leaching vessels where, over a period of 24 h, more than 90 % of the uranium in the ore is dissolved using sulfuric acid and pyrolusite (an oxidant);
- The uranium in solution is then separated from the depleted ore in a seven-stage washing circuit;
- After separation, the acidity of the depleted ore (tailings) is partially neutralised with lime before being pumped to the RWD, whilst the leach solution is clarified and filtered;
- The uranium is extracted from the leach solution and concentrated, and then pumped to precipitation tanks;
- A bright yellow uranium compound (ammonium diuranate), commonly referred to as 'yellowcake' is precipitated using ammonia;
- In the final stage of the process, the yellowcake is heated to 800 °C to produce the final product – uranium oxide, a dark green powder; and
- The product is packed into 200 L steel drums. These are sealed and transported by road, using an accredited transport company, to a secure holding facility and then exported by ship.

Following the completion of open cut mining in 2012, ERA continued to process stockpiled ore until 8 January 2021, when the Authority required processing to cease. The last drum of uranium oxide was sold on 31 May 2022, completing the mine’s operational stage after producing a total of 132,000 tonnes of uranium oxide.

2.1.6 Process plant

The process plant area is shown in Figure 2-2 and includes all infrastructure associated with the processing of uranium ore and production of uranium oxide. Construction of the processing infrastructure began in 1979, and has since been replaced, upgraded, or added to over the life of the mine.

Following the cessation of processing activities on 8 January 2021, the process plant has commenced decommissioning and demolition activities as described in *Section 9 Closure Implementation*.

2.1.7 Tailings and process water storage

The Ranger Water Dam (RWD) formerly known as the Tailings Dam or Tailings Storage Facility (TSF), and Pit 1 and Pit 3, are approved to store tailings and process water in accordance with relevant conditions detailed in the Authorisation (*Section 3 Closure Obligations and Commitments*).

2.1.7.1 Ranger Water Dam

The Ranger Water Dam (RWD)[3] was commissioned as the Ranger Tailings Dam in 1980 classified as a "ring dyke" forming an approximate square with sides of about 1 km in length. The initial dam was based on a proposed crest level of 51.0 mRL[4]. Designed structural additions have increased the crest level to 60.5 mRL. The eastern, southern and western walls run along ridges that approximate catchment divides separating Coonjimba Creek from adjacent surface water catchments, including Gulungul Creek to the west and the Djalkmarra and Georgetown catchments to the east.

Neutralised mill tailings were deposited within the RWD from 1980 to 1996, after which time mill tailings were sent to the mined-out Pit 1 in accordance with regulatory approvals. Once Pit 1 reached its maximum tailings level, mill tailings were re-directed back to the dam from 2008 through to February 2015, when the mined-out Pit 3 became available for tailings storage. At this time, the tailings within the dam was estimated at 27 M t.

Tailings management was initially subaqueous due to concerns with radon gas emissions. In 1987 tailings deposition within the RWD was changed to sub-aerial due to: (a) studies which showed that radon gas emission was not an issue; and (b) concerns with low water levels causing the floating tailings pipelines to become stranded on tailings "islands".

Details on the transfer of tailings from the RWD to Pit 3 and the rehabilitation activities associated with the closure of the RWD are provided in Chapter 9.3.3 of *Section 9 Closure Implementation*.

The free process water inventory held in the RWD is progressively reduced through passive evaporation and water treatment via the brine concentrator (BC).

Performance of the RWD is monitored, with annual inspections conducted by independent engineers, in accordance with the Authorisation and operated in accordance with the requirements of the Australian National Committee on Large Dams and International Commission of Large Dams guidelines for tailings dams design, construction, operation and closure (ANCOLD 2019). The data is reported to the Regulators to confirm that the structure continues to perform according to its design and operational criteria. All ERAs tailings storage facilities are operated in accordance with the Rio Tinto Standard D5: *Management of Tailings and Water Facilities* (Rio Tinto 2015), which covers all development phases from planning, design through construction, operation, closure and post-closure where applicable.

2.1.8 Water management

Water management is the most significant environmental and operational aspect of the Ranger Mine and is an integral part of the ERA Health, Safety and Environment Management System.

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[3] The Ranger Water Dam is the former Tailings Storage Facility (TSF) or Tailings Dam.

[4] Reference Level abbreviated to RL. Denotes a specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the RWD or depth of Pit 3.

It encompasses all aspects of water capture, storage, supply, distribution, use and disposal. Water is managed according to the Ranger Water Management Plan (RWMP), which describes the method used to control water on site (ERA 2022). The management plan, which fulfils the requirements of the Ranger Authorisation (0108-18) and is approved annually by regulators, outlines the approach ERA takes to:

- protect the wider environment, particularly Magela Creek and Gulungul Creek from the impacts of ERA operations;
- meet all current statutory requirements;
- manage water inventories and discharge mechanisms based on water quality according to the whole of mine approach rather than the source of the water;
- ensure data is collected to inform both operational and closure based decisions; and
- strategically manage process and pond water inventories in accordance with current closure planning and strategies.

Water at the Ranger Mine is categorised into different classes according to its source and composition (Appendix 2-1). Each class of water is managed in a specific way, in accordance with the Ranger Water Management System (Table 2-3).

Table 2-3: Water classes and their management

Water class	Description and treatment
Process water	The most impacted water class on site. Currently stored in the RWD (formerly the TSF) and Pit 3. The process water inventory is derived predominantly from water that has passed through or encountered the uranium extraction circuit, and rainfall from designated process water catchments.
Pond water	Water of a quality that requires active management. Derived from rainfall that falls on the active mine site catchments. The main storage facilities for pond water include Retention Pond 2 (RP2), RP3 and RP6.
Release water	Release water is derived from incident rainfall that falls on catchments within the mine footprint and is of a high enough quality that it is routed through passive treatment systems or staging points for management and release.
Potable water	Potable water is sourced from the Brockman Borefield located in the south-east of the RPA. A second production borefield (Magela Borefield) was established to the north of Jabiru East, primarily as a source of supply for Jabiru East and the Ranger Mine village. Grey water (e.g. from showers and toilets) is treated on site and pumped into septic tanks and then to leach drains.
Treated water	Treated water is water that has passed though one of the three water treatment plants, the Osmoflow Brine Squeezer (OBS) or through the Brine Concentrator (BC). Treated water is divided into the following categories: Water treatment plant permeate: Water that has been treated to remove a significant amount of its dissolved solids to allow it to be released.

Water class	Description and treatment
	BC distillate: Purified water that is produced by the BC. Treated distillate is subject to release criteria. OBS permeate: water derived from further reverse osmosis treatment of water treatment plant brines by the Brine Squeezer. Water quality is equivalent to water treatment plant permeate.
Reject streams	Water treatment plant brines: Water that contains the remaining dissolved solids removed from the pond water. Brines are typically discharged to the process water inventory. However, brines may be discharged to the pond water inventory based on operational requirements. BC brines: Residue water after the distillate has been extracted. OBS brines: residue water that contain the remaining dissolved solids removed from the treatment of pond water brines. Typically, discharged to the process water inventory or alternatively to pond water inventory based on operational requirements. High Density Sludge product water: water arising for the lime treatment process of the HDS plant to remove most salts present in process water. HDS product water may be either recycled to the process water inventory, or subject to further approvals, sent directly to the water treatment plants or discharged into the pond water inventory.

The Ranger Mine footprint is divided into catchment areas shown in Figure 2-5 that generate surface runoff and/or seepage as a result of incident rainfall. Each catchment may comprise of several elements including retention ponds, sumps, collection basins and groundwater interception ponds. The water circuit for the Ranger Mine, combining the five water classes, the different treatments and water management features, is shown in Figure 2-6. A description of the individual water management elements is provided in the following sections.

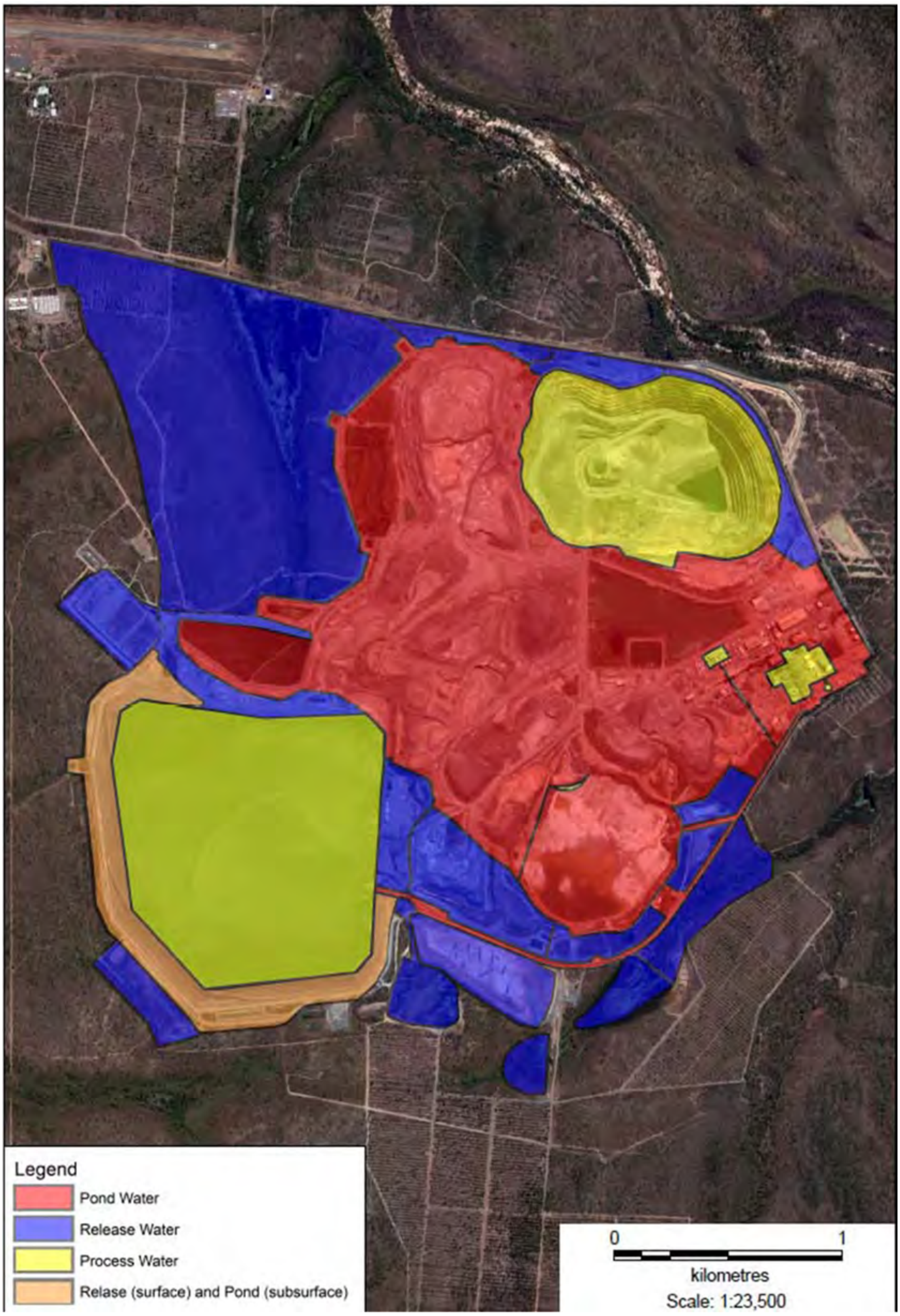

Figure 2-5: General arrangement of water class catchments on the RPA (Deacon, 2017)

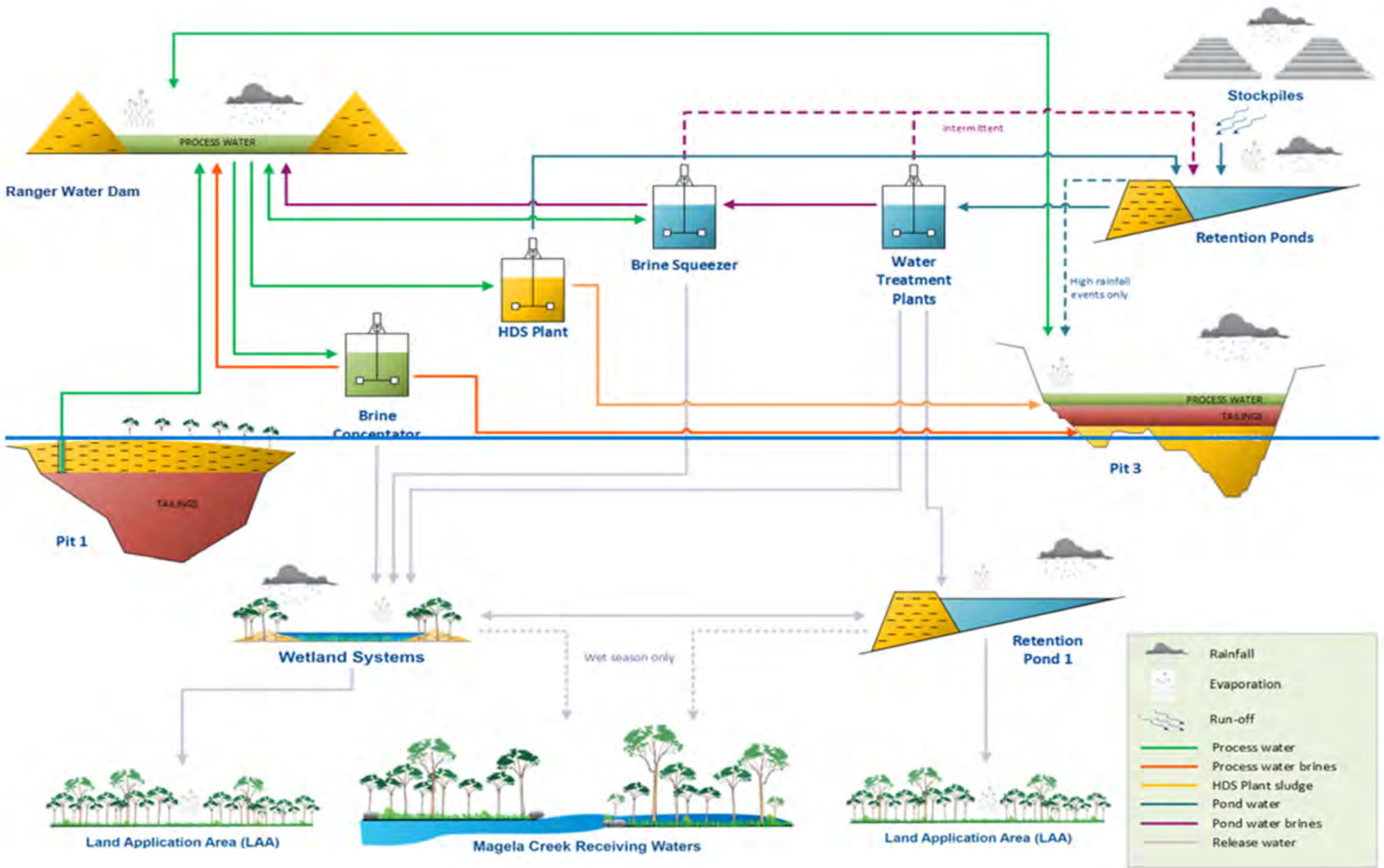

Figure 2-6: Ranger Mine water circuit

2.1.8.1 Retention ponds

Four retention ponds at the Ranger Mine provide sediment control, dilution and storage of pond and managed release waters (Figure 2-1):

- Retention Pond 1 (RP1) (capacity = 390 ML) an earthen embankment that dams Coonjimba Creek, and receives release quality water for discharge into Coonjimba Billabong (both passively and actively) or for active discharge into Magela Creek.
- Retention Pond 2 (RP2) (capacity = 1,150 ML) an earthen wall impoundment in the former Djalkmarra Creek catchment (now subsumed by Pit 3). RP2 is the primary storage of pond water with distribution networks to the water treatment elements.
- Retention Pond 3 (RP3) (capacity = 61 ML) an earthen impoundment within RP2. Water from RP3 is transferred to RP2 via a spillway and pumped for use on site.
- Retention Pond 6 (RP6) (capacity = 976 ML) a turkey-nested, double-lined pond that receives water from RP2 transfers and rainfall.

2.1.8.2 Wetland filters

The RP1 wetland filter comprises a series of earthen embankments forming an impoundment with discrete cells arranged in a series. The wetland filter has an ecosystem dominated by water lilies and native reeds (*Eleocharis* sp.). Upon entering the wetland, water flows through each of the cells under gravity over a path length of approximately 1,000 m. The last cell of the wetland filter can be equipped with a pumping station and a controlled overflow channel that spills to RP1.

The primary role of the wetland filter is to attenuate uranium from the water using biogeochemical processes before the water is discharged via passive flow to RP1, used in land application, operations for dust suppression or as construction water. RP1 wetland filter is currently removed from operational use and its operation will be assessed at a future date.

The Corridor Creek wetland filter is the only wetland filter currently in operation at the Ranger Mine (Figure 2-7 and Figure 2-8). This wetland filter is a combination of natural and constructed wetlands cells with a surface of approximately 17 ha and a total water volume of approximately 38 ML at full capacity. Constructed in 2001 and situated at the head of the Corridor Creek Catchment, the Corridor Creek wetland filter was designed primarily to passively treat (i.e. polish) ammonia from treated pond water permeate and uranium from surface water runoff. The Corridor Creek wetland filter is now used to re-mineralise and remove heat from the brine concentrator distillate (clean water from process water treatment, *Section 9 Closure Implementation*) and polish ammonia from distillate.

Figure 2-7: Corridor Creek wetland filter view one (CCWLF)

Figure 2-8: Corridor Creek wetland filter view two (CCWLF)

2.1.8.3 Land Application Areas

The Land Application Areas (LAAs) have been used at the Ranger Mine since 1985 and have a total area of approximately 350 ha. ERA defines land application as the process by which water (release water, permeate, wetland polished water) is applied to the LAAs through a network of distribution pipes and sprinkler heads, maximising evapotranspiration loss whilst minimising surface pooling and seepage, and preventing surface runoff during operations. Table 2-4 provides a generalised description of each operational LAA. Figure 2-9 shows all LAAs on the RPA, noting that Magela LAA was decommissioned in 2007. Further information on the studies undertaken in the LAAs is provided in *Section 5 KKN Supporting Studies* and a description of the rehabilitation to be carried out is provided in Chapter 9.3.4 of *Section 9 Closure Implementation.*

Table 2-4: LAA description of generalised water management

Land Application area	Description
4A Corridor Creek Land Application Area (CCLAA)	The CCLAA is comprised of a network of pipes and sprinkler heads located to the south of Pit 1. The area is approximately 135 ha. This area receives waters from Georgetown Creek median bund leveline (GCMBL) and Georgetown Creek Brockman Road (GCBR) and is operated during daylight hours only. There are no bunding requirements during active operation of CCLAA.
4C & D Djalkmarra Land Application Area (DLAA)	The DLAA is comprised of a network of distribution pipes and sprinkler heads set out across a tract of sparse native woodland north of the Pit 3 access road. The area is approximately 38 ha. This area receives permeate (via Coonjimba Billabong 2 catchment) only and is operated during daylight hours only. There are no bunding requirements during active operation of DLAA.
4E RP1 Land Application Area (RP1LAA)	The RP1LAA is comprised of a network of distribution pipes and sprinkler heads set out across a tract of disturbed sparse woodland to the west of RP1. The area is approximately 43 ha. This area receives release waters from RP1 and can be operated 24 hours a day and is suitable for flood irrigation. There are no bunding requirements during active operation of RP1LAA.
4F RP1 Extension Land Application Area (RP1Ext LAA)	The RP1Ext LAA is comprised of a network of distribution pipes and sprinkler heads set out across a tract of native woodland to the west of RP1. The area is approximately 8 ha. This area receives release waters from RP1 and is operated during daylight hours only. There are no bunding requirements during active operation of RP1 Ext LAA.
4G Jabiru East Land Application Area (JELAA)	The JELAA is comprised of a network of pipes and sprinkler heads that covers an area on the old Jabiru East town site. The area is approximately 52 ha. This area receives release waters from RP1 and is operated during daylight hours only. Whilst release quality water is used for irrigation on the JELAA there is no requirement for bunding.

Legend

Land Applications Areas

- 4A. Corridor Creek LAA
- 4B. Magelo LAA
- 4C. Djalkmarra LAA
- 4D. Djalkmarra LAA ext.
- 4E. Retention Pond 1 LAA
- 4F. Jabiru East LAA
- 4G. Retention Pond 1 LAA ext.

Ranger Mine

Mine Closure Plan 2022

Land application areas at the Ranger Mine

Figure:	Drawing Number:	Revision:
2 - 9	22545_029	A.1

Drawn By:	Approved By:	Date:	Map Size:
J. Rivera	M. Ryan	29/09/2022	A3

0 630 1,260

Metres

Coordinate System: GDA 1994 MGA Zone 53

Figure 2-9: Land Application Areas

2.1.8.4 Water treatment infrastructure

ERA utilises a range of infrastructure to treat process and pond water and some reject streams at the Ranger Mine including:

- Three water treatment plants to treat excess pond water to a level suitable for release to the environment;
- The Brine Concentrator treats process water for release to Magela Creek, via the Corridor Creek system (Figure 2-10);
- The Brine Squeezer provides an additional stage of treatment for pond water through the water treatment plants; and
- The High Density Sludge (HDS) plant treats process water to a water quality similar to pond water (Figure 2-11).

Further details on the water treatment infrastructure and process can be found in *Section 9 Closure Implementation*.

Figure 2-10: Brine Concentrator

Figure 2-11: High Density Sludge plant at Ranger Mine

2.1.8.5 Treated water release

Wet season release

Discharge of treated pond water can be to RP1, Collection Basin 2 (CB2), Corridor Creek Wetland Filter (CCWLF) system and GCMBL in accordance with regulatory approvals, where applicable. Water can be released from the RPA to the environment from the following locations:

- Collection Basin 7 (CB7);
- Djalkmarra Pump Station 12 (DJKPS12);
- Djalkmarra Release Point (DJKRP), treated pond water (WTP permeate) and distillate only;
- Georgetown Creek 2 (GC2); and
- RP1.

To assist in managing potential impacts to Magela Creek, all these locations are incorporated in the Release Plan Calculator (RPC) to assist with determining water quality at MG009 during releases.

Irrigation, dry season release:

In the dry season, ERA irrigates to the Land Application Areas (LAAs). Land application follows the general principles of maximising evapo-transpiration loss, minimising surface pooling and seepage as well as preventing surface run-off during operations.

2.1.9 Site water model

Water management and closure planning at the Ranger Mine has been supported since 2006 by a dynamic water and solute balance model. The model considers the characteristics, connectivity and operational rules associated with the material elements of the process and pond water circuits at the Ranger Mine, and the planned changes to the nature of those elements through to completion of closure. Elements include process and pond water catchments and storages, water treatment plants, the BC, HDS plant and other planned additional process water treatment facilities. The model also contains approximations for the release water catchments and storages, and the facilities and rules for managed release to the environment.

The understanding of the site's water systems, as captured in the model, was routinely tested during the site’s operating phase by an annual validation and calibration process. This process took advantage of the extensive array of water related measurements around the RPA to reconcile model predictions against actual observations and provide updates to the model to address any identified variations.

The forecasting approach applies multiple sequential periods of historical daily rainfall data to the model as an estimate of the possible variation in future rainfall. Model results are collected for each period, simulated, and statistically analysed to provide confidence traces for each variable of interest.

The historical rainfall data for the forecast has been sourced from a point interrogation ('data drill') at a geographic point corresponding to Jabiru Airport, of a climate database prepared by the Science Delivery Division of the Queensland Government Department of Science, Information, Technology and Innovation (Jeffrey *et al.* 2001). The current rainfall data set in use commences on 1 January 1889 and runs through to June 2022.

Typically, median forecasts are used for planning across closure timeframes, with higher confidence forecasts (generally corresponding to higher rainfall) used for contingency and capacity planning. The model's forecasts for the inventory of free process water in the TSF and Pit 3 over time are presented in Figure 2-12.

Revisions continue to be made to the water model in response to updated measurements of site process water inventory and changes in closure plan tactics.

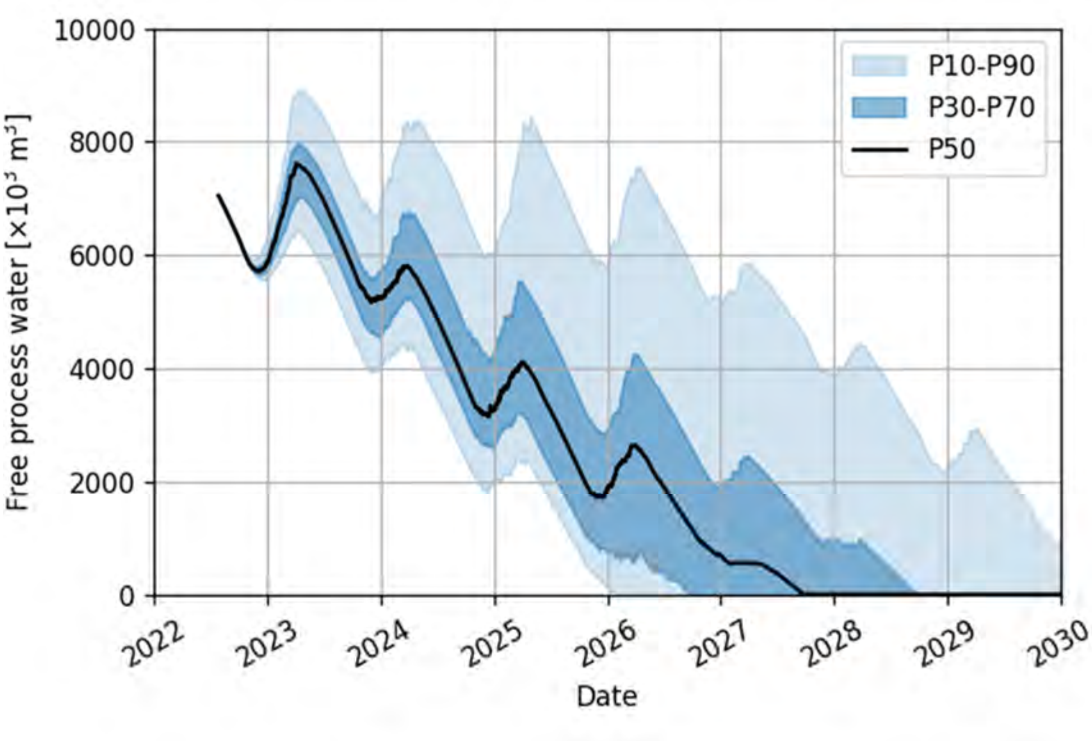

Figure 2-12: Site water model free process water inventory forecast (August 2022)

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APPENDIX 2-1 WATER MANAGEMENT TERMINOLOGY

TERM	DEFINITION
Water Classes	The separation of site water volumes based on their source, properties and management requirements. For the Ranger Mine, the defined water classes include: process water, pond water, release water and potable water.
Process water	Water that has either passed through the uranium extraction circuit; has come into contact with the processing circuit (i.e. milling, leaching, solvent extraction); or has come into contact with a process water storage facility (i.e. TSF, Pit 1 underdrain and Pit 3). Process water quality is characterised by high dissolved solids. Process water must be contained on site unless treated via an approved treatment process.
Pond water	Water derived from rainfall on active mine-site catchments or disturbed surfaces, which subsequently needs to be actively managed or treated before it can be disposed to the environment.
Release water	Water derived from the runoff from undisturbed catchments within the mine footprint and from the various water treatment product streams, which is of a quality suitable for disposal to the environment.
Potable water	Water that is used for drinking and ablution purposes, including safety showers, and parts of the plant where high quality water is required, such as within the demineralisation plant.
Water Management System	All the infrastructure and operations required to manage water on site. This includes capturing, storing, transferring, treating and disposing water.
Storage Facility	A designated area or structure where water of a particular class will be contained prior to future transfer, treatment or disposal.
Retention Pond	A large artificial pond that collects runoff and stores pond water prior to treatment (RP2, RP6) or stores release water prior to discharge to the environment (RP1).
Collection basin	A small artificial basin that captures runoff from a localised area, for immediate transfer onward to a retention pond.
Treatment Facility/Process	Infrastructure designed to treat water of a particular class through to a higher quality product.
Brine Concentrator (BC)	A treatment plant that uses mechanical vapour recompression technology to evaporate process water, producing a clean product stream (distillate) suitable for disposal to the environment, and a waste stream called Brine Concentrator brine.
Water Treatment Plant (WTP)	One of three ultrafiltration/reverse osmosis treatment plants that treats pond water to produce a clean product stream (permeate) suitable for disposal to the environment and a waste stream (WTP brine).

TERM	DEFINITION
Brine Squeezer (BS)	A reverse osmosis plant that further processes WTP brine to recover additional permeate. The waste product (Brine Squeezer brine) is considered process water.
High Density Sludge (HDS) plant	A plant that treats process water with lime to produces a moderately clean product stream (HDS product) that can be considered pond water, and a waste stream (HDS sludge).
Wetland filter	An artificial wetland that can receive mildly contaminated water and treat it so that it can be considered release water.
Land Application Area	A designated area where irrigation of release water may occur during the dry season.
Treatment products	
BC distillate	The clean product resulting from treatment of process water through the BC. Considered release water.
WTP permeate	The clean permeate from treatment of pond water through one of the three WTPs. Considered release water.
Brine Squeezer permeate	The clean permeate from treatment of WTP brine or process water through the Brine Squeezer. Considered release water.
HDS product	The product water stream arising from treatment of process water through the HDS plant. Considered pond water.
Treatment wastes	
WTP brine	The brackish liquid waste arising from treatment of pond water through one of the three WTPs. WTP brine is either recycled to pond water, further processed by the Brine Squeezer or directed to process water.
BC brine	The concentrated salt liquid waste arising from treatment of process water through the BC. BC brine is either recycled to process water or injected into the underfill of Pit 3.
Brine Squeezer brine	The salty liquid waste arising from treatment of WTP brine or process water through the Brine Squeezer. Directed to process water.
HDS sludge	The alkaline waste slurry arising from treatment of process water through the HDS plan. This is directed to Pit 3 for final disposal.

3 Closure obligations and commitments

Issued Date: October 2022

Revision #: 1.22.0

4 Stakeholder engagement

Issued Date: October 2022

Revision #: 1.22.0

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Cover photograph: Nursery seedlings for revegetation being cared for by Kakadu Native Plant Supplies Staff

GLOSSARY

Below are key terms that are used in this section.

<table>
<tr><th>Key term</th><th>Definition</th></tr>
<tr><td>Environmental Requirements</td><td>The Ranger Environmental Requirements are attached to the S.41 Authority and set out Primary and Secondary Environmental Objectives establishing the principles by which the Ranger operation is to be conducted, closed and rehabilitated and the standards that are to be achieved.</td></tr>
<tr><td>Mine Closure Plan (MCP)</td><td>A dynamic plan presenting all past, present and future rehabilitation activities of the Ranger Project Area in order to demonstrate that closure activities will achieve the relevant Environmental Requirements. Submitted annually for approval, the plan provides updates of the preceding year.</td></tr>
<tr><td>Minesite Technical Committee (MTC)</td><td>The Minesite Technical Committee, convened in accordance with Attachment A of the Working Arrangements for the Regulation of Uranium Mining in the Northern Territory dated 30 May 2005, is tasked with:
Reviewing proposed and existing approvals and decisions under NT legislation
Reviewing technical information in relation to Ranger Mine, including monitoring data and environmental performance
Collaboratively developing standards for the protection of the environment
Developing strategies to address emerging issues
The MTC consists of the representatives of the Department of Industry, Tourism and Trade, the Supervising Scientist, ERA and the Northern Land Council. Representatives of the Commonwealth Department of Industry, Science, and Resources may also attend MTC meetings.</td></tr>
<tr><td>Mirarr</td><td>Mirarr is a patrilineal descent group. Descent groups are often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre).
The Mirarr are the Traditional Owners of the land encompassing the RPA.</td></tr>
</table>

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ACF	Australian Conservation Foundation
AFANT	Amateur Fisherman's Association (NT)
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
ASIC	Australian Securities and Investment Commission
ASNO	Australian Safeguards and Non-Proliferation Office
DISR	Commonwealth Department of Industry, Science and Resources
DITT	Department of Industry Tourism and Trade
DPMC	Department of Prime Minister and Cabinet
EDONT	Environmental Defenders Office
ER(s)	Environmental Requirements
ERA	Energy Resources of Australia Ltd
GAC	Gundjeihmi Aboriginal Corporation
siaIAEA	International Atomic Energy Agency
JKL	Jabiru Kalbolkmakmen Limited
KKN	Key Knowledge Needs
MCP	Mine Closure Plan
MERRG	Monitoring Evaluation and Research Review Group
MOU	Memorandum of Understanding
MTC	Minesite Technical Committee
NGO	Non-government Organisations
NLC	Northern Land Council
NP	National Park
NT	Northern Territory
RCCF	Ranger Closure Consultative Forum
RPA	Ranger Project Area
RWD	Ranger Water Dam Formerly Tailings Storage Facility (TSF) or Tailings Dam
SIA	Social Impact Assessment
SSB	Supervising Scientist Branch
TSF	Former Tailings Storage Facility now Ranger Water Dam (RWD)
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WA	Western Australia

Abbreviation/ Acronym	Description
WARC	West Arnhem Regional Council
WASWG	Water and Sediment Working Group

4 OVERVIEW OF STAKEHOLDER ENGAGEMENT

The ERA approach to stakeholder engagement is centered on maintaining our relationships based on mutual respect, active partnership, transparency and long-term commitment. ERA will continue to connect with and respect Mirarr culture and the aspirations of local communities as we create a positive legacy and achieve world class, sustainable rehabilitation of the Ranger mine.

Our approach to stakeholder engagement has fostered collaboration and cooperation with a diverse range of stakeholders on the following key aspects of closure:

- the overall planning process and schedule;
- engineering and design criteria for technical aspects of closure such as water treatment, tailings transfer, backfilling of mine pits and the final landform design;
- post-mining land use, closure objectives and closure completion criteria;
- legal requirements and obligations associated with the various agreements for the mine and Jabiru township; and
- land tenure and governance.

Table 4.1 identifies the main external stakeholders engaged on the Ranger Mine closure and rehabilitation. Figure 4-1 demonstrates the linkages between stakeholders and ERA. The discussions with stakeholders are coordinated through the forums listed in Table 4-2. Appendix 4.1 provides a register of stakeholder engagements over the last 10 years.

All ERA employees and contractors are respectful of stakeholders and are engaged in delivering a positive legacy for the rehabilitation of the Ranger Mine.

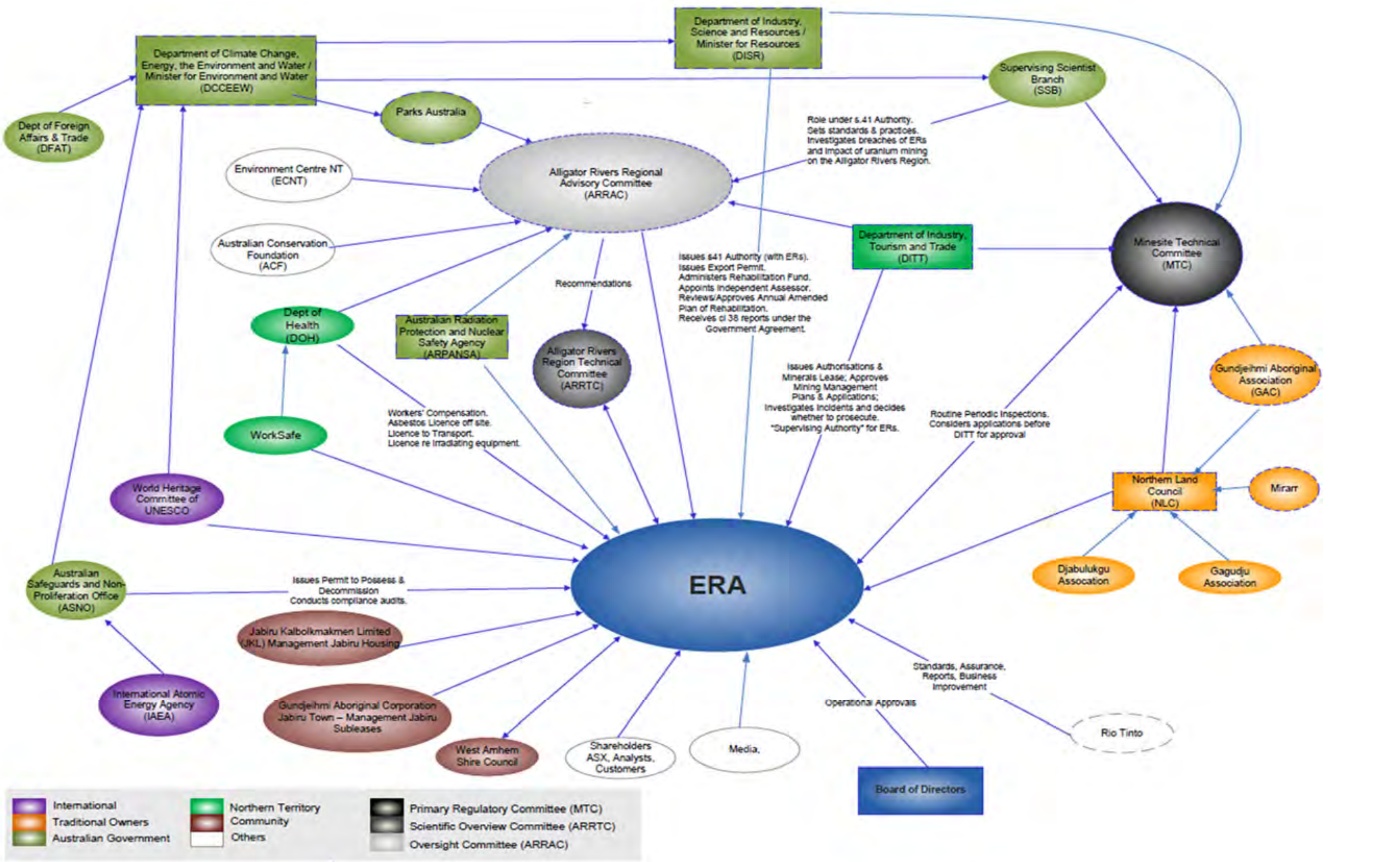
Consultation with stakeholders is undertaken in accordance with an engagement framework that includes:

- ERA Communities Policy;
- ERA Communities and Social Performance Plan;
- ERA Communication Standard;
- ERA Community and Stakeholder Engagement Plan (ERA 2018);
- ERA Community Consultation, Engagement and Communication work instruction; and
- a number of existing engagement forums and tools.

Table 4-1 Ranger Mine closure stakeholders

Stakeholder group	Description
Traditional Owners and local Aboriginal groups	Gundjeihmi Aboriginal Corporation (GAC) Gundjeihmi Aboriginal Corporation Jabiru Town (GAC JT) Northern Land Council (NLC) Djabulukgu Association Gagudju Association Warnbi Aboriginal Corporation
Federal Government	Aboriginal and Torres Strait Islander Commission Australian Safeguards and Non-Proliferation Office (ASNO) Australian Securities and Investment Commission (ASIC) Department of Agriculture, Fisheries and Forestry Department of Foreign Affairs Department of Prime Minister and Cabinet (DPMC) Department of Industry, Science and Resources (DISR) Minister for Industry and Science Minister for Resources Parks Australia
Northern Territory Government	Department of Education Department of Health Department of Industry, Tourism and Trade (DITT) Department of Infrastructure, Planning and Logistics (DIPL) Department of the Chief Minister and Cabinet Minister for Mining and Industry Jabiru Kabolkmakmen Limited Northern Territory Treasury
Regional Council	West Arnhem Regional Council (WARC)
Primary regulatory committee	Minesite Technical Committee (MTC)
Regional scientific overview committee	Alligator Rivers Region Technical Committee (ARRTC)
Regional overview committee	Alligator Rivers Region Advisory Committee (ARRAC)
International agencies	International Atomic Energy Agency (IAEA) European Parliament standing committees World Heritage Committee of UNESCO

Stakeholder group	Description
Other NGOs (non-government organisations)	Amateur Fishermen’s Association NT (AFANT) Australian Conservation Foundation (ACF) Environmental Defenders Office NT (EDONT) Minerals Council of Australia - NT Northern Territory Environment Centre World Wildlife Fund
Business community	Rio Tinto Uranium Rio Tinto Limited Shareholders Suppliers
Local community	Jabiru businesses/organisations Jabiru Kalbolkmakmen Limited (JKL) Gundjeihmi Aboriginal Corporation Jabiru Town Local social and recreational groups Residents Tourists



Department of Industry, Science and Resources / Minister for Resources (DISR)
Department of Climate Change, Energy, the Environment and Water / Minister for Environment and Water (DCCEEW)
Supervising Scientist Branch (SSB)
Dept of Foreign Affairs & Trade (DFAT)
Parks Australia
Environment Centre NT (ECNT)
Alligator Rivers Regional Advisory Committee (ARRAC)
Role under s.41 Authority. Sets standards & practices. Investigates breaches of ERs and impact of uranium mining on the Alligator Rivers Region.
Australian Conservation Foundation (ACF)
Department of Industry, Tourism and Trade (DITT)
Minesite Technical Committee (MTC)
Issues s41 Authority (with ERs). Issues Export Permit. Administers Rehabilitation Fund. Appoints Independent Assessor. Reviews/Approves Annual Amended Plan of Rehabilitation. Receives cl 38 reports under the Government Agreement.
Recommendations
Dept of Health (DOH)
Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)
Alligator Rivers Region Technical Committee (ARRTC)
Issues Authorisations & Minerals Lease; Approves Mining Management Plans & Applications; Investigates incidents and decides whether to prosecute. "Supervising Authority" for ERs.
Routine Periodic Inspections. Considers applications before DITT for approval
Gundjeihmi Aboriginal Association (GAC)
Workers' Compensation. Asbestos Licence off site. Licence to Transport. Licence re irradiating equipment.
WorkSafe
World Heritage Committee of UNESCO
Northern Land Council (NLC)
Mirarr
ERA
Australian Safeguards and Non-Proliferation Office (ASNO)
Issues Permit to Possess & Decommission Conducts compliance audits.
Djabulukgu Association
Gagudju Association
Jabiru Kalbolkmakmen Limited (JKL) Management Jabiru Housing
International Atomic Energy Agency (IAEA)
Gundjeihmi Aboriginal Corporation Jabiru Town – Management Jabiru Subleases
Standards, Assurance, Reports, Business Improvement
Operational Approvals
Rio Tinto
West Arnhem Shire Council
Shareholders ASX, Analysts, Customers
Media,
Board of Directors
International
Traditional Owners
Australian Government
Northern Territory
Community
Others
Primary Regulatory Committee (MTC)
Scientific Overview Committee (ARRTC)
Oversight Committee (ARRAC)

Figure 4-1 Ranger Mine Stakeholder Matrix

Table 4-2 Stakeholder Engagement Forums

Engagement forum	Frequency	Comment
Minesite Technical Committee (MTC)	Bi-annually (additional meetings held as required)	The MTC is the formal forum for key advisory and stakeholder groups to discuss and resolve technical environmental management matters relating to the closure of the Ranger Mine, regulatory functions of the NT Government, functions of the Supervisory Scientist, and the views of the Mirarr and other affected Aboriginal people. It includes representatives of the Northern Territory Department of Industry, Tourism and Trade (DITT) (Chair), Commonwealth Department of the Climate Change, Energy, the Environment and Water (DCCEEW), Supervising Scientific Branch (SSB), Energy Resources of Australia Ltd (ERA), Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC) (the Commonwealth Department of Industry, Science & Resources (DISR) are invited as an observer).
Ranger Closure Consultative Forum (RCCF)	Monthly	The RCCF is a formal forum for ERA to discuss progress and matters relating to the closure of the Ranger Mine with the key stakeholder group representatives from the DISR, SSB, DITT, and the NLC/GAC. The purpose of the forum is to provide ongoing updates of closure activities, confidence in the closure strategy for achieving environmental requirements, information on upcoming approvals, and to receive feedback from stakeholders on studies, applications and the close-out progress of Key Knowledge Needs (KKN).
Alligator Rivers Region Technical Committee (ARRTC)	Bi-annually	The ARRTC was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* and reviews the appropriateness and quality of scientific research conducted by Northern Territory and Commonwealth Government agencies, ERA and others relating to protection of the environment from the potential impacts of uranium mining in the Alligator Rivers Region. Members include an independent Chairperson, the Supervising Scientist, independent scientific members, a member representing the NLC and a member representing environmental non-government organisations. http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrtc
Alligator Rivers Region Advisory Committee (ARRAC)	Bi-annually	The ARRAC was established under the Commonwealth *Environment Protection (Alligator Rivers Region) Act 1978* and facilitates communication between Government, industry and community stakeholders on environmental issues associated with uranium mining in the Alligator Rivers Region. Members include an independent Chairperson, the Supervising Scientist, representatives from several Northern Territory Government departments, Office of the Administrator of the Northern Territory, several Commonwealth Government departments, non-government organisations (NGOs), ERA and other uranium mining/exploration companies that operate in the region.

Engagement forum	Frequency	Comment
		http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrac.
Ecosystem Restoration Forum	As required, several per year	Communication and consultation with stakeholders focusing on ecosystem restoration closure criteria and KKNs.
Investor briefings	Bi-annually	Briefings provided by the ERA Chief Executive regarding ERA operations to all company shareholders.
Relationship Committee	Quarterly	The Relationship Committee was established under the Ranger Mining Agreement between ERA and the NLC in 2013 to review processes and ensure effective information sharing between ERA and the Mirarr Traditional Owners and their representatives.
Ministerial briefings	Regularly as required	Briefings are provided to both Federal and Northern Territory Ministers and senior advisors on operations of the Ranger Mine, including aspects of closure.
Kakadu Board of Management	Quarterly, ERA update provided bi-annually	Kakadu National Park (NP) is a park jointly managed by Parks Australia and the Traditional Owners of Kakadu. A board of management has been established as part of the governance structure for the NP and consists of Commonwealth Government representatives, Park Management and Traditional Owners from each region in the NP. ERA provides a regular operations update, including mine closure status, and consults with the broader Indigenous population through this forum.
State of the Nation	Quarterly	Presentations and question and answer sessions provided to all ERA personnel and contractors on ERA operations by either the Chief Executive or General Manager Operations including aspects of closure, Jabiru and stakeholder engagement.
Closure Criteria Working Group	No longer required	The Closure Criteria Working Group was established by the MTC for the purpose of developing the closure criteria for the rehabilitation of the Ranger Mine. The Closure Criteria Working Group also had sub-groups responsible for the development of the technical criteria for each of the following elements: landform, radiation, water and sediment, flora and fauna, soils and cultural. The MTC decided that closure criteria had progressed enough that this working group was no longer required. Rather, the specific technical groups would continue to develop criteria and report directly into the MTC.
Water and Sediment Working Group (WASWG)	No longer required	Communication and consultation with stakeholders focusing on surface water and sediment closure criteria and KKNs. These discussions now occur in each of the above-mentioned relevant forums.

Engagement forum	Frequency	Comment
Monitoring Evaluation and Research Review Group (MERRG)	No longer required	MERRG was formed in response to the submission of the application to progress Pit 1 final landform, in order to further communicate and consult with stakeholders regarding Pit 1 revegetation monitoring activities. Pit 1 has now undergone initial rehabilitation and monitoring success is reported in the above-mentioned relevant forums.

4.1 Engagement with Traditional Owners

ERA are committed to engaging with the Traditional Owners and local Aboriginal groups through our established engagement processes such as:

- In January 2013 a suite of agreements covering the Ranger Project Area were signed by the Mirarr Traditional Owners, ERA, the Northern Land Council, and the Commonwealth Government. These agreements cover the mining operations at the time and a range of pre-2013 issues. They also provide a structured approach for ongoing engagement and collaboration between the Gundjeihmi Aboriginal Corporation (GAC) and ERA.
- The 2013 agreements resulted in the formation of a relationship committee with ERA to promote information sharing and collaboration and an agreed approach to increasing opportunities for local Aboriginal participation in business development, training and employment.
- ERA engages GAC and Mirarr Traditional Owners through other channels (e.g. Cultural Reconnection Steering Committee) to discuss and negotiate on matters including water management, cultural heritage and environmental protection, employment and training, housing and town planning, involvement in decision making processes and royalties.
- The GAC and ERA are represented on the Kakadu West Arnhem Social Trust and each contribute funds on an annual basis.
- The Mirarr Traditional Owners are also represented via the GAC on the Closure Criteria Committee Working Group and are formal members of the Ranger Minesite Technical Committee (MTC).

4.2 Managing socio-economic impacts

The Ranger Mine has been a significant contributor to the socio-economic life of Jabiru, the West Arnhem region and the Northern Territory more broadly for more than 40 years. This has been through economic inputs and social aspects such as its residential workforce and community involvement.

The potential socio-economic impacts of the closure of the Ranger Mine have been the subject of considerable engagement with key stakeholders.

The contributions by ERA were documented in the Jabiru Social Impact Assessment (SIA) in July 2017. The ongoing participation in the Jabiru Taskforce by ERA, the outcomes of the Ranger closure feasibility study, and the funding commitment from the Commonwealth and Northern Territory Governments to support implementation of the Jabiru Masterplan have contributed to a clearer understanding of ERA's intended contribution to the community through the rehabilitation period.

A Memorandum of Understanding (MOU) on the future of Jabiru Township between the GAC, the Commonwealth and Northern Territory Governments, and ERA was signed in August

2019. The MOU commits the signatory parties to support the vision for Jabiru and the contribution each will make, including ERA. ERA will play an important role in working with stakeholders to agree a clear plan for Jabiru remediation activities and transition.

ERA acknowledge that considerable work remains to be done in planning for life beyond Ranger and agreeing how this is undertaken is the particular focus of the next phase of stakeholder engagement.

REFERENCES

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Energy Resources of Australia (ERA) 2018. *Community and Stakeholder Engagement Plan*. Energy Resources of Australia Ltd (ERA), Darwin.

APPENDIX 4.1: RANGER MINE CLOSURE STAKEHOLDER CONSULTATION REGISTER

30 JUNE 2022 – 1 JULY 2012

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
30/06/22	Cultural Reconnection Steering Committee visit	ERA, NLC, GAC, Umwelt	Visit to Ranger Project Area by Gundjeihmi Aboriginal Corporation traditional owners, as part of the Ranger mine cultural reconnection program. The visit included stops at: • Pit 1 • The trial landform • The stone tool scatter • Coonjimba Billabong	A very positive response was received to the Pit 1 planting. Bininj mentioned that the andikkala herbs should only be planted in sand sheet or other sandy areas as they require very soft ground. Concerns were raised about the extent of bushland that would need to be removed, surrounding the trial landform, to reduce the incline of the final landform slopes. Discussions were had regarding a stone tool scatter identified in the proximity of the trial landform. It was pointed out by Bininj that the materials could not be covered over or removed. At Coonjimba Billabong there was discussion around the plan to take a sample of any edible plants that could be subjected to analysis. The two most accessible plant foods were said to be various parts of waterlilies and the corms of *Eleocharis dulcis*, known as *ankurladj* in Kundjeyhmi (a perennial aquatic grass-like sedge to 1m high with small tubers in the root system). A sample of edible corms of some water lilies were taken for analysis.	Non-minuted
28/06/22	ERF meeting #23	ERA, SSB	Progress on development and agreement of ecosystem sustainability and similarity criteria Progress updates on relevant projects Ecological risk assessment / KKN gap analysis State-Transition modelling	Libby M recognised and voiced the future need for the universal formatting of data in order for State and transition modelling etc. with the various datasets and methods of data collection to date. Needs to be a standard database to pull appropriate data from for particular assessments	SSB to send rearticulation of assessment methods to stakeholders by end of the week. ERA to then review and have comments by next ERF meeting (12 July). ERF group to review Anna Richards report in relation to physical soil structure criteria for justification and relevance for inclusion ERA to send out proposed next steps for state and transition model by 26 July ERF meeting to stakeholders
17/06/22	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Brine injection • Catchment management trial • Pit 3 capping ERA and SSB discussed the Pit 3 application adequacy assessment.	None minuted	None minuted
16/6/22	Meeting	SSB, ERA	Update on scope of the TSF and Coonjimba groundwater studies	Scope to include review of previously defined sources terms with updated data including waste rock vadose zone leachate, and TSF plume	Scope elements requested are confirmed as included in the study scope

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
14/06/22	ERF meeting #22	ERA, SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Progress updates on relevant projects Ecological risk assessment / KKN gap analysis / trajectory workshop	NLC asked whether LAA survey data could be integrated into existing App to be able to compare to reference plots NLC suggested conducting a live review of risk assessment questions with stakeholders SSB commented that there is a general view that fauna has not been addressed in current S&T model and needs to be populated NLC suggested that SSB data from other mine sites be sent and used by ERA in populating S&T model	Send supporting documentation for ecosystem closure criteria and future monitoring plans prior to meeting (end of the week) ERA and SSB to coordinate joint surveys for impact and recovery in June/July 2022 SSB will try and report back to ERA by COB 14 June 2022 on ERA consultant S&T model report prior to ERA workshop on 15 June 2022 SSB to follow up understorey workshop report review and comments from ERA SSB to consider additional value/information “naturalness” brings to criteria (e.g. is it duplicated in other criteria) and report back to ERF Discuss nutrient cycling sampling at TLF, Pit 1 and Jabiluka as well as full overstorey survey of TLF SSB and ERA to consider NLC response to the ecological risk assessment questions and report to ERF to decide next steps ERF to consider stakeholder (including ARRTC) involvement in, and process for, the “holistic” S&T model referred to by ERA
10/06/22	3D Printed Model of the Final Landform catch up	ERA, NLC, CDU	Discussed development of an interactive platform to compliment the 3D printed model, for use in discussions with Traditional Owners.	None minuted	ERA to provide movie of rehabilitation process in language (as found on the ERA external website).
08/06/22	Routine Periodic Inspection	ERA, SSB, DITT, NLC	Pit 1 Revegetation and post wet season inspection	None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
23-25/05/22	ARRTC 50	ARRTC members & observers	ERA gave presentations on: • An overview of the reforecast for Ranger mine rehabilitation • Key closure updates on a range of topics • Metals and Sediments • Targeted VAF and Site survey • State and transition model • Ranger Fauna Nest boxes • TSF and Coonjimba catchment and contaminated material management study • Ranger final landform 7.0 design • Ranger PFAS investigation update • Revegetation monitoring update SSB gave presentations on: • Updates on a range of topics • Comments on development of KKNs and new projects • Joint project list • PFAS update • Radiation update • Landform update • Ecosystem restoration work • Hazard and Risk Assessment of emerging contaminants • Eutrophication update • Long term monitoring strategy and transitioning between monitoring methods • Transitioning between monitoring methods Updates from stakeholders, including the Northern Land Council and Environmental NGOs.	For the SSB landform update Dr Wilkinson commented that in future, wet rainfall scenarios will be the most likely scenario. Dr Chris Humphrey confirmed a focus of proposed simulations would also be increasing the frequency and/or intensity of large rainfall events in model simulations. Dr Stauber noted that uncertainty was being qualitatively analysed in the VAF and queried if something like a Bayesian model could be applied where uncertainty is built in, providing a more quantitative analysis. For the SSB report on Hazard and Risk Assessment of emerging contaminants Dr Rumph highlighted there was a spuriously high potassium result for Georgetown Billabong and to check if this may be due to a low sample size or an outlier Prof Zichy-Woinarski noted that a comparison and assessment of temperature and other microclimate effects between nest boxes and natural hollows should be made. Mr Tayler noted that linking the project to SSB natural analogue sites, installing nesting boxes in these locations, would have advantages in utilising the environmental data associated them Dr Wilkinson commented that he is pleased to see the detail being incorporated into drainage lines as part of FLF 7.0. Prof Dixon recommended that Dr Humphrey review the new international ecological restoration standards in drafting of SSB's long-term monitoring strategy. Prof Dixon commented that grasses are a concern for revegetation and one issue to redress this dominance is to promote a more diverse understorey. Prof Zichy-Woinarski commented that there is a need to understand TLF trajectories and timing In future, there is opportunity to look at the role of the ARRTC committee, and at what point throughout the mine closure process their work is most valuable. The committee believes there needs to be increased integration and visibility of processes. The committee would like to see more work on risk assessments of emerging contaminants	NLC to give update on Cataloguing the Cultural World Heritage Values on the Ranger Project Area at ARRTC 51 ERA to provide update on 2022 Mine Closure Plan at ARRTC 51 SSB to send out Kate's Nabarlek papers/data on ecosystem restoration risk assessment prior to Nabarlek field trip ARRTC (Libby) to send decision tree to SSB and ERA between meetings Seek ARRTC involvement in ecosystem restoration state-transition model workshop planning for 2022 ARRTC to be involved in ecosystem restoration KKN gap analysis SSB to share annotated outline of its long-term monitoring strategy with ARRTC for review and input ERA to provide presentation on the strategy behind and results from ERA's landform monitoring program (amended for clarity at ARRTC50, follow on from ARRTC 48.4). This presentation will include data on landform undulation.
20/05/22	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Shellsol disposal • VAF site surveys • Pit 3 current activities ERA and SSB discussed the Pit 3 application	None minuted	None minuted
17/05/22	STARS Foundation visit to Ranger Mine	Jabiru STARS Foundation students & teachers, ERA	Took students around Ranger Mine to see key features of the mine, whilst discussing future careers in STEM.	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
11/05/22	Routine Periodic Inspection	ERA, SSB, DITT, NLC, Coffey	Annual Ranger Water Dam Inspection	Stakeholders inspected the RWD a selection of the points discussed and noted have been included. • ERA noted that there were nine juvenile trees or shrubs on the internal walls. These have the potential to develop into large, deep rooted trees and thus need to be removed. ERA have engaged a contractor to remove the trees. ERA expects this work to be completed by mid-July. Coffey noted that anything that could become deep-rooted needs to be removed. • SSB noted that residual material had been stockpiled in the north western corner of the dam. ERA advised that all material had been removed to Pit 3. • SSB noted that erosion on the inner northern wall was more pronounced than during the inspection of the TSF to verify the removal of tailings which occurred a few weeks prior. • Coffey had conducted a visual inspection of the erosion on the North Wall on 11 May 2022. Coffey advised that there were sections of the North Wall where there is looser 'extra' material which is eroding. This material is Zone 1A clay core material, however, it's overbuild and not fully compacted clay core. • Coffey noted that visual inspections in the boat were useful. Visual inspections should be added to the TARP.	There were no new agreed actions. Stakeholders noted that actions relating to vegetation removal and updating the TARP to include visual inspections would be included in the Coffey annual inspection report and including them in the RPI action list would be duplicative.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
06/05/22	Ranger MTC	ERA, DITT, SSB, NLC, GAC, DISER	DITT provided an overview of compliance and regulatory matters. • Reported environmental incidents • Plans to review check monitoring program for Ranger • Location of the EMU (raised in the context of environmental reforms) • Updates on the Authorisation review ERA provided updates on: • Gamba grass reporting • Turbidity exceedances in Gulungul Creek • Dry season civil work son the Southern Boundary Road • Schedule of major applications • Catchment conversion trials Discussion was had regarding titling and submission of applications.	SSB, GAC, NLC and ERA commented on the value of EMU being important to stakeholder confidence in ERA operations and validation of models. SSB advised that turbidity exceedances in Gulungul Creek, attributed to instrument failure or erosion causing localised turbidity in the vicinity of the probe, were not of environmental significance.	DITT to clarify with ERA relationship and titles of water monitoring documents. DITT to confirm acceptance of Ranger Wet Season Report 2021. ERA to present rehabilitation progress report at next MTC. ERA to finalise investigation reports for acid spill incident of 11 November 2021. ERA to finalise investigation reports for residual process water incident of 7 April 2022. DITT to work with SSB to review EMU check monitoring proposal for consideration at next MTC. DITT to finalise internal review of Authorisation and circulate draft Authorisation for comment. ERA to report on Gamba detections and eradication success at MTC analogous to browsing ant and Spigelia. ERA to conduct remediation works on Southern Boundary Road. ERA to submit to DITT additional detail for Pit 3 injection bores. ERA to submit an application for the catchment conversion trial including the caveat that if required the area will be reworked if needed to conform to the final landform approval, environmental risk assessment, anticipate outcomes and monitoring to demonstrate performance. DITT to formally acknowledge submission of final applications, circulate to members for comment, collate comment and formally request further information from ERA, ERA to submit response to request, DITT to circulate revised application to members for comment prior to making approval decision.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
28/04/22	ARRAC 57	ARRAC members & observers	ERA presented on health and safety, process safety, environmental performance, water management, progressive rehabilitation, environmental studies and approvals updates. • Spigelia monitoring and tracking • Browsing ant surveillance program • 2021/22 wet season rainfall • Pond and process water treatment and releases • Magela and Gulungul water quality • Tailings transfer • Pit 3 capping and backfill. • Revegetation of Walem Madjawulu-1 (Pit 1) • Ranger Closure Project reforecast The SSB provided an update on research, monitoring, assessment, audit and verification program activities between 1 July 2021 and 28 February 2022 DITT provided an update on regulatory matters. Justin O'Brien provided a verbal update on behalf of the Gundjeihmi Aboriginal Corporation (GAC) Chris Brady provided a verbal update on behalf of the Northern Land Council Paul Purdon provided an update on behalf of the NT Environment Protection Authority Bradley Feldtman provided a verbal update on behalf of the NT Department of Health Cameron Lawrence noted that ARPANSA provided a written report to the committee and took the report to be read Matthew Crawshaw provided an update on behalf of the Department of Industry, Innovation and Science	In response to queries from Dr Charles Webb, Katherine Smith noted that the SSB research program is on track to have information available and projects closed in time to inform key rehabilitation-related activities. Chris Brady noted that the 99% species protection limit for PFAS had been exceeded, yet SSB's monitoring did not detect changes in biological communities. Keith Tayler noted that SSB's biological monitoring sites are upstream of Gulungul Confluence. Kirsty Howey noted that it was positive to see ERA acknowledging the true cost of rehabilitation and beginning pit backfill operations in line with expectations of the Traditional Owners. Keith Tayler noted that ERA are forecasting for 25 years of post closure monitoring and maintenance but that lease relinquishment will be based on achieving closure criteria not on a specific timeframe. Justin O'Brien noted that work should commence on tasks which will be triggered by the passing of the *Atomic Energy Act (Cwlth*) amendment bill, such as preparing a new section 44 agreement. Matthew Crawshaw agreed that some work could begin prior to the bill passing. Cameron Lawrence noted that the process of finalising changes to the dose conversion factors is nearing completion. ARPANSA intend to publish changes to Radiation Protection Series 9 and 9.1 in the coming months. No impact on Ranger is expected as dose levels at Ranger are low.	ERA will present groundwater monitoring results to the Committee Members to advise if presentation slide packs can be uploaded to GovTeams
22/04/22	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Drilling program • BC distillate EC trigger value increase • Pit 1 & CRS water quality monitoring update • Visual erosion monitoring – Pit 1 & Stage 13 • Catchment conversion project update • Contaminated sites – PFAS interim results	None minuted	ERA to add split to recycle versus split to injection to the 'Brine injection' metric. ERA to update 'Ranger Mine Closure Applications Schedule' metric to include the updated FLF and TSF application dates. ERA to arrange an offline discussion around the reporting mechanisms for Pit 1 monitoring commitments made in the Pit 1 Ecosystem Re-establishment Plan. ERA to confirm that organic nitrogen has been included in the analysis suite for CRS-UG.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
13/04/22	Routine Periodic Inspection	ERA, SSB, DITT, NLC	Weeds, fire, and feral animal management	None minuted	ERA to provide details of the environmental risks which were identified in the brine concentrator HAZOP assessment. ERA to provide an incident report for the gamba grass detection. ERA to provide an update on embedding light vehicle washdown procedures in the vehicle site access procedure. ERA to provide the investigation report for the process water spill during the decommissioning of the enhanced evaporation system.
April 2022	Submission of the Kakadu Board Report for inclusion in the Kakadu Board of Management Meeting	Kakadu Board of Management members	Provide information to the board on a range of topics including: • Previous quarter operations • Rehabilitation at Ranger • Closure works • Funding • Corporate updates • Community updates	N/A	N/A
10/03/22	Routine Periodic Inspection	ERA, SSB, DITT, NLC	Water treatment and release management and follow up on Gulungul Creek turbidity exceedances.	None minuted	ERA to undertake an investigation to identify the source of turbidity guideline value exceedances at GCLB during this wet season. Investigation could include monitoring turbidity at GCT0 to identify potential mine related source.
08/03/22	GAC Board Meeting	GAC Board, ERA, Stephanie Howden (Umwelt)	Discussed bush tucker project, Pit 1 rehabilitation progress, seed collection permit, Djarr Djarr rehabilitation, Cultural Heritage Audit mitigation works and Madjedbebe fencing project.	N/A	N/A
24/02/22	Pit 3 application stakeholder update	ERA, SSB, NLC	Update on VAF, ALARA, WQMF associated with Pit 3 closure. TSF remediation in the Pit 3 application.	Non-minuted	Non-minuted
18/02/22	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Closure execution • Pit 1 PMP/SMP monitoring • Drilling program • OBS water treatment • BC off spec distillate sampling (results to date) • Drone Deploy • Catchment conversion trial • PFAS	None minuted	ERA to Develop “Process water to be Treated” metric. ERA to include presentation on Pit 1 CRS performance wet season to date at March RCCF
11/02/22	Pit 3 application stakeholder update	ERA, SSB, NLC	Discuss issues and actions from stakeholder engagement on the water pathways risk assessment.	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
10/02/22	Routine Periodic Inspection	ERA, SSB, NLC, DITT	Conversion of the Tailings Storage Facility (TSF) to a process water storage facility and process safety update.	None minuted	ERA to provide the consolidated Pit 3 geotechnical risk assessment, any associated findings and the outcomes of improvements to the prism array to stakeholders. ERA to provide the results of the HAZOP study to stakeholders.
08/02/22	ERF meeting #21	ERA, SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Progress updates on relevant projects Ecological risk assessment Ranger Mine Closure Plan	ERA and NLC flagged confusion around responsibility of work, on new project scopes, given some new SSB project work has been assigned against trajectory-related KKNs for which ERA has responsibility.	Send project/activity list to stakeholders for a cross-mapping exercise against SSB projects and KKNs Provide feedback and analyses from Anna Richards on current soil data Send SSB the data collection plan for upcoming full survey of TLF Organise reconnaissance trip to Paradise Farm with NLC and others. Send updated risk assessment timeline and new layout of question spreadsheet Coordinate SSB review of WAVES modelling validation for TLF and Pit 1
07/02/22	Casual catch-up	ERA (FE) SSB (KT)	Non-minuted	Non-minuted	Non-minuted
01/02/22	3D printed project model	ERA (SR) Water Solutions (JM) CDU (RF)	Review existing flood modelling files for suitability for use in the 3D printed project model for NLC/GAC.	Non-minuted	Non-minuted
28/01/22	Surface Water Model Comments	ERA, SSB, IGS (AL)	Discuss Surface Water Model comments from SSB for clarification prior to ERA responding. Prioritised work required for Pit 3 Application that needed to be responded to in the comments.	Non-minuted	Non-minuted
28/01/22	Pit 3 Application Stakeholder Meeting	ERA,	Pit 3 Application preparation updates following an MTC item request (MTC held 19/01/2022)	General feedback provided on items raised by ERA.	None minuted
20/01/22	Formal non-regulatory meeting	David Boustead, Regional Director, Dept of Chief Minister and Cabinet Jeanie Govan, Regional Development Officer West Arnhem	Discussed current and future social services and infrastructure services in Jabiru, ongoing regular catch-ups, future collaboration opportunities e.g. social impact assessment.	Non-minuted	Ongoing fortnightly catch-up and/or dependent on David's visit to Jabiru, organise site visit for NTG represents David will inform us of dates, continue to discuss social impact assessment and social services and infrastructure programs.

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19/01/22	Ranger MTC	ERA, DITT, SSB, NLC, GAC, DISER	DITT provided updates on • The submission status of statutory documents. • Other regulatory matters including: ○ Draft Authorisation amendments ○ S29 requirements • Environmental Protection Act reforms, with a focus on Ranger related matters ERA provided updates on: • Radiation monitoring • Reforecasting • Upcoming reports and plan submissions inc. potential Pit 3 plans after the BPT exercise • Pit 1 final tailings level • Rehabilitation reporting metrics • HDS plant operation and sludge disposal SSB provided an update on current projects and assessments. MTC discussed the publication of SSB verification reports.	DISER noted that the program for the February parliament sitting weeks were not yet available and as such there was no update on the Atomic Energy Act. NLC remain concerned about the 2026 timeline for completion of rehabilitation work. GAC provided comments on the draft authorisation amendments: • Supportive of NTG accepting MCP as the MMP • Some terminology is unclear • Remove obsolete sections as the mine is no longer in production • Clarify what standalone applications are, then the process under the Working arrangements. They are primarily applications to the commonwealth minister outlined in the MCP. DITT advised that there would be a separate meeting to discuss the amendments to the Authorisation. SSB requested a pre-submission briefing regarding the Pit 3 closure application. GAC noted that there is not yet a complete process for ERA to apply for and for the minister to issue a close out certificate.	ERA to advise MTC of future Noetic process safety visits. DITT to clarify whether ERA has submitted whole of site groundwater conceptual model in accordance with Annex D.6 of Ranger Authorisation. DITT to provide written advice on the legal standing of the small standalone application. DITT to circulate draft Ranger Water Quality Objectives Monitoring and Reporting Requirements document to MTC. DITT to clarify the legal standing of minor applications in writing. DITT to also provide a written clarification of the process. DITT to circulate draft S29 guidance to MTC members for comment ERA will provide MTC with an update for Spigelia creek line inspections ERA to submit application to vary final tailings level in Pit 1 ERA to submit draft of Pit 1 close out report to MTC
13/01/22	Routine Periodic Inspection	ERA, SSB, NLC	Radiation and *Spigelia* management	Stakeholders were satisfied with the outcomes of the investigation into the Radon monitoring non-conformance and that appropriate remedial action had either been taken or was planned.	None minuted
January 2022	Submission of the Kakadu Board Report for inclusion in the Kakadu Board of Management Meeting	Kakadu Board of Management members	Provide information to the board on a range of topics including: • Previous quarter operations • Rehabilitation at Ranger • Closure works • Funding • Corporate updates Community updates	N/A	N/A
2022 ad-hoc	Meeting	ERA, GAC, Cth agencies	Discussions regarding amendments to the Atomic Energy Act	Non-minuted	Non-minuted
2022 ad-hoc	Verification site visits	SSB	Site visits to complete various closure verifications.	Non-minuted	Non-minuted
2022 weekly	Casual catch-up	ERA (SP) SSB (JM)	Non-minuted	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
14/12/21	ERF meeting #20	ERA, SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria	SSB is finalising draft scopes for several new projects, which will be provided to stakeholders for comment prior to the next meeting. ERA will provide scopes/reports on S&TM, WAVES and fauna projects to stakeholders by early 2022 ERA noted that due to re-forecasting, the 2021 RMCP may not be submitted in its entirety. However, Chapter 5 Technical Studies may be provided to stakeholders for review soon.	None minuted
09/12/21	Routine Periodic Inspection	ERA, SSB, DITT, NLC	Site-wide water monitoring and management in preparation for the 2021/22 wet season.	Cleaning of the TSF walls and floor was substantively completed and cleaning verification had commenced. The clay floor was clearly visible and few evaporated salts were noted on the floor. At the time of the inspection, tailings were not being deposited over the lined disposal area in the south-western corner of the Pit rim. There was a substantial build-up of tailings along the lined section of the wall which will need to be washed into the pit. Stakeholders inspected RP2 from the embankment wall and noted that water levels were low in preparation for wet season rainfall.	ERA to provide evidence to stakeholders that the Brolga dredge underwent radiation clearance in preparation for being removed from site.
09/12/21	Aquatic monitoring meeting	BMT, ERA (SI), SSB (AH, CH)	Aquatic monitoring program needs.	Non-minuted	BMT updating monitoring program design. To be reviewed by SSB initially then presented to broader stakeholder group.
08/12/21	Relationship Committee Meeting	ERA, GAC	Provide update on various topics: • Looking after country • Cultural heritage • Rehabilitation projects • Jabiru housing remediation • Community partnership General project works update	Comments recorded in RCM minutes	Response, actions and/or resolutions recorded in RCM minutes
02/12/21	Casual catch-up	ERA (FE) SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
01-03/12/21	Kakadu Board of Management Meeting	Kakadu Board of Management	ERA tabled its update to the Kakadu Board Report providing updates on a number of topics: • March 2022 quarter operations review • Rehabilitation reforecast • Ranger rehabilitation • Pit 3 methodology Funding	N/A	N/A
30/11/21-01/12/21	Pit 1 & TLF monthly monitoring	ERISS	Monitoring activities as per the Pit 1 and TLF monitoring plans including: • Drone surveys (imagery and laser scanning) • Walkthroughs • General observations	Non-minuted	Non-minuted

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30/11/21	ERF meeting #19	ERA, SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Project progress updates LAA inspection • ARRTC meeting reflections/follow up	Understorey workshop report currently being updating to address stakeholder comments SSB and ERA both are finalising scopes and internal approvals for new projects. Risk review workshop postponed until early 2022	ERA Compile available data on soil sampling on waste rock SSB provide rationale for 1 ha vegetation survey plot sizes
26/11/21	Pit 3 BPT workshop	MTC stakeholders	Pit 3 capping works	Non-minuted	Non-minuted
24/11/21	Routine Periodic Inspection	ERA, SSB, DITT	TSF cleaning and CRS Sump	Bulk tailings removal is being prioritised and well advanced. Remnant tailings are relatively easily distinguishable from other floor and wall materials such as clay and sand in most areas due to their distinctive colouring, fine texture and layered form. Minor dusting that remained within the TSF walls was noted in the south-eastern section of the TSF. A recent storm event had flooded parts of the TSF. Some large puddles of water remained. There were a substantial number of dead, mature melaleuca trees located in the former Djalkmara creek line near the confluence with Magela Creek. Dead trees tended to be in sandy areas. Healthy and stressed trees appeared in close proximity to the dead trees. Melaleuca trees in surrounding areas did not appear to be affected in the same way. The cause of the dieback is unknown. ERA advised that they would check the groundwater quality in the area using existing bores and provide an update to SSB.	ERA to provide stakeholders with an investigation report for the 14/11/21 sulphuric acid leak, when completed. ERA to provide stakeholders with an investigation report for the radon monitoring non-compliance, when completed.
23/11/21	Workshop: Apply Mg vulnerability assessment framework to SWM results	ERA, SSB, NLC, GAC (M. Taylor), DITT, ARRTC (L. Rumpf), BMT	Scoring, uncertainty and process reviewed in the meeting for application to Coonjimba Billabong and a creek site. Informs aquatic ecosystem risk and ALARA at onsite waterbodies.	Videos (> 5 hours) and transcript (256 pages) of Microsoft teams meeting recorded.	Report due late January.
22/11/21	Meeting	ERA, SSB	TSF What is Clean Plan Inspection Test Plan	Non-minuted	Finalise ITP plan for review at upcoming RPI

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17-19/11/21	ARRTC49	ARRTC members & observers	ERA gave presentations on: • General comments and updates • Updates on learnings from and monitoring of Pit 1 • PFAS • Closure criteria • Vulnerability assessment framework • Water pathway risk assessment • Ranger surface water model • Key issues and research at Jabiluka SSB gave presentations on: • Ecosystem restoration work plan and discussion of forthcoming risk assessment • WASQ work plan • ERL restructure • PFAS monitoring investigations • SSB monitoring strategy and long term monitoring plan NESP presented, for endorsement on project and KKN close-out, on • WS7H: RES-2017-022 Ecohydrology and sensitivity of riparian flora WS7F: RES-2018-002 Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity	Dr Stauber commented that there is no faith in the current PFOS 99% protection guideline value (GV). Data show so far that PFOS would not be an issue with exceedances of 99% GV. She is happy that ERA are undertaking more sampling. Dr Wilkinson commented that SSB need to ensure statistical design is considered in developing monitoring programs, referring to monitoring programs on turbidity as a measure of erosion of the landform. Dr Mudd noted that it was good to see that a source-pathway-receptor approach is being undertaken for SSB PFAS sampling Dr Stauber raised the problem of what to compare the PFAS monitoring data to, given the guideline is flawed. It is difficult to determine risk when we don't yet have sensible GVs. Dr Wilkinson said it was good to see how calibration of the Ranger Surface Water Model has performed well and robust sensitivity analysis has been undertaken. This is a good tool for assessing scenarios and meeting closure criteria. Would be good to start quantifying peak concentrations vs the associated conditions, including probabilities. ARRTC have the sense that they are missing the latent opportunities of face-to-face discussion with online meetings and look forward to being able to travel again. ARRTC are happy to meet and assist between meetings. Dr Gavin Mudd commented that Ranger is a big hall mark for the world, IUCN etc and the landowners. It is critical that issues are ironed out so we can work towards a future adaptive management on the right trajectory. Prof Dixon informed everyone that they are finalising, through SER, international standards for mine lands ecological restoration. He noted the drafting committee, and the board, are extremely focused on key sites and Ranger is one that is mentioned due to its World Heritage location.	SSB to present review of SSB Landform Work Plan SSB to provide review of SSB Radiation Work Plan ARRTC to provide ERA with access to unpublished re-vegetation advice SSB to provide ARRTC with the scopes of the 4 new projects to address the ecosystem trajectory which covers use of data from mine sites such as Nabarlek, Jabiluka etc ERA to provide presentation on upcoming work related to State and Transition Model SSB to follow up presentation on Nabarlek including but not limited to Kate Harries PhD work ERA to follow up presentation on Jabiluka ecosystem restoration – including maps of the area SSB to organise ARRTC field trip associated with ARRTC50 (May 2022) ERA to Present on RMCP. Presentation to indicate areas of major change (e.g. complete re-writing of Chapter 5) ARRTC to provide to ERA and SSB an alternative approach to structured expert elicitation to assess vulnerability that could inform ERA's Vulnerability Assessment Framework. SSB to discuss assessment methods for closure criteria on erosion/turbidity with interested parties ARRTC to obtain & distribute (Clem Duvert's NESP) ecohydrology paper to ARRTC, SSB and stakeholders SSB to discuss RES-2021-014 (fauna closure criteria, goals) and RES-2021-015 (fauna closure criteria, indicators) with Prof Woinarski ERA to provide ARRTC with seed metric data that show the disparity between viable seed and germinable seed to ensure seed when used is at its optimum germinable state SSB to add KKNs to slide 13 of ERL presentation and distribute to ARRTC ERA to provide/ discuss with Dr Rumpff BPT docs and framework to inform discussions on uncertainty and decision making
12/11/21	Casual catch-up	ERA (FE) SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
10/11/21	Meeting	ERA SSB	PFAS SAQP	Non-minuted	Non-minuted
09/11/21	Casual catch-up	ERISS ERA	ARRTC preparation	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
08/11/21	Erosion and sediment working group	SSB (JM, MS, AC) ERA (SR, SP, YF)	Update on dry season upgrades at Pit 1/CRS for erosion and sediment control.	Non-minuted	Non-minuted
26-27/10/21	Pit 1 & TLF monthly monitoring	ERISS	Monitoring activities as per the Pit 1 and TLF monitoring plans including: • Drone surveys (imagery and laser scanning) • Walkthroughs General observations	Non-minuted	Non-minuted
20/10/21	Cultural Reconnection Steering Committee	NLC, GAC, CDU	3D Model of Ranger Project Area • Ranger Mine visit to burial sites, grinding stones, natural rocky escarpments	Non-minuted	Non-minuted
20/10/21	Site visit	ERISS	Inspection of the LAAs	Non-minuted	Non-minuted
19/10/21	ERF Meeting #18	SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Jabiluka and Djarr Djarr revegetation monitoring Project progress updates Scope/logistics of risk review workshop	Chris H noted that SSB intends to present to ARRTC changes to SSB's ecosystem restoration research program at the upcoming November meeting. Mike W noted the possibility that the upcoming risk assessment review may identify additional work that needs to be done (i.e. KKNs).	Provide a) available Jabiluka vegetation data (ideally in spreadsheet format), b) a bibliography of previous reports and species and c) a list of species that have been planted.
15/10/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Closure execution project updates • Pit 1 revegetation monitoring updates • Aquatic ecosystem vulnerability background Ecological vulnerability assessment framework	None minuted	ERA to revise Pit 3 bathymetric survey slide to better visualise tailings levels across Pit 3. ERA to develop alternative process water metric following completion of tailings transfer to Pit 3.
14/10/21	Routine Periodic Inspection	SSB, NLC, DITT	• Pit 1 wet season preparation, TSF cleaning and R3 Deeps decommissioning.	SSB advised that ERA was still to come back to stakeholders on their verification techniques for clean and until this occurred verification activities could not commence. Stakeholders also noted that the strategy for verifying that the floor and walls are clean of tailings needs to be agreed before rip rap is replaced on the dam walls or other preparatory works that may mask cleaning activities are undertaken.	ERA to organise a meeting with stakeholders to discuss the strategy for verifying tailings cleaning and obtain consensus on the verification program. ERA to provide a memo to stakeholders explaining the changes to the GCT2 sump.
05/10/21	ERF Meeting #17	SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Jabiluka and Djarr Djarr revegetation monitoring Project progress updates	SSB just received a draft report from Sean Bellairs, summarising the understorey functional group workshop. Development of assessment methods and patch metrics/naturalness indicator is not fully developed/agreed and needs to be progressed.	SSB to provide a copy of draft report compiled by Sean Bellairs, summarising outcomes the understorey functional group workshop. SSB to provide rationale for 1 ha vegetation survey plot sizes. SSB to forward relevant information and instructions prior to risk review meeting.

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30/09/21	Meeting	SSB, NLC, DITT	Surface Water Modelling Update – Sensitivity Analysis and Validation Calibration Update.	General comments on uranium and sulfate partitioning in billabongs, use of decay functions within the model, and applicability and use of developed natural run-off water quality relationships. Formalised question to be provided by stakeholders to ERA following review of reports.	Modelling reports to be provided to stakeholders, reports distributed to stakeholders on 18th October 2021.
28-29/09/21	Pit 1 & TLF monthly monitoring	ERISS	Monitoring activities as per the Pit 1 and TLF monitoring plans including: • Drone surveys (imagery and laser scanning) • Walkthroughs General observations	Non-minuted	Non-minuted
27/09/21	Meeting	SSB Coffey ERA	• Conversion of the TSF to a water dam	Non-minuted	Non-minuted
24/09/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Closure execution project updates • PFAS progress update & introduction to Cardno team • Airport contaminated sites investigation Pit 1 Ecosystem Re-establishment Plan monitoring commitment updates	None minuted	None minuted

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23/09/21	ARRAC 56	ARRAC members & observers	ERA presented on health and safety, process safety, environmental performance, water management, progressive rehabilitation, environmental studies and approvals updates. • Spigelia monitoring and tracking • Browsing ant surveillance program • Pond and process water treatment and releases • Decommissioning of process plant and make safe activities • Process water treatment • Ranger 3 Deeps final backfill • Tailings transfer • Pit 3 capping and backfill. Work to determine the optimal capping method and purchase wick material is underway. • Revegetation of Walem Madjawulu-1 (the area formally known as Pit 1) has commenced • Nursery propagation and seed collection is on track for revegetation of the final landform • A cultural reconnection activity has been undertaken on Pit 1 with collaboration with Traditional Owners to install habitat areas (rocky outcrops). • A detailed PFAS site investigation is underway • Ongoing studies include groundwater modelling, surface water modelling, the contaminated sites investigations, bush tucker project, Pit 1 and stage 13.1 surface water monitoring and radiation dose assessment • The land application area soil assessment has been completed • The acid sulfate soils investigation indicated that there are ASS and this will require more investigation	Chris Brady noted inconsistencies between the ERA and DITT reports, the absence of Nabarlek and Jabiluka check monitoring, progress towards Ranger mine closure timeframes and uncertainty around the process for granting exemptions from the Authorisation. Justin O'Brien noted that a letter provided from DITT to ERA regarding tailings management and the Ranger Authorisation requirements on 23 September 2021 was confusing.	Secretariat to circulate Susan O'Sullivan's paper to all members.of minutes.
21/09/21	Erosion and sediment working group	SSB (JM, MS, AC) ERA (SR, SP, YF)	• Update on dry season upgrades at Pit 1/CRS for erosion and sediment control.	Non-minuted	Non-minuted
20/09/21	Meeting	SSB Coffey ERA	Conversion of the TSF to a water dam	Non-minuted	Non-minuted
17/09/21	Casual catch-up	ERA (FE) SSB (KT)	Non-minuted	Non-minuted	Non-minuted
15/09/21	Informal meeting	SSB (JL, MS) ERA (EF, SL, SR) Subject matter experts (TC, GH)	CAESAR Lisflood modelling discussions on parameter optimisation	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
13/09/21	Informal meeting	CDU (RF) ERA (SR)	Catch up meeting to discuss progress on 3D printed model of the Ranger Final Landform	Non-minuted	Non-minuted
09/09/21	Erosion and sediment working group	SSB (JM, MS, AC) ERA (SR, SP, YF)	Update on dry season upgrades at Pit 1/CRS for erosion and sediment control.	Non-minuted	Non-minuted
09/09/21	Informal meeting	SSB (JM, MS, AC) ERA (SR, SP, AD, FS, YF, TB)	Discuss engineering limitations of accurately measuring flow into CRS.	Non-minuted	Non-minuted
09/09/21	Routine Periodic Inspection	SSB, NLC	Contaminated sites, hazardous substances, waste and hydrocarbon management.	The rubber waste laydown area was located on the top of the western stockpile. This is not the area shown in the NMP001 Non-Mineral Waste Management Plan in Figure 2. This will require updating in the next iteration of the plan. ERA advised that the former rubber waste laydown area, shown in Figure 2 of NMP001, was buried in the process of backfilling Pit 1 and decommissioned as part of constructing the Pit 1 final landform. Stakeholders opportunistically inspected a short section of the haul route for transfer of tailings between the TSF and Pit 3. The road appeared well maintained with no visible tailings spills. Stakeholders noted that resourcing for emergency response team was a red light and had been for two months.	ERA to review digital waste disposal records to confirm that data is being entered correctly from hardcopy waste disposal forms. ERA to consider altering the hard copy receivables form to mirror the waste tracking register so that inputting data is more straightforward. ERA to update the contaminated sites register to include the new general waste landfill location.
07/09/21	ERF Meeting #16	SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria Final Landform Application Scope Closure Trajectory Monitoring Plan Pit 1 baseline soil sampling Fire report	Agreement that nutrient cycling criteria have reference to trajectories removed. ERA circulated a draft table of topics to be addressed in the Final Landform Application (FLA) for feedback to help with ERA's reforecast. SSB indicated that the list still appears to reflect what should be included in the FLA. ERA circulated a first pass draft of a Completion Criteria Monitoring Plan (vegetation only) which they are looking at including in the 2021 RMCP - some preliminary discussion about monitoring plots (size, permanent vs random). LAA inspection scheduled October. It was agreed that the report by Garry Cook is a useful compilation of relevant information on effects of fire on vegetation in the region and has some key considerations that ERA can use in developing a fire management strategy for the rehabilitated site.	SSB seek clarification from Anna Richards (CSIRO) on rationale for retaining the trajectory/similarity to reference aspect within the litter decomposition nutrient cycling indicator. SSB to provide feedback to ERA on the draft Final Landform Application topics, to identify if there may be any major gaps. SSB to provide feedback to ERA on the draft Closure Trajectory Monitoring Plan. ERA to provide a copy of draft LAA remediation plan. SSB to provide ERA with a copy of the Sampling Analysis Quality Plan for soil nutrient and biota sampling. ERA to consult with SSB and NLC on identifying the next steps for development of fire management strategy for revegetation.
31/08/21-01/09/21	Pit 1 & TLF monthly monitoring	ERISS	Monitoring activities as per the Pit 1 and TLF monitoring plans including: • Drone surveys (imagery and laser scanning) • Walkthroughs General observations	Non-minuted	Non-minuted

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31/08/21	Jabiluka MTC Meeting	MTC members	ERA provided updates on: • Fire, weed and track management activities on site • Mulch & direct seeding trials • Vent shaft monitoring • Potential vegetation reference sites and revegetation survey	SSB noted that the Jabiluka lease is due for renewal in 2024 and raised concerns regarding the status of closure planning. NLC reiterated that personnel accessing the Jabiluka lease should complete the Jabiluka induction prior to accessing the site.	ERA to provide further correspondence with a proposal for a post-fire resilience study at Djarr Djarr for considerations by stakeholders.
30/08/21	Informal meeting	SSB (JM) ERA (SR)	Billabong sediment sampling results and report • Pit 1/CRS erosion and sediment monitoring	Non-minuted	Establish an erosion and sediment working group (ERA, SSB) to meet fortnightly
27/08/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Closure execution project updates • Catchment conversion quarterly update • Pit 1 2020/2021 wet season workshop summary Pit 3 backfill design overview	None minuted	ERA to organise a meeting of the Tailings working group to discuss the consolidation model update and density profile, to determine what will be required for the Pit 3 Application. ERA to add MOL to graphs in the monthly metrics slide pack. ERA to review and update the format for studies slides presented at RCCF to align with the SSB/ERA joint project list. ERA to recommence inclusion of the brine injection metric now that the system has re-started. For future reporting of remnant tailings transfer amounts, provide reference to total amount requiring transfer to show overall progress to plan ERA to add a tracking register for monitoring commitments made in the Pit 1 Ecosystem Re-establishment Plan by SSB and ERA. Pit 1 sediment/erosion monitoring group to be established.

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23/08/21	ARRTC 48	ARRTC members & observers	ERA provided the committee with a virtual tour of the Ranger mine including the Tailings Storage Facility, Pit 1 and Stage 13. ERA provided updates on: • key closure activities including decommissioning of the processing plant, process water treatment, R3D final backfill, tailings dam, Pit 3 capping and backfill, revegetation of Pit 1 and seed collection of local native species. • PFAS, noting that Cardno have been engaged to undertake the work and is currently undertaking a gap assessment and developing a sampling and analysis quality plan (SAQP) to identify where additional investigation needs to take place. • Spigelia eradication project. • Work to update closure criteria. • Solute transport studies, supporting groundwater studies and the surface water model. • ERA presented on ecosystem trajectories and developing an adaptive management plan.	Dr Rumpff advised she would provide Ms Parry with some additional references on decision making frameworks. Rapid and qualitative assessment of risks is a good approach. Prof Kingsley advised that structured expert elicitation is a very important mechanism in the absence of all the information. Further, direct seeding and associated technologies will be important in the future for secondary plantings and responding to deviations for example replanting after catastrophic disturbance. Dr Wilkinson advised that adaptive management plans needs to be developed to address potential issues, there is concern that progressive rehabilitation will happen across site without strategies in place. Dr Stauber advised ARRTC wants to see how projects/KKNs feed into assessment of applications and the framework that connects to monitoring and management plans. Prof Woinarski noted additional knowledge needs/risks are being identified as time goes on so there is a need to see these are captured. ARRTC also wants to see a well-targeted comprehensive monitoring plan for ecosystem restoration.	ERA to provide update on learnings from and monitoring of Pit 1 which covers • Ecosystem restoration (esp. comparison of different planting trials) • Landform design and performance ERA to advise whether the new GW modelling included assessment of changes to the model run times, calibration, or convergence ERA to provide presentation on strategy for monitoring program – to include priorities and an example ERA to provide ARRTC with S&T model report (April 2020) along with SSB and NLC's comments
10/08/21	ERF Meeting #15	SSB, NLC	Progress on development and agreement of ecosystem sustainability and similarity criteria. ARRTC close-out process.	SSB performed preliminary cross-mapping exercise to assist in identifying indicators with monitoring overlap. ERA presentation on high-level issues/questions regarding criteria trajectory monitoring plan. Risk review workshop needed to ensure that SSB and ERA projects over the next few years are addressing the highest priority knowledge needs.	Schedule risk assessment workshop in October.
09-13/08/21	Annual Stakeholder Audit	SSB, NLC	Assessment of ERA's compliance with selected environmental management plans submitted in support of the Mining Management Plan.	The audit found that ERA was generally compliant with the commitments made in their management plans and was undertaking activities as required by their internal procedures.	A list of key findings (non-conformances, conditional findings and observations) was provided to ERA by email on 21 September 2021. Follow-up discussions were held between selected members of the audit team and ERA representatives during RPIs in October and November 2021. These meetings allowed ERA to demonstrate progress towards addressing findings from the audit.
06/08/21	GW and SW modelling meeting	ERA, INTERA, SSB, IGS	INTERA presented GW concentration maps Additional conceptualisation discussion for GW/SW interaction	Non-minuted	Non-minuted
05-06/08/21	Pit 1 & TLF monthly monitoring	ERISS	Monitoring activities as per the Pit 1 and TLF monitoring plans including: • Drone surveys (imagery and laser scanning) • Walkthroughs General observations	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
August 2021	Submission of the Kakadu Board Report for inclusion in the Kakadu Board of Management Meeting	Kakadu Board of Management members	Provide information to the board on a range of topics including: • Previous quarter operations • Rehabilitation at Ranger • Closure works • Funding • Corporate updates • Community updates	N/A	N/A
30/07/21	Casual catch-up	ERA (FE) SSB (KT)	Key topics of discussion were: • Annual Stakeholder Audit on 9 August • Upcoming ARRTC. Covid cancelled site visit • Upcoming Visit by Keith and his leader Simon Banks delayed due to Covid • Resources • Atomic Energy Act amendment • Pit 3 capping • Authorisation update • Airport handover and contaminated sites assessment	Non-minuted	Non-minuted
29/07/21	GAC visit	GAC Cultural Reconnection Steering Committee, KNPS	Visit to Pit 1 to see newly constructed rock pile habitats and check on seedlings planted in March 2021. • Visit to Georgetown Billabong.	Non-minuted	Non-minuted
28/07/21	Meeting	ERA, SSB, DITT	Meeting to discuss Authorisation review and update	Non-minuted	Non-minuted
21-22/07/21	Routine Periodic Inspection	SSB, NLC	Pit 1 Monitoring Plan. Pit 1 ecosystem establishment trials status.	None minuted	ERA to provide stakeholders with the outcome of the investigation into the tailings dusting incident of 1 July 2021. ERA to provide a presentation on the ARCHER risk management system with a focus on environmental risk management.
19/07/21	Criteria workshop	SSB, NLC	Meeting to agree on ecosystem restoration closure criteria goals and indicators.	Non-minuted	Agreeance achieved
16/07/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • KKN close-out and joint project list • PFAS monthly progress update • Closure execution project updates Upcoming process water treatment approvals	None minuted	None minuted
07/07/21	Meeting	ERA, SSB, DITT, NLC	• Pit 3 Capping Backfill and Waste Disposal application	Non-minuted	Non-minuted
01/07/21	Casual catch-up	NLC (Chris Brady) CDU (Rohan Fisher) ERA (Sarah Reid)	Second discussion held about the development of a 3D Model of the Ranger Final Landform. Timelines for project execution established.	Non-minuted	Non-minuted

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25/06/21	Ecosystem Restoration Forum (ERF #13)	SSB/ERISS, NLC	Closure Criteria – Ecosystem sustainability and similarity	MP indicated that ERA would be interested in testing vegetation data within undisturbed areas of the RPA. CH suggested that it is very likely that any of these areas within the RPA would fall within the bounds of the reference ecosystem. Discussion on the species richness indicator. CB suggested that overstorey and midstorey do not need to be distinguished – only overstorey (i.e. > 1.5 m) is needed. In relation to the updated draft vegetation distribution indicator, MP indicated that it is difficult to visualise how this would look and that ERA needs time to consider this further. CB suggested that patchiness may not be visible within a single vegetation type (i.e. as opposed to between vegetation types). LM agreed that it depends on scale. CB suggested that the sustainability indicator for recruitment could potentially be simplified to state that key species are recruiting.	SSB to provide a 'shiny app' that will allow ERA to test species lists against the reference ecosystem for compositional similarity. SSB to provide an illustration of how the vegetation distribution indicator would be assessed.
25/06/21	Pit 3 tailings consolidation	SSB (John Miller)	Pit 3 consolidation	Non-minuted	Non-minuted
24/06/21	Casual catch-up	SSB, Newcastle University	Meeting to discuss proposed parameter optimisation for the Landform Evolution Model.	Non-minuted	Non-minuted
24/06/21	Understory workshop	SSB/ERISS, NLC, Experts from CDU and KNPS	Determining a 'functional' approach for understorey species classification and closure criteria indicators.	Non-minuted	First draft of functional approach and understorey classification complete.
23/06/21	Meeting	ERA, SSB, DITT, NLC	Pit 3 Capping Backfill and Waste Disposal application	Non-minuted	Non-minuted
18/06/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 Ecosystem Re-establishment Plan update • KKN close-out and joint project list • Tailings transfer and Pit 3 tip head • Surface water pathways risk assessment • Brine injection status update Process water treatment status update	None minuted	ERA to report on catchment conversion works each quarter at RCCF.
18/06/21	Casual catch-up	SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
17/06/21	WASWG	SSB, NLC, GAC, DIIT, Rio Tinto	Water & sediment KKNs and associated projects.	Non-minuted	Non-minuted
16/06/21	Site inspection	ASNO	Inspect decommissioning works and assess conformity with the approved decommissioning plan.	Non-minuted	Non-minuted
11/06/21	Paradise Farm visit	SSB, NLC	Appropriate fire regimes for revegetation and surrounding ecosystems.	Non-minuted	Non-minuted
11/06/21	Source Term discussion	SSB (AL), ERA (DS)	Discussion on feedback regarding potential shallow groundwater source below and downstream of RP1 in the post closure solute transport modelling.	Non-minuted	Non-minuted

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10/06/21	Ecosystem Restoration Forum (ERF #12)	SSB/ERISS, NLC	Closure Criteria – Fauna criteria	Discussed shifting ant approach away from 'functional' to align with other fauna groups. Also discussed whether 'exotic' ants could be covered by new indicator; NLC noted that transformer ant species would be main concern, as opposed to just presence of exotic species. Discussion on whether tree hollows (habitat availability) requires an indicator, as long as there is confidence that ecosystem trajectory will occur.	SSB and NLC review comments provided by ERA on current draft of similarity and sustainability indicators. SSB to meet with CDU experts to clarify their advice on what approach could be taken in regards to ants and exotic fauna approach.
10/06/21	Routine Periodic Inspection	SSB, DITT, NLC	Post-2020/21 wet season inspection of Jabiluka site. Progress of rehabilitation and general site condition.	Stakeholders and ERA noted an increase in native grass cover at the toe in the former decline portal area and in the central area of the Jabiluka rehabilitating area. The reestablishment of vegetation, including ground cover, in these areas had only met with limited success preciously. ERA advised that they had seeded the area with several grass species in December. DITT noted that improvement in the condition of revegetation in the disturbed Jabiluka footprint. NLC noted ERA's commitment to provide a report on the expected trajectory and management of the rehabilitated vegetation at Jabiluka to stakeholders which was recorded at the November 2020 RPI. SSB noted that the Jabiluka lease is due for renewal in 2024 and that closure criteria had yet to be established for Jabiluka.	Stakeholders to complete ERA Jabiluka induction. At the Jabiluka MTC scheduled for 1 July 2021: • Stakeholders to discuss potential regulatory implications of this requirement • ERA to present on the methods for seeding • ERA to present on progress of vent shaft sampling ERA to establish a mechanism to collaboratively plan and control fires at Djarr Djarr to support ongoing weed management efforts.
08/06/21	Casual catch-up	NLC (CB), CDU (RF), ERA (SR)	Discussion held about the development of a 3D Model of the Ranger Final Landform.	All in agreement with 3D Model development approach, objectives and proposed outcomes.	ERA to commence works with CDU on 3D Model development.
08/06/21	Meeting	ERA, SSB, DITT, NLC	Pit 3 Capping Backfill and Waste Disposal application	Non-minuted	Non-minuted
07/06/21	Casual catch-up	SSB (KT), ERA (FE, SP)	Non-minuted	Non-minuted	ERA and SSB agreed that it is important that ARRTC has reviewed all of the science underpinning the major applications and the RCMP prior to SSB providing endorsement for approval. ERA and SSB will develop an integrated research schedule for the August ARRTC meeting. ERA will include project projected timings/resources in the project schedule. SSB will tighten up the project/KKN closeout process. SSB and ERA will adhere to the hard deadline for submission of items to ARRTC. ERA will provide a sample project reporting dashboard to provide some ideas as to how ERA/SSB can best portray progress against schedule to ARRTC.
02/06/21	Meeting	ERA, SSB, DITT, NLC	Pit 3 Capping Backfill and Waste Disposal application	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
28/05/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 and Stage 13 UAV monitoring trial • Pit 1 revegetation • Catchment conversion works • 2021 drilling works • Acid Sulfate Soils ARRTC follow-up discussion PFAS scope and approach	None minuted	ERA to add total water treated slide to the metrics slide pack. ERA to report on catchment conversion works each quarter at RCCF.
27/05/21	Ecosystem Restoration Forum (ERF #11)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE). • Closure Criteria (CC) - Sustainability and Similarity ecosystem restoration standards; Fauna criteria.	Agreement was reached that the CRE species list is reasonable and representative of common species in the area. Noted that there is still some uncertainty in relation to fire species and timing of planting. Discussion on necessity for including 'framework' in vegetation goals and indicators.	All to review revised similarity and sustainability indicator tables, for discussion at the next meeting. ERA to provide relevant background information pertaining to understorey functional groups. All to review revised fauna goal/attribute table, for discussion at the next meeting.
27/05/21	AARTC member site visit	ARRTC member (SW), SSB	Site visit held to show the Landform ARRTC member around Ranger Mine, and talk through the current status of closure and proposed final landform execution.	Non-minuted	Non-minuted
24-25/05/21	ARRTC 47	ARRTC members & observers	SSB gave presentations for discussion and endorsement on; • WS4A_SSB RES-2018-003 Identification and mapping of Groundwater Dependent Ecosystems; and • CT1A-BOTH RES-2017-032 Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (aquatic pathways). SSB gave a presentation on the revision of the Landform Stability Rehabilitation Standard, for information. ERA gave presentations for information on; • 1221-09 WS5A-BOTH Water Pathway Risk Assessments Presentation (Release pathways onsite); • 2020/2021 sediment sampling investigation (ERA); and • 1221-11 WS1A-ERA (Non-aquatic) Contaminated sites sampling presentation (ERA). ERA gave a presentation on 1260-06 WS3D-ERA Surface water groundwater interaction for discussion and endorsement. ERA and SSB gave joint presentations on; • 1260-04 WS6C-ERA Eutrophication Risk Study, for discussion and endorsement; and Joint ERA/SSB Ecosystem Restoration Workplan and Development of Standards/Closure Criteria, for information.	ARRTC raised the issue of the 2026 date and arrangements beyond that date. Mr Taylor noted the Department of Industry, Science, Energy and Resources has prepared a Bill that will likely be passed well ahead of the 2026 date. Dr Stauber reiterated her concerns about the lack of information about the influence of radionuclides on periphyton and the method used to derive radionuclide guidelines. ARRTC continues to see significant risk around the monitoring framework. Ensuring issues are being captured with a line of sight is extremely important. Dr Mudd noted it was paramount for ARRTC to visit sites to help validate what is discussed in meetings. Mr Tayler expressed concern regarding access to preliminary PFAS data and transparency.	ERA to prepare a presentation on Jabiluka covering key issues and research. Prepare a presentation on the strategic monitoring programs. Provide timetable of individual work components, showing interdependencies as part of the joint project list. Provide radionuclide results as part of the 1221-06 Aquatics sediments project close out. Respond to Dr Stauber question of why the GCT2 site wasn't sampled for metals when it was sampled for ASS. Provide information on PFAS work. Distribute report on 1221-09 WS5A-BOTH Water Pathway Risk Assessment (release pathways onsite) for ARRTC's information SSB and ERA, in consultation with ARRTC Chair, to provide a timetable for future adaptive management related activities (as a possible precursor to a workshop). Provide a presentation on groundwater maps.

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21/05/21	Pit 3 tailings consolidation	SSB (John Miller)	• Pit 3 consolidation	Non-minuted	Non-minuted
19-20/05/21	Ecosystem Closure Criteria Workshop	SSB/ERISS, ARRTC (part) NT experts	Workshops to progress the development of ecosystem (vegetation and fauna) closure criteria.	Agreement on some indicators for goals	Continue to develop closure criteria for inclusion into the Ranger Mine Closure Plan
13/05/21	Routine Periodic Inspection	SSB, DITT, NLC	Ranger TSF Annual Inspection (incorporating post wet season inspection).	Stakeholders noted that the washdown area at the TSF west wall notch has the potential to be trafficked by light vehicles that may not be subject to wash down procedures. These vehicles may then potentially transfer tailings outside of the TSF footprint. Additionally, workers on foot may inadvertently walk through tailings and transfer tailings outside of the TSF footprint. J. Miller (SSB) asked if the dam engineer was satisfied that TSF drawdown was completed in accordance with recommendations. G. Ralls (Coffey) responded that he was satisfied that drawdown was completed in accordance with recommendations and there was negligible surveyed impact from the drawdown. J. Miller (SSB) asked if leaving the dam dry will impact its ability to hold water. G. Ralls (Coffey) does not anticipate any issues of that nature. G. Ralls (Coffey) noted that the wet season and wave action would pose a risk to the exposed clay core and that existing rilling indicates that more could occur. ERA plans to reinstate the rip rap. G. Ralls (Coffey) noted that the dam has been holding water and solids for many years and this bodes well for using it as a water storage for three wet seasons.	ERA should implement a strategy (such as area isolation and boot cleaning) to ensure tailings in the washdown areas are not transferred outside of the TSF footprint by vehicles or workers. ERA to provide the investigation report, RP2 water quality data and ITP for a leak in the underdrain bore pipeline.
10-13/05/21	Society of Ecological Restoration Australasia (SERA) Conference	Conference participants	Presentation on Ranger's Species Establishment Research Program (SERP). Presentation on Trial Landform (TLF). Booth to display ERA's closure plan and showcase some of our nursery grown plants.	Non-minuted	Non-minuted
07/05/21	Ecosystem Restoration Forum (ERF #10)	SSB/ERISS, NLC, CSIRO	Conceptual reference ecosystem (CRE). Closure Criteria (CC) - Sustainability and Similarity ecosystem restoration standards. Progress on joint ERA-SSB workplan and ARRTC questions.	It was agreed that some species found in reference sites would require further discussion as to whether they are included in the final CRE species list. Discussion on inclusion or omission of certain culturally-desired species.	SSB to provide DBH and stem density data corresponding with the updated CRE species list. ERA to finalise proposed planting list for discussion.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
06/05/21	MTC	MTC Members	DITT proposed a merger of MMP and MCP and aim to update the Authorisation in Q1 2021. ERA provided updates on: • Environmental incidents • Standalone application schedule, submission times, stakeholder consultation strategies and assessment turn around expectations • Staff resourcing in relation to key closure/rehabilitation activities • Status and progress of statutory reporting approvals • Tailings transfer • TSF cleaning and “what is clean?” • Pit 3 application changes DITT provided updates on: • Authorisation 0108 variation • Assessment of MMP • Environmental/mining regulatory reform • Licencing of extraction/abstraction bores DISER provided an update on the Annual Plan of Rehabilitation	SSB and NLC expressed concern that ERA may not have enough resources to undertake tasks simultaneously, particularly related to ecosystem reestablishment. SSB highlighted that in some cases in the past the turnaround time for ERA responses for comments were long, suggesting a resources shortfall. In particular concerns were raised regarding responses to Management Plans which have time implications such as the Water Management Plan. SSB and NLC advised they are very supportive of verification process and commended ERA on their cooperation and engagement.	ERA to advise MTC members of dates of the NOETIC process safety visits and if attendance is possible. All present agreed to expedite their own responses and inputs to improve turnaround times. ERA will complete a preliminary gamma survey of the dry TSF floor, timing will be dependent on floor being available, (ie clean and dry), to test effectiveness as a verification tool for demonstrating the TSF floor is clean and compliant with ER 11.2 ERA to investigate drone surveys as alternative verification methods. ERA to arrange a follow up workshop or discussion in June to consider results of surveys and other assessments options e.g. drone surveys. ERA to add a scope section to the TSF "what is clean" plan to make clear that it does not include transport of tailings. MTC agreed that ERA can commence wicking as there are no perceived risk to the external environment from the process of installing wicks. DITT to write letter to ERA referencing 2019 MCP acknowledging environmental risk is low and that the MTC Members agree for ERA to commence wicking. DITT recommended that stakeholders not review the 2021 MMP, as it replicates the 2020 MCP, and going forward the 2021 MCP will cover similar matters as in the MMP. It was agreed that the 2021 MMP would not be assessed. DITT to write to ERA, advising they have submitted the 2021 MMP in compliance with their authorisation. Draft letter to be circulated to members. DITT to liaise with the DEPWS and provide MTC with details of how the environmental regulatory reform changes will affect Ranger. ERA to present on the implications to the long term water management strategy in consideration of Pit 1 interim water management results to date, at the May 2021 RCCF.
05/05/21	Casual catch-up	NLC	ERA approach for including culturally important species in revegetation and planting lists.	Non-minuted	Non-minuted

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May 2021	Submission of the Kakadu Board Report for inclusion in the Kakadu Board of Management Meeting	Kakadu Board of Management members	Provide information to the board on a range of topics including: • Previous quarter operations • Rehabilitation at Ranger • Closure works • Funding • Corporate updates Community updates	N/A	N/A
30/04/21	GW catch-up	ERA (DS, EF, SV), SSB (AL), IGS	• General catch-up to review additional data requirements and drilling plan.	Non-minuted	Non-minuted
27/04/21	Ecosystem Restoration Forum (ERF #9)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - sorghum/fire issues. Closure Criteria (CC) - Sustainability and Similarity ecosystem restoration standards. Ecosystem restoration standards workshops.	SSB proposed to accommodate a functional groups approach for understorey, reflecting proposals for a functional classification for understorey, discussed by the group at the previous meeting	ERA and NLC to consider the draft indicators and report back to the group. ERA and NLC to consider material provided by SSB (complete species list) and report back to the group. SSB to prepare for the group a summary of different functional classifications that could be considered in preparing species lists for understorey.
23/04/21	GW and SW modelling general catch-up	ERA (DS, EF), SSB (AL, CH, AH, BM, JM)	General groundwater and surface water catch-up to discuss state of current studies, stakeholder review of studies, future projects including drilling and introduction of new team at SSB to support groundwater and surface water modelling studies.	SSB communicated that a formal letter will be sent to ERA later that day requesting ERA to provide additional detail from solute transport studies. Letter received by ERA after the meeting on 23/4/2021.	ERA to action information request.
23/04/21	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
22/04/21	ARRAC 55	ARRAC members & observers	ERA presented on health and safety, operational, environmental, water and closure activity updates. • Practical completion of tailings dredging • Cleaning of TSF wall and floor underway • Revegetation status updates on Pit 1 and Stage 13 • Seed collection status for final landform • Completion of a number of groundwater model studies • Surface water model configuration and calibration updated following stakeholder recommendations • Bushtucker project • Flora samples taken and report completed • Fauna sampling project scheduled for late 2021 • Pit 1 and Stage 13 surface water monitoring review planned for end of 2020/2021 wet season Radiation dose assessment is underway	Keith Tayler noted that the short-term risks of contamination below the TSF are being managed; however a longer-term plan may need to be developed.	None minuted

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16/04/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • ARRTC review preparations by ERA and SSB • Make safe and decommissioning • Pit 1 revegetation • Pit 3 wicking trial • TSF cleaning	None minuted	ERA to present on 2021 drilling plan at May RCCF. ERA to present on Pit 1 Revegetation post planting survey at May RCCF. ERA to provide further update on wicking works at May RCCF.
15/04/21	Routine Periodic Inspection	SSB, DITT, NLC	• Revegetation, nursery and ecosystem re-establishment.	Stakeholders noted some areas of water logging, in Pit 1 WM1C. ERA advised that in research trial planting, planting was avoided in areas with evidence of waterlogging. Waterlogging is recorded in monitoring observations. Stakeholders noted the growth of saplings at Stage 13.1A since they were planted, approximately 12 months ago. Most plants appeared in good health however some eucalypt mortality was observed.	None minuted
13/04/21	MERG	SSB/ERISS	Ecosystem decision making framework	Agreement on plan to place a decision making framework into the Pit 1 monitoring plan	None minuted
13/04/21	Ecosystem Restoration Forum (ERF #8)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - sorghum/fire issues. Closure Criteria (CC) - responsibilities; sustainability. Nutrient cycling reports.	ERA and NLC have concerns that Sorghum dominance is the result of high fire frequency, which has resulted in impacts on KNP. This is not considered a sustainable fire regime, for either the surrounding area or the rehabilitated site. Can take on a functional approach to understorey grass, rather than the specific species. ERA is responsible for developing closure criteria and SSB is responsible for ecosystem restoration standards. Collaboration is needed to ensure that all stakeholders are in agreement prior to ERA putting this forward for ministerial approval.	SSB to re-examine fire history data for the reference ecosystem and map out areas of fire intensity. SSB to provide complete species list that has been updated following inclusion of the two new Georgetown reference sites. SSB to review their original comments for ERA nutrient cycling report to see if there is anything critical that should be amended.
07/04/21	RSWM Update Meeting #6	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Meeting to discuss parameters to be assessed as part of RSWM sensitivity analysis.	Non-minuted	Non-minuted
30/03/21	Ecosystem Restoration Forum (ERF #7)	SSB/ERISS, NLC, CSIRO	Conceptual reference ecosystem (CRE) - sites; species. Closure Criteria (CC) - sustainability.	Concerns about the regularly burnt areas within the reference ecosystem. Focus on sustainable pattern of fire. Discussion on dry species (*E. phoenicia*, *E. tectifica* and *E. tintinnans*). Removal of Georgetown plots 1 and 2 and include the two recently surveyed plots in the CRE. Concerns about the amount of Sorghum in plots, maybe look at some sites with a lower fire frequency (potentially less sorghum).	Draft report on sustainability closure criteria to be distributed prior to sustainability closure criteria workshop. Members to provide dot points of thoughts/comments regarding CRE for next meeting and consider the issues of fire and sorghum. SSB to re-examine fire history data for the reference ecosystem and map out areas of lower fire frequency. NLC to ask about some sites known to have lower fire frequency.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
25/03/21	Planting ceremony	GAC, NLC, Cultural Reconnection Working Group	First planting event at Pit 1	Non-minuted	Non-minuted
12/03/21	Casual catch-up	SSB (KS)	Non-minuted	Non-minuted	Non-minuted
10/03/21	Landform KKN and project catch-up	ARRTC Landform member, SSB	Discussion on KKN's and projects relating to Landform and agreement on actions to progress towards close out.	Non-minuted	Non-minuted
8-9/03/21	Surface Water Pathway Risk Assessment	SSB/ERISS, NLC observing	Water and sediment quality. Risk assessment of mine contaminants to the aquatic ecosystem and people (first workshop).	Non-minuted, workshop discussions reflected in scores entered into risk spreadsheet or changes to descriptors and/or methods of assessment.	Review of process and preliminary results via ARRTC, WASWG, RCCF. Draft report distribution for review. Second workshop planned for H2 2021.
05/03/21	Fauna Closure Criteria Workshop	SSB, ARRTC (partial) and NT experts	Review proposed fauna closure criteria.	General agreement on the key goals to take forward.	Another workshop to be planned.
04/03/21	Ecosystem Restoration Forum (ERF #6)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - riparian and seasonally-inundated areas; Georgetown site selection.	NLC emphasised the need to determine what are the constraints, and hence what is an appropriate reference community, before undertaking surveys. It was generally agreed the priority should be finalising the woodland reference ecosystem, how this will be assessed, before looking at potentially constrained areas later.	SSB to plot locations of the two new Georgetown reference sites against existing sites and provide to stakeholders.
04/03/21	Ranger MMP	DITT	Discussion of the Mining Management Plan and options to incorporate into the Mine Closure Plan.	Non-minuted	Non-minuted
19/03/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 research planting update • TSF clean and Pit 3 dumping update SSB provided updates on: • Copper and zinc guideline values Toby McGrath from Water Solutions Pty Ltd gave a presentation on the simulations and results from the Surface Water Model update.	None minuted	None minuted

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11/03/21	Routine Periodic Inspection	SSB, DITT, NLC	Land use management (Weed and Fire management).	C. Brady (NLC) and M. Welch (SSB) raised a concern about weed management. Currently, ERA does not have a formal weed management plan for the area. These areas do not have their own specific management plan, however are within the remit of the Ranger Weed Management Plan. Stakeholders suggested that a risk rating system be more formally developed, for weed management, such that priority is also given to areas where the risk is on the boundary with KNP and around waterways that can lead offsite. Stakeholders recommended that current or future surface areas that are likely to be part of the final landform surface should be assessed as part of weed mapping to identify if seed banks require management in advance of final landform design. This information will be required to inform the future Final Landform Application and demonstrate that weed impacts will not impact on rehabilitation success.	None minuted
25/02/21	Site visit	GAC, NLC, Cultural Reconnection Working Group	Inspection of Georgetown area for potential reference sites (CRE).	Non-minuted	Non-minuted
23/02/21	Pit 3 tailings consolidation	SSB (John Miller)	Pit 3 consolidation	Non-minuted	Non-minuted
19/02/21	GW catch-up	ERA (DS, AN), DITT (MS, LH)	General catch-up to discuss current GW closure projects and operational reporting with DITT.	Non-minuted	Non-minuted
19/02/21	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Higher (and lower) rainfall dates • Pit 1 update (CRS, sediment monitoring, moisture probes) • Stage 13.1C proposal and Stage 13 learnings • TSF tailings transfer to Pit 3 • Pit 3 capping update • CPT, VST and tailings sampling update February 2021 sediment sampling update	None minuted	None minuted
18/02/21	Site Visit	GAC, NLC, Cultural Reconnection Working Group	Inspection of Pit 1, Stage 13.1A & B, and TLF. • Discussion on revegetation strategy.	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
February 2021	Submission of the Kakadu Board Report for inclusion in the Kakadu Board of Management Meeting	Kakadu Board of Management members	Provide information to the board on a range of topics including: • Previous quarter operations • Rehabilitation at Ranger • Closure works • Funding • Corporate updates Community updates	N/A	N/A
15-16/02/21	ARRTC 46	ARRTC members & observers	*Ecosystem restoration* SSB/ERA presented on CRE/CC work plan. ERA presented on Species Establishment Research Program (SERP) and matrix. Project close-out discussions for: • RES-2019-017 (ESR5B_BOTH): Developing restoration trajectories to predict when the restored site will move to a sustainable ecosystem. • RES-2017-007 (ESR1C_BOTH): Deriving species composition measures and their environmental. correlates to assess ecosystem restoration similarity. • RES-2019-012 (ESR1C_BOTH): Deriving vegetation community structural attributes that inform the conceptual reference ecosystem. • RES-2017-004 (CT2A_BOTH): Cataloguing the natural World Heritage values on the Ranger Project Area. Discussion and endorsement of KKN: ERS1A Tech Advice #29 "Intermittent flooding savanna species composition". *Climate Change* Comments on Climate Change research in Australia (Parks, NESP & ERA) and SSB projects of CC relevance. Status of ERA climate change studies (groundwater uncertainty analysis, future studies). Project close-out discussion for CT1A_BOTH. Ranger Uranium Mine Closure First Pass Climate Change Risk Assessment. *Ground and surface waters* Q&A session, with INTERA, discussing the reports submitted to ARRTC on the Solute Source Terms, Solute Transport model and Uncertainty Analysis. Presentation and discussion with Toby McGrath (Water Solutions Pty Ltd) on the Surface Water Model Update and GW-SW Interaction. KKN/Project close out discussions for: • KKN/Project: Update Groundwater Solute Transport Modelling and Conceptual Model (2019 INTERA Rpt).	Summary of comments from ARRTC included: • The Committee thanked SSB and ERA for the excellent work and ongoing effort, leadership, patience and persistence as complicated and complex issues were progressed. • ARRTC is pleased that so many KKNs/Projects were closed out for the meeting. ARRTC would like to see the feedback on closed KKNs/projects wrapped into a process so that a line of sight is maintained on where the feedback is taken up e.g., future KKNs, existing KKNs, workflows. • There has been good progress made in the conceptual reference ecosystem space. It will be important to document and explain any outstanding future research needs required going forward e.g., fauna, hollow-dependent taxa, artificial hollows etc. • ARRTC are keen to evaluate the big picture, and it would be prudent for ARRTC to ensure the building blocks in the workflows are scientifically robust and fit for purpose. • The committee notes that monitoring, early warning of failures and technical and management responses at Ranger mine will become increasingly important as the mine enters its rehabilitation stage. • An integrated risk/adaptive management framework will be important going forward in order for ARRTC to maintain oversight of risks, technical matters underpinning assessment and to confidently close out KKNs and projects. • Crucially, a long period of monitoring and maintenance is required after 2026 to ensure appropriate progress and consolidation of the rehabilitation. The Committee has little visibility yet of the programs proposed to ensure this necessary monitoring and adaptive management can or will occur. ARRTC remains concerned in the uncertainty of future resourcing and support over the coming years and beyond 2026. Any significant reduction in resourcing at this critical time will have a negative impact on the successful and robust closure and rehabilitation of the Ranger mine.	ARRTC Secretariat to organise a time, before ARRTC 47, for ERA to have a discussion with Scott Wilkinson relating to the iterative development of the Ranger landform design. SSB to attend. SSB/ERA to ensure future close-out project/KKN documentation and presentations indicate relationship(s) between the project/KKN being closed and other current/future work. ERA with assistance from SSB to provide compendium on previous work on climate change effects on the Ranger project area, what work is proposed to be undertaken in future, what will be excluded. SSB to give a presentation at ARRTC 47 on the current PhD project at Nabarlek. SSB to give a presentation at ARRTC 47 on its current and long-term monitoring strategy. SSB to distribute work completed on tracer studies at Ranger. SSB to amend documentation for WS7C close out to rearticulate the risk to stygofauna associated with breaches of the Mg:Ca ratio of <9:1. SSB to include a KKN for Ecological Investigations Levels (EILs) needed for the contaminated sites assessment. ERA to give presentation at ARRTC 47 on ERA sediment sampling results. SSB to present on progress on ecosystem restoration workplan memo. ERA to summarise the core discussions around climate change held with fire experts, and re-issue the Climate Change report with that summary as an appendix

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			• RES-2009-002 (WS5A_BOTH): The toxicity of U to sediment biota of Gulungul Billabong. • RES-2020-021 (WS7A_SSB): Deriving site-specific guideline values for copper and zinc. • KKN WS7A_SSB: Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios? *Contaminated sites* ERA presented on billabong sediment sampling and ASS next steps. ERM presented on WS1A-ERA LAA soils assessment. • Reporting on KKN/Project close-out, based on supplied documentation and presentations given during the meeting.		
12/02/21	Ecosystem Restoration Forum (ERF #5)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - riparian and seasonally-inundated areas; Georgetown site selection.	NLC suggest that ERA should take advantage of drainage lines to provide variability (habitat diversity to attract fauna), rather than a homogenous habitat across the entire landform. • SSB will be establishing an additional two survey plots (*Eucalyptus tetrodonta / miniata* dominated) in the Georgetown area. NLC will be proposing consultation with TO's, with consideration of cultural perspectives (i.e. land management practices), for both existing and new sites.	ERA to provide maps (for both waste rock and non-waste rock areas) showing locations across the rehabilitated site where seasonally inundated savanna and riparian communities may be required. SSB to consult with NLC and ERA on Georgetown site selection and arrange for site visit to potential sites. SSB to provide ERA with feedback on the 2019 and 2020 nutrient cycling reports.
11/02/21	Routine Periodic Inspection	SSB, DITT, NLC	Make Safe for Crushing Circuit, Mill and Processing area.	Stakeholders explained that the purpose of the inspection was to understand the process of make safe activities for the processing plant and progress to date. J. Miller (SSB) noted that the authorisation still contains a requirement for periodic scrubber interlock testing. ERA should seek an exemption from DITT for this testing now that the extractions system will no longer be used to mitigate dust associated with crushing activities. M. Sandgren (SSB) noted that there was no place for radiation clearances or survey results to be recorded in the packs. D. Dumesny indicated that discussions with the Specialist Radiation Safety Advisor were underway to determine how radiation surveys and clearances would be conducted and recorded.	ERA to provide stakeholders with updated information on how radiation clearances will be recorded in the decommissioning work packs.
08/02/21	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
05/02/21	Casual catch-up	SSB (KS)	Non-minuted	Non-minuted	Non-minuted
05/02/21	Casual catch-up	DITT (MS)	Non-minuted	Non-minuted	Non-minuted

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02/02/21	Ecosystem Restoration Forum (ERF #4)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - Georgetown plots; disturbance in reference sites. Closure Criteria (CC) - Sustainability. ARRTC46 - joint workplan memo; presentations.	SSB will select new 1 ha sites within Georgetown area in consultation with ERA and NLC, with the aim to commence surveys ASAP. NLC indicated that Traditional Owner's would likely be interested in participating in the site selection process.	SSB will forward sustainability table to ERA to determine which aspects they're working on. SSB to send out presentation and associated shapefiles on disturbance assessment work, for review and potential follow up discussion. SSB to email NLC and GAC on provision of locations for cultural heritage sites to consider when selecting new Georgetown reference site locations.
28/01/21	RSWM Update Meeting #5	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Meeting to present on updated groundwater to surface water interaction in RSWM.	Non-minuted	Non-minuted
22/01/21	Pit 3 tailings consolidation	SSB (John Miller)	Pit 3 consolidation.	Non-minuted	Non-minuted
21/01/21	Routine Periodic Inspection	SSB, DITT, NLC	Surface water monitoring and release management.	Stakeholders noted a gully forming on the Pit 1 landform batter to the north-east of the CRS inlet channel. Sediment from the gully was observed within the Pit 1 perimeter drain with rock baffles appearing to contain the majority of the sediment. C. Brady (NLC) noted the presence of grasses at the revegetation trials at Stage 13.1 and that this strengthened the case for using herbicides during revegetation trials. RPI attendees noted that the potential risk to the offsite environment from herbicide application is low whilst no releases are occurring from targeted catchments.	SSB to respond to the report provided by ERA evaluating the risk posed by glyphosate to aquatic environments and provide ERA with guidance on expectations for further work on herbicide monitoring and investigations. ERA to provide stakeholders with an investigation report pertaining to the release of permeate before the diversion system was activated, noted in the routine Water Quality Report for 1-27 December 2020. ERA to update the Release Plan Calculator to include the Corridor Road Sump.
19/01/21	Ecosystem Restoration Forum (ERF #3)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) Closure Criteria (CC)	SSB believes that the historical survey data used by ERA to develop CREv2 needs to be aggregated and possibly some new 1 ha plots implemented, to ensure that the data are comparable and scientifically defensible.	SSB and NLC to review and provide feedback on ERA draft memo addressing ARRTC questions.
07/01/21	Casual catch-up	SSB (MS)	Sediment monitoring at Pit 1 & Stage 13	Non-minuted	Non-minuted
07/01/21	Ecosystem Restoration Forum (ERF #2)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - plan Closure Criteria (CC) - plan	CRE: a) disturbance and implications for sites; b) species list; and c) implications for future monitoring Closure Criteria: a) review of quantitative parameters proposed by SSB at previous ARRTC meeting; b) benchmark criteria to actual closure criteria examples; c) sense check the closure criteria; and d) what does success look like?	Create memo with initial responses to ARRTC questions, including work plan. Indicate when each item will be addressed. Present progress on CRE, closure criteria and work plan to ARRTC at February meeting.
2021 ad-hoc	Meeting	ERA, GAC, Cth agencies	Discussions regarding amendments to the Atomic Energy Act	Non-minuted	Non-minuted
2021 ad-hoc	Verification site visits	SSB	Site visits to complete various closure verifications.	Non-minuted	Non-minuted
2021 weekly	Casual catch-up	ERA (SP) SSB (JM)	Non-minuted	Non-minuted	Non-minuted

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18/12/20	RCCF	GAC, NLC, DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Pit 3 consolidation model update • Water model assumptions update • HDS sludge disposal • Pit 1 wet season preparations and CRS works update • PFAS update Solute transport update (source terms, solute transport and uncertainty analysis, SW/GW interactions)	None minuted	ERA to provide higher rainfall scenario schedule dates. ERA to provide MTC members with data from the PFAS preliminary investigation (as per the Ranger Authorisation Annex D.8).
17/12/20	Routine Periodic Inspection	SSB, DITT, NLC	• Audit follow-up and preparations for cessation of processing	None minuted	None minuted
16/12/20	Pit 3 tailings consolidation	SSB (John Miller)	Pit 3 consolidation	Non-minuted	Non-minuted
16/12/20	RSWM Update Meeting #4	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Discussion on progress made to date on the model update. Discussion on proposed approach to implement an updated groundwater to surface water interaction following completion of INTERA GW/SW interaction study.	Non-minuted	Non-minuted
14/12/20	Casual catch-up	SSB (MS)	Sediment monitoring at Pit 1 & Stage 13	Non-minuted	Non-minuted
14/12/20	Ecosystem Restoration Forum (ERF #1)	SSB/ERISS, NLC	Conceptual reference ecosystem (CRE) - Mattiske report; disturbance and reference sites/plots. Closure Criteria (CC) ARRTC Questions on Ecosystem Restoration	Key outcome: A plan of work that needs to be completed in the next 6 months. NLC is seeking clarification on how proposed ongoing monitoring of reference site will inform the ACRE (i.e. can an agreed reference ecosystem change over time?). ARRTC have raised questions on the impact of disturbance on the reference sites/ plots and whether 'impacted' sites should be included in developing the CRE.	ERA to review and respond to SSB comments on the proposed CREs ERA and SSB to work through data and methods used to derive ACRE V2 to reach agreement on the CRE SSB will undertake analysis of disturbance for all the reference sites and plots. ERA prepare a document that will contain the responses to all the ARRTC questions. All to consider purpose and frequency of monitoring of the reference sites
11/12/20	Casual catch-up	NLC (CB)	Non-minuted	Non-minuted	Non-minuted
11/12/20	Weekly catch-up to end the year	SSB (JM, AL)	Non-minuted	Non-minuted	Non-minuted
04/12/20	Casual catch-up	SSB (KS)	Non-minuted	Non-minuted	Non-minuted
04/12/20	Casual catch-up	DITT (MS)	Non-minuted	Non-minuted	Non-minuted
02/12/20	RSWM Update Meeting #3	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Discussion on progress made to date on the model update. Presentation of groundwater model exfiltration maps following action in previous RSWM update meeting.	Non-minuted	Non-minuted
26/11/20	Casual catch-up	SSB	Review of ARRTC Ecosystem Restoration questions	Non-minuted	Non-minuted
20/11/20	Casual catch-up	NLC, SSB	Ecosystem reconstruction	Non-minuted	Non-minuted

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20/11/20	RCCF	GAC, NLC DITT, SSB, DISER	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 wet season preparations and CRS works update • End of milling and make safe activities • Hydro mining update • 2020 billabong sediment sampling program • Pit 3 tailings studies update Pit 1 trials update	None minuted	ERA to submit Erratum to Commonwealth and NT ministers, noting the typographical error in 2020 Mine Closure Plan regarding the maximum water level to be maintained in R3D vent shaft.. The vent shaft water level maximum should be -20 mAHD, not -25 mAHD. ERA to provide an estimated date of completion for the contaminated sites report/s. ERA to catch-up with SSB to discuss fine sediment monitoring/observations to be undertaken at CRS. ERA to add CRS water quality results to the Water Quality Reports and present results at future RCCFs.
19-20/11/20	Routine Periodic Inspection	SSB, DITT, NLC	• Pre-2020/21 wet season inspection of Jabiluka site. Progress of rehabilitation and general site condition. Completion of dry season work.	Stakeholders noted the significant growth since the plant out in Stage 13.1A.	ERA to provide evidence that there is a system to ensure all statutory reports are submitted on time, e.g. Evidence of all statutory reporting deadlines entered into SAP.
18/11/20	RSWM Update Meeting #2	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Discussion on progress made to date on the model update and proposed approach to implement an updated groundwater to surface water interaction.	SSB requested during the meeting that maps are produced to visualise the groundwater model exfiltration locations and corresponding input nodes in the surface water model. Request was followed up by email from SSB on 23/10/2020.	ERA had INTERA develop maps using which were presented in follow up RSWM update meeting (2/12/2020) and provided to SSB with supporting documentation (18/12/20).
13/11/20	Casual catch-up	NLC	Non-minuted	Non-minuted	Non-minuted

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9-11/11/20	ARRTC 45	ARRTC members & observers	Ecosystem restoration trials (Stage 13.1 Pit 1) project update. Joint ERA/SSB project list and report. ARRTC report back to whole meeting on Chair's summary and discussion of Committee's views on KKN amendments and project close-outs. Project updates on: • Effects of surface and groundwater egress of mining-related solutes on stream ecological connectivity (WS7F). • Ecohydrology and sensitivity of riparian flora (WS7H) • Radon exhalation from waste rock on the Ranger trial landform (RAD3E). • SSB update on BRUVnet technology for fish surveys. Follow up discussion on groundwater session and outstanding question on surface water session of Water Workshop. KKN close-out WS3G and WS7G. Project close-out: Background COPC in groundwater (WS1A), ASS Conceptual Model (WS1A), natural World Heritage values (CT2A), restoration trajectories development (ESR5B). KKN amendment on LAN2A and LAN2B, and information for future KKN close out on LAN2B. KKN removal of LAN3E and WS8A. SSB's supervision, assessment and monitoring activities. Reports from NLC, DITT, Environment NGO. Post meeting discussions on closeout application for KKN WS7c.	Prof Craig Simmons noted ARRTC had several questions and concerns regarding aspects of the trials and will instigate a process to ensure concerns and ideas are provided to ERA. To minimise resourcing required for reporting, ARRTC agreed that the ERA and SSB reports could be provided on an annual basis at each November meeting, coinciding with the production of ERA's RMCP and SSB's Annual Technical Report. Prof Simmons acknowledged the volume and quality of work undertaken by ERA and SSB in preparing reports and presenting to the Committee. Where possible, ARRTC leads will work with SSB and ERA offline and make recommendations to the Committee to close-out more KKNs in between meetings. ARRTC were interested in a field trip to Ranger in May. ERA advised that workarounds, such as the use of drone footage or virtual tours, might be possible if there are still COVID restrictions around travel.	ERA to populate a matrix of logistical and technical constraints for species proposed for vegetation establishment, based on advice to be provided by ARRTC on which species-specific characteristics should to be listed in the matrix. SSB to coordinate an Ecosystem Restoration workshop before the next ARRTC meeting. ERA to provide Lindsay Hutley for the NESP riparian vegetation sensitivity project: (i) appropriate groundwater solute modelling results, and (ii) selection of exposed locations onsite for assessing field effects of magnesium sulfate on vegetation. ERA to ensure that the re-charge rate in the uncertainty analysis in the ground water model (produced by INTERA) covers the likely extreme wet and extreme dry re-charge scenarios. ERA to provide quantitative evidence that preferential flow paths are not material to the result of the groundwater model. ARRTC to provide feedback on the scope of ERA's Phase 3 surface water modelling work by 20 Nov, noting that the report was uploaded to GovTEAMS during ARRT45 and ERA are rapidly moving to execution. SSB to provide sulfate closure criteria information (including Darren Baldwin reports) to ARRTC. ARRTC to provide feedback on the climate change risk assessment report provided by ERA during ARRTC45. SSB to provide update to ARRTC on how environmental monitoring data collected from other sites in Alligator Rivers Region are assessed. ERA to provide ARRTC with information on next steps associated with assessment of ASS risks on Ranger site. SSB and ERA to convene a workshop on Ecosystem Restoration before the Feb 2021 ARRTC meeting. Dr. Libby Rumpff to collate ARRTC concerns prior to the Ecosystem Restoration workshop.
05/11/20	RSWM Update Meeting #1	ERA (DS, EF), Water Solutions, SSB (AL), Water Technology, IGS	Initial meeting to present and discuss scope for RSWM model update.	Non-minuted	Non-minuted
29/10/20	Casual catch-up	SSB (MS, JL), Rio Tinto	Landform Evolution Model	Non-minuted	Non-minuted

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23/10/20	RCCF	SSB, DISER, DITT, GAC, NLC	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 wet season preparation and CRS works • TSF wall and floor cleaning • Geotechnical investigations in Pit 3 • Pit 1 tailings settlement monitoring • BC upgrade • Pit 3 underdrain bore • Billabong surveys • Sediment monitoring preparations SSB presented on: • Stage 13 sediment movement investigation • Turbidity assessment • Summary of ERA/SSB discussion on emerging contaminants and nutrients KKN close out discussion.	None minuted	ERA to organise TSF wall cleaning inspection for DITT. ERA to reinstate Pit 1 decants by the end of November 2020.
22/10/20	Water & Sediment Workshop	ARRTC members & observers	Intera and Water Solution presentation of solute transport modelling.	Feedback on modelling to date	Ongoing progress of the modelling projects
21/10/20	GW Model – Uncertainty Analysis Meeting #8	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #8 to discuss progress on post closure solute transport modelling with uncertainty analysis. Present preliminary results from uncertainty analysis groundwater modelling.	Non-minuted	Non-minuted
20/10/20	Casual catch-up	Parks Australia	Parks Australia permit discussions, for field preparations including: • Bushtucker (fauna) Billabong sediment sampling	Non-minuted	Non-minuted
19/10/20	Hazard Assessment	SSB	• Emerging contaminants hazard assessment.	None minuted	None minuted
19/10/20	Casual catch-up	SSB, 2rog Consulting	SSB presented on the proposed changes to the approach for assessing turbidity for Ranger minesite closure.	Non-minuted	Non-minuted
19/10/20	Pit 1 Revegetation Discussion (#2)	SSB, NLC	Discussion on the proposed revegetation research trials for Pit 1 – monitoring. Discussion on detail provided, developing monitoring schedules, nutrient and soil monitoring, and possible collaborative monitoring.	Non-minuted	Non-minuted
16/10/20	Pit 3 tailings consolidation	SSB (John Miller)	Pit 3 consolidation.	Non-minuted	Non-minuted

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15/10/20	Routine Periodic Inspection	SSB, DITT, NLC	Crushing circuit, mill and processing area: • Preparation for shutdown • Improvements and initiatives • Scrubber interlock testing • Bulk ammonia storage status • Uranium stack emissions results Incident 01/10/20: Browsing Ant (Lepisiota frauenfeldi) update. Pit 3 CPT progress. Pit 1 water diversion system construction.	Stakeholders noted that if scrubbers and ventilation systems were used during the make safe period, as equipment and ducting are cleaned, there may be the requirement to monitor Uranium stack emissions past the cessation of processing. This should be considered as part of the make safe work program.	ERA to provide hazardous material disposal plan updated to reflect management following cessation of processing.
13/10/20	Pit 1 Revegetation Discussion (#1)	SSB, NLC	Discussion on the proposed revegetation research trials for Pit 1 – set up Discussion on direct seeding methods, water crystals, Bracke planting device, fertilisation and water risks, how results will be used to determine final method.	Non-minuted	Non-minuted
09/10/20	MTC	DITT, SSB	DITT proposed a merger of MMP and MCP and aim to update the Authorisation in Q1 2021. ERA provided updates on: • Environmental incidents and environmental audit • Application updates • Pit 1 and Stage 13 revegetation updates and issues • Browsing ants incidents summary • Pit 1 wet season preparation reporting and the interim Pit 1 release system updates • Pit 3 application planned in December 2020 Members provided summary of acid tank incident inspection on request from ERA. COVID-19 restriction updates.	GAC does not support changing of the Authorisation and wants to wait until the Section 41 Authority of the Atomic Energy Act is amended and a review of the Working Arrangements is completed. SSB is satisfied with incident report, action closed. ERA agreed that that Peter Wilkinson from Noetic would meet with SSB after each oversight visit. MTC members question about the potential for impacts on Georgetown Billabong due to sediment deposition and how the sluice gates shall operate if a trigger-value is met. ERA advised the risk mitigation mechanism. SSB advised that the Pit 3 application will need to specifically address surface water/groundwater interactions work and the integration of the groundwater model and the surface water model. Projects and/or KKNs relevant to the Pit 3 application will need to be closed out by ARRTC prior to SSB endorsing the application.	ERA to send through S29 regarding brown browsing ant. ERA to send indicative information regarding drilling scope of works.
02/10/20	Pit 3 tailings consolidation	SSB (JM)	Non-minuted	Non-minuted	Non-minuted
29/09/20	WASWG	SSB, DPIR, Rio Tinto, NLC	Item discussed: • ARRTC planning Water and sediment studies to inform Pit 3 application.	Kath Smith requested that material be provided to ARRTC 3 weeks ahead of meeting.	Pass on science information to MTC for consideration of approach to closure criteria for nutrients. ERA to provide information to SSB on source for emerging contaminants ERA-SSB work together to complete KKN close-out for emerging contaminants. Chris H to provide information on method for turbidity closure criteria assessment.
21-25/09/20	Authorisation Audit	SSB, DITT, NLC	• Audit of transition to closure	Audit report	Actions tracked through RPI

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18/09/20	Pit 3 tailings consolidation	SSB (JM)	Non-minuted	Non-minuted	Non-minuted
17/09/20	ARRAC 54	ARRAC members & observers	ERA presented an overview of the company's operational performance, health and safety, process safety, environmental performance, water management, progressive rehabilitation and studies and approvals for the reporting period including: • Pit 1 backfill completion • Revegetation status updates on Pit 1 and Stage 13 • Groundwater model studies progressing, background COPC updated • Surface water model results provided to stakeholders • Bushtucker project with flora samples taken and draft report completed • Conceptual mode for ASS completed • Contaminated site drilling program undertaken Approval status updates	None minuted	ERA to provide SSB with updated rehabilitation schedules to be incorporated into future SSB ARRAC reports.
11/09/20	Pit 1 sediment monitoring	SSB, NLC	• Discussion on proposed sediment monitoring at Pit 1.	Non-minuted	Non-minuted
04/09/20	GW Model – Uncertainty Analysis Meeting #7	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #7 to discuss progress on post closure solute transport modelling with uncertainty analysis. Review finalised source terms, discussion on approach for updating groundwater to surface water interaction and discussion on uncertainty analysis progress.	Non-minuted	Non-minuted
04/09/20	Pit 3 tailings consolidation	SSB (JM)	Pit 3 consolidation.	Non-minuted	Non-minuted
26/08/20	Casual catch-up	SSB (AL)	To discuss Pit 1 sump/drainage in preparation for sediment monitoring works.	Non-minuted	Non-minuted
25/08/20	WASWG	SSB, NLC, Rio Tinto, DPIR	Items discussed: • ASS sampling plan • Nutrient update • Closure criteria Pit 3 application relevant projects	Non-minuted	Non-minuted
21/08/20	RCCF	SSB, DPIR, GAC, NLC, DIIS	ERA provided updates on: • Monthly metrics and monitoring • Pit 1 consolidation ongoing monitoring program implementation • TSF Notch • Underdrain bore • ASS conceptual model	None minuted	ERA to communicate program objectives and activities when scoped and approved for Magela Creek Sand Investigation. ERA to provide stakeholders with the North Ramp 2 Report by Coffey and use of the amphibious excavator. ERA to add approvals tracker to future RCCF slide packs. ERA to add a more suitable Pit 1 pore water metric slide for future RCCFs.

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20/08/20	Routine Periodic Inspection	SSB, DITT, NLC	• Revegetation and ecosystem restoration preparation, groundwater monitoring and management and contaminated sites.	Stakeholders discussed the behaviour of surface water infiltration into the new Pit 1 landform and how that water might be monitored and managed. Stakeholders discussed the current status and intended future use of the turbo misters. They are not currently being used. ERA is seeking further information about their performance and approval will be sought before they are operated. Stakeholders discussed whether closure aspects were included in the scope of work for ERM to review of the performance of the GCT2 interception system.	ERA to document their seed collection and management procedures and strategies. ERA to provide the procedures to stakeholders for review. ERA to provide a draft of the integrated management strategy for Pit 1. SSB to organise a meeting time for presentations which were postponed at the August RPI. ERA to add the Pit 3 temporary laydown area to the contaminated sites register. ERA to update stakeholders on how teams at ERA are integrating contaminated site knowledge and data and how data from the contaminated sites assessments are incorporated into the contaminated site register.
13/08/20	Background COPC project	ERA (DS), SSB (AL)	Follow up on the study recommendations and future monitoring requirements identified in Background COPC study.	Non-minuted	Non-minuted
07/08/20	ARRTC mid-term briefing	ARRTC members & observers	SSB provided sediment and sediment contaminant information on U and sulfate. ERA provided updates on regular INTERA/IGS meetings on groundwater uncertainty analysis. Discussion on nutrient assessment and corresponding KKN close-outs. Updates on ecosystem restoration trajectories, world heritage values.	Non-minuted	Non-minuted
31/07/20	GW Model – Uncertainty Analysis Meeting #6	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #6 to discuss progress on post closure solute transport modelling with uncertainty analysis. Review progress on source term data analysis and discussion on uncertainty analysis progress.	Non-minuted	Non-minuted
28/07/20	WASWG	NLC, SSB, DPIR, Rio Tinto, GAC	Presentation on tiered risk assessment approach provided by Chris Humphrey, risk is negligible from nitrate and phosphate and low for ammonia. Discussion of whether numeric closure criteria required or to rule out need for criteria based on risk assessment. SSB provided update on review of U partitioning paper and discussions with ARRTC members on the need for sediment closure criteria.	None minuted	ERA to review SWM report to assess how modelled recessional/below sill level periods align with assumptions used in risk assessment ERA to look into the SWM to explore the assumptions around the biological, chemical and physical processes that underlie the modelled outputs. SSB and ERA to look into knowledge needs/model improvement to assess if Gulungul billabong will act as a sink for nutrients. ERA to send paper on local U Kd values to Andrew Harford. ERA to follow up with BMT for feedback on Mg additional lines of evidence memo. ASAP so issues can be reviewed ahead of the upcoming ARRTC meeting.
24/07/20	Pit 3 tailings consolidation	SSB (JM)	Pit 3 consolidation	Non-minuted	Non-minuted

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23/07/20	Routine Periodic Inspection	SSB, DITT, NLC	Hydrocarbons, and waste management. Water treatment and management.	Stakeholders noted a general improvement in process safety since last month, as COVID-19-related restrictions have eased and allowed issues to be resolved. Stakeholders discussed the potential for recycling materials from onsite. ERA advised that it the radiation clearances required would be prohibitively onerous.	None minuted
17/07/20	RCCF	SSB, DPIR, NLC, DIIS, GAC	ERA provided updates on: • Monthly metrics and monitoring • Seed harvest • ERA closure personnel resourcing • Pit 1 revegetation • World Heritage values SSB provided supporting lines of evidence for the Mg rehabilitation standard.	None minuted	ERA to prepare a plan for stopping the decant pumps in Pit 1 once 95% consolidation has been achieved including the ongoing monitoring program to be implemented and presented to stakeholders in the August RCCF. Send ERA State and Transition Model scope of work to SSB for review. Pit 1 revegetation and ripping trials plan to be finalised and distributed to stakeholders. Present Acid Sulfate Soil Conceptual Model at the August RCCF.
16/07/20	Casual catch-up	Djurrubu Rangers	Discussed bushtucker (fauna) project and Djurrubu Rangers' involvement.	Non-minuted	Non-minuted
10/07/20	Pit 3 tailings consolidation	SSB (JM)	Pit 3 consolidation.	Non-minuted	Non-minuted
26/06/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
25/06/20	GW catch-up	ERA (DS, AN), SSB (AL)	General catch-up on groundwater related on operational reporting and closure studies underway at ERA.	Non-minuted	Non-minuted
25/06/20	KKN Projects	SSB	KKN Projects Close-out timelines	Non-minuted	Non-minuted
19/06/20	GW Model – Uncertainty Analysis Meeting #5	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #5 to discuss progress on post closure solute transport modelling with uncertainty analysis. Review progress on source term data analysis and discuss modifications to HLU extents following review of parameter data.	Non-minuted	Non-minuted
19/06/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
18/06/20	MERRG	SSB	Non-minuted	Non-minuted	Non-minuted
16/06/20	GW catch-up	ERA (DS), SSB (AL)	General catch-up and follow up on ARRTC #44 action 44.4	Non-minuted	Non-minuted
15/06/20	Closure criteria	SSB	Non-minuted	Non-minuted	Non-minuted
12/06/20	Pit 3 tailings consolidation	SSB (JM)	Pit 3 consolidation	Non-minuted	Non-minuted
12/06/20	Casual catch-up	SSB (KT), ERISS (KS)	Non-minuted	Non-minuted	Non-minuted
05/06/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
02/06/20	WASWG	Rio Tinto, SSB, DPIR	Item discussed: • Action tracker Pit 3 application contents agreed	Reiteration that actions to complete closure criteria is the highest priority.	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
29/05/20	Pit 3 tailings consolidation	SSB (JM)	• Pit 3 consolidation	Non-minuted	Non-minuted
29/05/20	RCCF	GAC, NLC, DPIR, SSB	ERA provided updates on: • Monthly metrics and monitoring • Wet season update • Radon exhalation at the TLF • Ranger closure radiological impact assessment update • Surface water model updates • Process water balance: pore water in tailings vs free water above tailings • Closure studies monitoring program PFAS SAQP updates • Stage 13 preliminary vegetation survival Ecosystem Working group	None minuted	Follow up meeting required to discuss pore water versus free water and decide on the best metric to use. ERA to communicate program objectives and activities when scoped and approved. Consider the collection of bone during the fauna sampling project in addition to organs and flesh.
29/05/20	Casual catch-up	SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
26/05/20	ERWG update for individuals that missed previous meeting	ERWG member, Rio Tinto	Preliminary Pit 1 Revegetation Plan	Non-minuted	Follow-up meeting scheduled.
22/05/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
20/05/20	MTC	MTC members	ERA provided updates on: • Applications • Pit 3 commitments • Stage 13 revegetation trial update • Weed control • MCP progress update The committee discussed: • Ranger Authorisation 0108-18 variation • Annual water management plan and groundwater monitoring plan • Tailings removal • Infrastructure maintenance and inspection regime • Radiation team resources • Calciner and Product Packing Stack emission testing Funding issue	The MTC is ok with ERA using the new guidelines provided this is approved by the Ministers. GAC and NLC considers environmental protection of the Alligator Rivers Region a Commonwealth responsibility. DPIR considers funding of the SSB a Commonwealth responsibility.	DPIR to provide draft Authorisation and make available for Stakeholder review with a target of 29 May 2020. DPIR to arrange a forum for discussion on the proposed draft of the authorisation prior to 30th June (~15th June). ERA to provide a plan by July, with ERA arrange a workshop with stakeholders by end of July, to discuss how ERA are going to comply with the Environmental Requirements to remove tailings from TSF and place into Pit 3.
18/05/20	Brine Squeezer [Process Water] post-submission meeting	SSB, GAC, DISER	• Q&A following submission of application.	Concerns for minor technical clarifications re permeate quality, pH, Mn, bunding and pilot trial. Emphasised need to apply bunding for controlled process water during trials as well as during full-scale operation.	ERA to provide data comparison of BS process permeate with WTP brine permeate.
18/05/20	Discussion regarding ERWG	SSB, NLC	The purpose of the ERWG and plans going forward	Non-minuted	Non-minuted

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15/05/20	TLF Monitoring Plan	SSB	TLF Monitoring Plan (MERRG)	Non-minuted	Non-minuted
15/05/20	Pit 3 tailings consolidation	SSB	Pit 3 consolidation	Non-minuted	Non-minuted
15/05/20	Casual catch-up	SSB (KT), ERISS (KS)	Non-minuted	Non-minuted	Non-minuted
14/05/20	Water Management Reporting Structure	ERA (DS, AN, SP, DS), SSB (KT, AL, KT), DITT (MS, RV), NLC, GAC	Meeting to discuss and agree on changes to Water Management reporting and data requirements as Ranger transitions into closure.	"*To address these issues, we ask that ERA provide a table detailing all recommendations and closure considerations identified in the 2018/19 AGWR and include information on whether any associated work or additional monitoring will be undertaken. This table will be useful to help link the 2018/19 AGWR to relevant sections of the 2019/20 Groundwater Monitoring Plan. To avoid these issues in the future, we encourage ERA to consider submitting the Groundwater Monitoring Plan as a stand-alone document, ensuring it more effectively covers both operational and closure matters as required under the Authorisation."* Letter from SSB to DPIR 14/4/20	Proposed change timing of Water Management report submissions to stakeholders to allow findings of reports to be included in management and monitoring plans. Proposed creation of a standalone monitoring plan, Ranger Water Monitoring Strategy, to include both surface water and groundwater monitoring to meet operational and closure requirements.
12-13/05/20	ARRTC 44	ARRTC members & observers	ERA and SSB provided updates on: • Joint project list and report on schedule • RMCP SSB's assessment report and KKN close-outs • SSB's initial conceptual reference ecosystem & development of its Standard and assessment methods • ERA's developments towards agreed conceptual reference ecosystem and closure criteria • ERA report on closure criteria, vulnerability assessment and sulfate mapping • ERA report on ground and surface water modelling • SSB report on its Standards, emerging COPCs, mixtures, CERA2 Stakeholder updates	None minuted	None minuted
11/05/20	ERA faunal study	GAC, NLC	• ERA faunal study and approvals required	Non-minuted	Non-minuted
08/05/20	GW Model – Uncertainty Analysis Meeting #4	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #4 to discuss progress on post closure solute transport modelling with uncertainty analysis. Review of additional parameter data, discussion on uncertainty analysis progress and present initial source term data analysis.	Non-minuted	Non-minuted
08/05/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
05/05/20	WASWG	NLC, Rio Tinto, GAC, DPIR, SSB	Review minutes from last meeting Discuss the ERA-SSB joint project list for ARRTC Upcoming applications	None minuted	Advise of any changes to closure criteria table summarising actions and agreements by 8/4/2020. Review ERA response to water and sediment questions on the TSF floor application, which will be re-submitted mid-May. Chris Brady to discuss priorities for WASWG re Pit 3 application with Sharon Paulka and Keith Tayler and develop table by next meeting.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
05/05/20	ERWG	ERWG members	Pit 1 revegetation trials	Non-minuted	Non-minuted
01/05/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
30/04/20	MERRG	SSB	Regular catch-up	Non-minuted	Non-minuted
30/04/20	Casual catch-up	SSB (AL)	SW Uncertainty analysis	Non-minuted	Non-minuted
24/04/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
23/04/20	Brine Squeezer [Process water] stakeholder update	DPIR, DISER, NLC, ERISS, SSB	Update following risk workshop	None minuted	Planned submission for end of April. Planning for post-submission meeting within two weeks.
20/04/20	MERRG	SSB	Regular catch-up	Non-minuted	Non-minuted
17/04/20	RCCF	SSB, DPIR, GAC	Item discussed: • Rehabilitation standards update for water & sediment and landform • Wet season update • Covid-19 impacts on 2020 dry season projects • Water model update • Pit 3 underdrain bore and brine injection update • Stage 13 revegetation update • GW & SW modelling update Working group update	None minuted	ERA to come back with suggestions on what is the best Fugro survey and/or tailings monitoring program to inform environmental studies and the engineering for Pit 1.
17/04/20	Casual catch-up	SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
16/04/20	GW catch-up	ERA (DS, AN, MD), SSB (AL)	General catch-up on groundwater related operation report and closure studies underway at ERA.	Non-minuted	Non-minuted
16/04/20	North Notch 3 stakeholder meeting	SSB, NLC, DPIR	Post-submission briefing on the North Notch 3 application (submitted to stakeholders 2 weeks earlier)	None minuted	Stakeholders – continued with review of application ERA – no action
10/04/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
08/04/20	Brine Squeezer stakeholder meeting	DPIR, DISER, NLC, ERISS, SSB	Introduce application for Brine Squeezer process water treatment.	No major issues expressed. Reiterated concerned with failure and risk to environment. Interested in outcomes of the planned risk assessment. Suggested an update meeting post-risk assessment.	Continue to progress with risk assessment. Plan an update meeting for stakeholders post risk assessment.
08/04/20	WASWG	NLC, Rio Tinto, SSB, GAC, DPIR	Item discussed: • Closure Criteria • ALARA Project tracking	None minuted	Chris Brady to draft short statement for content that need to be provided to ARRTC. ERA to send out action tracking sheet weekly.
03/04/20	Casual catch-up	SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
27/03/20	GW Model – Uncertainty Analysis Meeting #3	ERA (DS), INTERA, SSB (AL), IGS (GH, TL)	Meeting #3 to discuss progress on post closure solute transport modelling with uncertainty analysis. Discussion on model parameter prior probability density functions.	Non-minuted	Non-minuted

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20/03/20	RCCF	SSB, GAC, DPIR, NLC, DIIS	Item discussed: • SSB presented initial conceptual reference ecosystem and proposed methods for assessing revegetation success • Pit 3 underdrain bore update • Tailings update, including Pit 3deposition plan, progress, geophysical survey, consolidation model sensitivity analysis, Pit 1consolidation model outcome, and result from Q3 2019 tailing characterisation. • Pit 3 process water update • TSF Floor • Groundwater and surface water model updates • Revegetation update for Stage 13 trial and ERA conceptual reference ecosystem Working group updates	None minuted	ERA to provide suggestion to decide the best survey/ monitoring program input into environmental studies for Pit 1.
20/03/20	Casual catch-up	SSB (KT)	• Non-minuted	Non-minuted	Non-minuted
17/03/20	KNPS contract model	Kakadu Native Plants	KNPs presented with new contract model for approval.	None minuted	Greg Williamson to liaise with Peter Christopherson

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13/03/20	MTC	MTC members	• ERA presented incident report and Pit 1 pond incident update. • Discussion for expected 2020 application and progresses towards them. • Pit 3 contaminated waste disposal area investigation progress: Additional monitoring bore has been drilled (P3_05) and increased monitoring frequency of existing bores. • ERA provide updates on Pit 3 underdrain bore and weed control. • ERA provide short update on Pit 3 deposition progress (Fugro geophysical survey), Pit 3 consolidation model sensitivity analysis, Pit 1 independent tailings consolidation modelling, findings from Q3 2019 in-situ tailings characterisation and tailings consolidation modelling. • MCP update. • PFAS risk on RPA and Jabiru Airport contaminated site survey. • Ranger Authorisation 0108 amendment MCP and MMP relationship discussion	SSB agree with the continued use of the Pit 3 waste disposal site providing it is remediated at closure. The committee agreed that there will be increasing commonality between the MMP and the MCP.	ERA to draft a letter re R3D water levels. DPIR to clarify the process for reporting a notifiable breach. ERA to: • Forward on investigation report and additional water management to the RWMP (resubmit update on 16th March). • Review implementation of commitments in the RWMP scheduled for May 2020 MTC. • Finalise TSF deconstruction application by 20th March • Submit North notch 2 application by 20th March. • Provide water quality data on brine squeezer next reporting submission. • Update the progress of the underdrain bore refurbishment by end of March/early April. SSB to undertake Spigelia weed assessment training. ERA to submit Pit 3 deposition plan, Pit 3 OMM, Fugro survey report, NGI report and CPT report by the end of March. ERA to provide current contaminated site register for airport and develop SAQP for PFAS at the airport. DPIR to review the authorisation in consultation with MTC members. ERA to provide update on the audit actions in the next RPI.

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12/03/20	WASWG	SSB, NLC, GAC, DPIR, ERM, BMT	• Updates on ASS conceptual model (ERM) • GW background COPC concentration (ERM) • Aquatic ecosystem vulnerability to magnesium • KKN close out • ALARA overview by ERA • Monitoring needs and plan on aquatic ecosystem	• SSB expect the ASS risks to be addressed in the Pit 3 application. SSB concerned about the water quality in sulfate concentration approaching guideline value of 10 mg/L.	ERA to: • develop road map showing how achievement of primary and secondary environmental requirements can be demonstrated • provide BPT results distribute ecosystem vulnerability to Mg report to stakeholders by end of April • with and without costing scored when water bodies and riparian zones are being considered • distribute ALARA paper to stakeholders by end of March • schedule workshop to redo the vulnerability assessment SSB to discuss ALARA with GAC ERA and SSB to review the plans for ASS monitoring when the ASS model report is available. ERM to include discussion of implications of choosing univariate versus multivariate analysis. SSB to ask GAC for input to monitoring aims (cultural criteria)
11/03/20	Climate change meeting	SSB, Kakadu Parks, GAC, NLC, DPIR	Item discussed: • Mine Closure risk screening • SME model scenarios • Recommendations for risk mitigation	• Non-minuted	Non-minuted
10/03/20	Stakeholder business update	Jabiru Area School personnel	• Present an update on key events relating to ERA's operations. This forum is a good opportunity to raise any questions or concerns you have about ERA's operations and the future of Jabiru.	Non-minuted	Non-minuted
05/03/20	Stakeholder business update	West Arnhem Regional Council personnel	Present an update on key events relating to ERA's operations. This forum is a good opportunity to raise any questions or concerns you have about ERA's operations and the future of Jabiru.	Non-minuted	Non-minuted
05/03/20	Stakeholder business update	Local businesses/organisations	Present an update on key events relating to ERA's operations. This forum is a good opportunity to raise any questions or concerns you have about ERA's operations and the future of Jabiru.	Non-minuted	Non-minuted
04/03/20	Introduction to Kakadu Native Plant Services	Kakadu Native Plants	Jacquie new to the business required intro and update of KNPs	Formalise future presentation on Ranger rehabilitation/revegetation	None minuted
28/02/20	Volunteer drivers for youth program	Red Lily Public Health	Discussed opportunities around ERA volunteer drivers for Youth program	Non-minuted	Non-minuted
27/02/20	Stakeholder business update	Jabiru Health Centre and Red Lily Public Health Program personnel	Present an update on key events relating to ERA's operations. This forum is a good opportunity to raise any questions or concerns you have about ERA's operations and the future of Jabiru.	None minuted	Include photo timeline of Pit 1 at the SBU scheduled in the second half of the year

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21/02/20	Casual catch-up	SSB (KT)	Non-minuted	Non-minuted	Non-minuted
18/02/20	ERA closure and rehabilitation vendor forum	90 suppliers in the NT and wider	Shared information with suppliers of the complexity of rehabilitation activities and seeking their held in solving some of the challenges and bring innovative solutions within a budget and a tight deadline	None minuted	None minuted
12/02/20	Pit 1 GW monitoring workshop	ERA (DS, AN, CN), SSB (AL, KT, CH, RB), IGS (GH)	Meeting to discuss groundwater monitoring aspects for Pit 1 to ensure monitoring meets all objectives.	Any new groundwater bores should align with existing ecosystem vegetation monitoring, unlikely an opportunity to monitor GW/SW interactions from Pit 1 landform, review of pit 1 groundwater monitoring required to ensure monitoring network adequately delineates any plumes, consider how groundwater WQ data could be used to test/validate groundwater model and removal of any existing bores tied to approvals need to go through further regulatory process outside of RWMP/GMP.	None minuted
10/02/20	Safety aspects at the nursery	Kakadu Native Plants	Discussed implementation of safety aspects at the Nursery - monitoring cameras, cyclone action plan, muster point maps, tags for first aid kits and fire extinguishers	None minuted	Provide feedback to Peter regarding the safety aspects discussed at the meeting.
07/02/20	GW Model Uncertainty Analysis Meeting #2	ERA (DS, CN), INTERA, SSB (AL), IGS (GH, TL)	Meeting #2 to discuss progress on post closure solute transport modelling with uncertainty analysis. Discussion on data review and development of prior probability density functions.	Non-minuted	Non-minuted
06/02/20	ERA standard operating procedures	Kakadu Native Plants	Initial meeting to clarify safety documents to be provided to KNPS including implementation of safety equipment at the Nursery	None minuted	Provide list of standard operating procedures, policies and CRM sheets. Organise meeting with ER Supervisor to look at safety equipment.
05/02/20	GW catch-up	ERA (DS, SV, AN), SSB (AL)	General catch-up on groundwater related on operational reporting and closure studies underway at ERA.	Non-minuted	Non-minuted
05/02/20	Business development & safety	Kakadu Native Plants	Brief meeting with KNPs to discuss contracts	None minuted	To ensure procurement team meet with KNPS to discuss contract options
30/01/20	TSF Sub-floor stakeholder engagement	DIIS, NLC/GAC, SSB, DPIR	Provide technical updates re drilling, GW/SW modelling and outcomes of BPT and risk assessment. Confirm format (i.e. notification v application).	Agreed formal application required as linked with TSF deconstruction which is of interest to CWTH. Interested in model assumptions. Difficult to recommend in absence of detail on contamination.	Planned submission in February 2020.

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29/01/20	WASWG	GAC, SSB, DPIR	Vanadium as a COPC with all available data provided by SSB and ERA. Use TLF data to update the SS simulation in SW model. Update and ERM project. SSB projects: • Billabong sediment sampling results were provided and will be assessed by Darren Baldwin. • Billabong sedimentation rates investigated • Cr6+ identified as a possible concern in surface water post closure ion Choice of sediment COPC	ERA commented on how to exclude impacts from disturbance (pig, buffalo etc) from sedimentation measurement methods chosen.	Paul Brown to review Melanie Trenfields's (SSB) speciation modelling work ERA to: • arrange ERM to present work at March WASWG • circulate conceptual models to WASWG group • send through sump and wetland vegetation observational data reports from Kyla Valdron Clark to SSB • provide additional info about bushtucker project to WASWG SSB to: • set up meeting to revisit billabong sediment sampling program. • provide draft/technical memo to ERA to help guide their planning day • provide update on findings at next meeting. • set up formal meeting further discussion send draft review of world heritage values on the RPA to WASWG
29/01/20	Business development in Jabiru	GAC	Discuss opportunity for partnership in business dev officer role	Non-minuted	• Non-minuted
24/01/20	RCCF	SSB, GAC, DPIR, NLC, DIIS	Item discussed: • Contaminated sites and drilling program • Closure drilling program • Groundwater/surface water studies • TSF updates • Rehabilitation and Ecology updates: Conceptual reference ecosystem, completion criteria and Stage 13 revegetation trial. Working group updates	Need to demonstrate Stage 13 irrigation can be supplied onsite and will not be impacted by HDS plant's input into water circle.	SSB and ERA to discuss whether aquatic sediment sampling scope needs to be redefined. Provide WABSI Framework to DPIR.ERA to provide 2org report to SSB. ERA to include DPIR into WASWG and MERRG.
23/01/20	Discuss business development	Trade & Innovation Anne Pearce	• Discuss business development officer role	Non-minuted	Determine NTG's appetite for partnership
22/01/20	GW/SW model interaction meeting	ERA (DS, SP, CN), INTERA, Water Solutions, SSB (AL, KT), Water Technology, IGS	This meeting is to discuss the concerns raised in the letter sent to ERA by SSB on the 18th December, overview of the projects in place to inform the interaction conceptualisation and to agree on a plan forward.	SSB expanded on concerns identified in letter dated 18th December 2019. Discussion around SW model calibration process including lack of downstream calibration due to mine influence and low confidence in GW/SW interaction as not based on observational data.	ERA to undertake study to develop a scientifically sound and robust GW/SW interaction conceptualisation, using site specific data for incorporating post closure GW modelling COPC loads into SW model. ERA to undertake update to SW model to include downstream, miner operational period calibration.

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19/12/19	SW Model Meeting	ERA (DS, CN, SP), SSB (AL, KT, JM)	Discussion on the model calibration methodology and approach for integrating the post closure groundwater loads to the surface water model. Meeting to clarify comments made in letter from SSB to ERA (SP) on 18th Dec 2019 and develop a plan to address.	*The SSB considers that integration between the groundwater and surface water models is critical in providing confidence the model is fit for purpose and capable of accurately predicting contaminant loads into the future. We believe the information provided to date does not provide confidence that the level of integration required has been met at this phase of the modelling, therefore we seek further clarification on the technical details.* Extract from letter to ERA dated 18th December 2019	ERA to organise meeting with all relevant subject matter experts and stakeholders in early 2020 clarify concerns and identify a suitable approach to address concerns. Meeting scheduled for 22/01/20.
13/12/19	North Notch 3 pre-submission stakeholder meeting	NLC, SSB, DPIR	Discussion of environmental risks surrounding further reduction in clay core crest height of TSF	Non-minuted	ERA continued drafting application, taking into account comments provided by stakeholders during the meeting
13/12/19	GW model meeting – Uncertainty Analysis Meeting #1	ERA (DS, CN), INTERA, SSB (AL), IGS (GH, TL)	Initiative meeting for post closure solute transport modelling with uncertainty analysis. Follow up discussion relating to head recovery modelling and closure monitoring bore design.	IGS raised sought clarity around bore calibration weighting, specifics on handling of climate change, and reporting of model uncertainty. IGS provided comments via email which INTERA and ERA will seek to address during modelling works. Follow up questions relating to head recovery modelling regarding recharge through waste rock. Follow up questions to closure monitoring bore design at Pit 1 and Pit 3. SSB/IGS support Pit 1 closure bore design, request that P3_CL_04 relocated closer to Pit 3.	ERA has received comments via email from IGS for consideration during post closure solute transport modelling. Next meeting 07/02/20 ERA/INTERA to update head recovery modelling with additional detail on recharge through waste rock ERA to relocate closure monitoring bore P3_CL_04 closer to pit, NW of P3-4B.
11/12/19	Collaborative field work	ERA (DS, SV), SSB (AL, JFS field team)	Collaborative field work to install 2 shallow monitoring bores. One located in a potential GW seep to the SW of the CCLAA (GCTS-7), the other halfway between CCLAA and seep (GCTS-11). SSB provided auger and obtained all permits/approvals for installation, ERA provided consumables and resourcing to install.	None-required.	None-required.
09/12/19	TSF Sub-floor stakeholder engagement	SSB, NLC (DPIR not available)	Introduce application for TSF Subfloor material management.	Interested in levels of contamination (drilling results).	Plan an update meeting after BPT UTE's finalised and risk assessment completed.
06/12/19	MERRG	ERA (CN, SR, DS), SSB (AL)	Discussed: • Pit 1 Construction monitoring plan – Amie has issued to her team for feedback • Contaminated sites drilling progress – Dave talked through Pit 1 monitoring • Status of monitoring frameworks following Ingrid's workshops – agree to focus on Stage 13 monitoring CCLAA monitoring bore installs planned	Amie and team were happy with the contaminated sites SAQP.	None minuted

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11-13/11/19	ARRTC 43	ARRTC members & observers	Item discussed: • ERA provided operation, rehabilitation updates, groundwater modelling and relevant studies to approvals. • KKN discussion • Joint project list (SSB/ERA) and report on schedule • Progressing SSB's Ecosystem Restoration Standard, metrics and application • Stage 13 revegetation trial • State-Transition modelling update • Water and sediment working group and program update • Other uranium site • Stakeholder updates	SSB note work ahead for ARRTC and the need to be focussed and systematic given the time between now and final rehabilitation is short. The pre-distributed KKN amendments were endorsed by the Committee subject to some minor clarifications and word alterations. The majority of projects were endorsed by the Committee, subject to addressing comments as actions. The Committee recognise that the current SSB and ERA research programs could raise additional questions and there could be a requirement for research from unforeseen eventualities. SSB will look for guidance from ARRTC to finalise SSB Ecosystem Restoration Standard metrics and application.	ERA to provide a summary of research related to the Pit 3 application including learnings from Pit 1 to ARRTC ERA/SSB project description to include intended outcomes and implications, and an indication of resources required. ERA/SSB to improve cross referencing in projects that address multiple KKNs. ERA/SSB to provide summaries of closed projects to ARRTC to detail outcomes and how information will be used. ERA and SSB to consider two additional projects identified by the committee that are required to address KKNs: - (WS2) Identify far field groundwater discharge points - (ESR8) Identify an appropriate fire regime to facilitate the development of a sustainable ecosystem on the rehabilitated landform Paul Brown (ERA) to review Barry Noller's report and provide to ARRTC. A session on monitoring to facilitate adaptive management to be included as an agenda item for the next meeting.
06/11/19	Site visit by DPIR	DPIR	Informal site visit by new DPIR representative, Max Smith, Manager Ranger Closure. Meeting with GM for site introduction. • Visited Processing area, Pit 1, Pit 3, and TSF.	Follow up emails raised concern regarding: TSF leakage detailed in video produced by GAC in 2013. Safe and secure deconstruction and deposition of industrial infrastructure in Pit 3. Requested to spend time with ERA SME's ahead of approvals and authorisations. Request to further understand groundwater and surface water interactions	ERA to co-ordinate sessions for transfer of important information to DPIR representative.
24/10/19	Groundwater meeting	ERA (DS, CN, AN), SSB (AL)	• CCLA EC anomaly in creek to the south. • Glenn Harrington's feedback forwarded to INTERA • Updated conceptual model report send through – SSB to undertake a 'validation' review to check Glenn's comments addressed by INTERA • Glenn to review Brian Barnett's assessment against GW modelling guidelines • Uncertainty analysis has been received by ERA from INTERA. Will be reviewed prior to issue to SSB • General discussion around level of interest in GW – SW interactions and model outcomes. For discussion once SW model report issued TSF solute transport model results in review by ERA, requested further feedback from INTERA. Results will be shared with SSB as updated	Ongoing consultation	ERA and SSB working on plan to auguring in a few shallow monitoring bores south of CCLA (with Andrew Nelson) – target 20/11. Subject to T/O approval (Amie to manage this)

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
21/10/19	MERRG	ERA (CN, IM), SSB (AL)	• Worked through Amie's comments on the Pit 1 Construction monitoring plan • Discussed thoughts on a MERRG metric • Discussed structure of Pit 1 Closure (rehab) phase / TLF monitoring plan • Ingrid discussed expectations for monitoring workshops next week	Ongoing consultation	Chris to finalise construction monitoring plan Chris and Ingrid to finalise structure of Closure phase monitoring plans for Pit 1 and TLF, to issue to stakeholders ahead of workshops
18/10/19	MTC	SSB, LC, GAC, DPIR, DIIS	ERA provided: • General update on general/water/resourcing activities in Ranger • Updates on closure activities including Rehabilitation progress report, tailings dam, Pit 1 and Pit 3 activities, onsite monitoring and rehabilitation, Pit 3 injection/dewatering bore • Provided TLF controlled burn report • Current approval schedule • report on S29 Environmental incident – Exotic species (West Indian Pinkroot) SSB provided updated for ARRTC and Ranger audit. DPIR is conducting a review of Ranger Authorisation. ERA requested to change Annual Groundwater Report and Water Management Plan submission date. • DPIR will review S29 reporting threshold.	Stakeholder agreed to change of submission date for Annual Groundwater Report and Water Management Plan. Stakeholder agreed to establish approval schedule and intermittent submission of completed studies prior to submission.	SSB to discuss modelling turbidity in surface water with ERA. ERA to provide MTC with a compilation of reports summarising the progress of tailings consolidation in Pit 1 and Pit 3. DPIR to complete a review of the approvals process and engage with stakeholders. ERA to send a letter formally requesting this change. ERA to update the schedule of applications and consult with stakeholder regarding assessment timeframes. DPIR to clarify S29 reporting requirements by end of November. ERA to provide the Incident Action Plan and Weed Spread Prevention Plan for the Indian Pinkroot to MTC stakeholders.
17/10/19	Casual catch-up	DPIR (MS)	Non-minuted	Non-minuted	Non-minuted
08/10/19	MERRG	SSB	Discussed draft Pit 1 research and monitoring plan document structure.	Decided to create 2x research and monitoring plans for Pit 1: Construction Phase (using existing draft) and Ecosystem Rehabilitation.	None minuted
01/10/19	WASWG	NLC, SSB, DPIR	Timeline for agreement on closure criteria still needs to be refined based on Application and rehabilitation schedules. ERA provided updates on projects (Mg effects, Acid Sulfate Soils, sediment monitoring and the SW model). Andrew Harford gave an update of SSB projects	General agreement from the group that using the Water Quality Management Framework (WQMF) is a good approach, incorporating the requirements of BPT and ALARA as required.	ERA to forward invite to the October 24 BMT meeting to WASWoG members ERA and SSB to check for historical vanadium data ERA to follow up on suspended sediments in SW modelling Paul Brown to review Melanie Trenfields's (SSB) speciation modelling work ERA to review papers where ALARA has been used outside of radiation field and present at later meeting ERA to forward her Mine Closure Conference paper and presentation to WASWoG members ERA to follow up about arrangements for Mark Taylor's involvement

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
18/09/19	ERA Closure update	Red Lily Health Board	Non-minuted	Continued engagement	Non-minuted
13/09/19	SSB meeting	SSB	• Landform modelling approach by SSB • Particle size distribution (PSD) scope (ERA) MERRG (monitoring evaluation and research review group)	• ERA advised final landform v6.2 is done and won't change unless major issues identified • SSB will issue tech memo on initial Pit 3 catchment modelling and provide feedback to ERA • SSB approved the proposed PSD methodology MERRG: ERA to translate Pit 1 rehab monitoring framework into monitoring plans for Pit 1 and TLF, plus develop a metric to track progress	None minuted
22/08/19	ERA Information Day and mine bus tour	General public	• Free public mine tours to learn about ERA's operations and closure projects.	• Non-minuted	Non-minuted
09/08/19	RCCF	SSB, DPIR, GAC, DIIS, NLC	• ERA provided closure updates for Stockpile Particle Sampling Program and Rehabilitation Studies and Land Trials (cool-burn, root excavation, species establishment program and trials). • SSB reported study result for aquatic organism community in surrounding groundwater environment. • KKN amendments • ERA provided information regarding groundwater modelling configuration, calibration and results. ERA provided closure site operation updates.	SSB recommended the following: • Large landform not to be disturbed by the plant establishment trials • The final concentration in billabong during dry season is contributed by not only evaporation but groundwater contamination input which is not considered in the model. • Closer internal communications with all parties to ensure most efficient outcomes. DPIR require updates regarding Pit 3 drilling progresses.	ERA provide report on Stockpile Particle Sampling Program and cool-burn weed control. Investigate any similarities between the aquatic organism community in groundwater and surface water environment. Further discussion for KKN development. Improve groundwater model to incorporate water quality parameters. Agreement on closer internal communications.
30/07/19	ERWG	NLC, SSB, DPIR, ARRTC	Reiteration of ERWG function and outcomes of meeting to date Update from SSB-ERA meetings regarding reference sites Outcomes from state and transition workshop ERA species establishment program. • 2019/20 planned pant establishment trials	Agreement with pit 1 working as a trial for rehabilitation. SSB acknowledge the need to clarify using full distribution data, Stakeholder agree the applicability of the state and transition model. SSB made suggestions on planned establishment trials and would like to see a manual outlining the purpose and methodology.	In next meeting provide: • Update of selection of reference sites • Update on species list for rehabilitation program Update on Pit 1 trials

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25/07/19	ERA Information Day and mine bus tour	General public	Free public mine tours to learn about ERA's operations and closure projects.	Non-minuted	• Non-minuted
20/06/19	ERA Information Day and mine bus tour	General public	Free public mine tours to learn about ERA's operations and closure projects.	Non-minuted	Non-minuted
03/06/19	Stakeholder business update	Parks Australia	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
24/05/19	MERRG	SSB	Monitoring	Ongoing consultation	None minuted
23/05/19	ERA Information Day and mine bus tour	General public	Free public mine tours to learn about ERA's operations and closure projects.	Non-minuted	Non-minuted
14-15/05/19	ARRTC 42	ARRTC members & observers	• ERA and SSB reported updates on operations and progressive rehabilitation at Ranger. • SSB provided update on SSB's research program and wet season monitoring. • KKN consolidation and amendments (removal). • Updates regarding surface and groundwater COPC guidelines/Standards revisions and mixtures work and CERA2, water quality frameworks, site-wide conceptual model update and calibrated/post-closure groundwater flow models for Ranger Mine, and solute transport model for Pit 3. • Ecosystem restoration updates including ERWG progresses and outcomes, Dixon's summary of rehabilitated/legacy mine-site tour, rehabilitation trajectories workshop and status of revised Ranger Revegetation Strategy. • Activities on other uranium site • CDU's progress report on NESP projects. Stakeholder updates	The Committee noted that the matrix of KKNs and projects is a long list and it is not clear that each KKN has an associated project. The committee has no objections to proceeding with the close-out/removal of few radiation KKNs (RAD3B, RAD3C, RAD4A, RAD4B, RAD4C and RAD6A). The committee queries about the water models' confidence for mixtures prediction. The committee it would be useful to consider likelihood in the context of Ranger revegetation management plan. The committee highlighted key outcomes that the revised strategy would need to achieve that certain assumptions relating to revegetation of the Ranger final landform still need to be substantiated. The committee commented on the role of billabongs as critical habitats for fish or their importance to the TOs and the broader landscape were not mentioned in fish migration studies. The committee mentioned monitoring data interpretation against criteria is worth consideration, and sampling efforts to collect such data would be resource intensive. The committee also noted terrestrial habitat and fauna in the context of the Ranger final landform is not considered.	SSB to work with ARRTC to distil outstanding questions/comments on the RMCP and reconcile with ERA's response previously provided. ERA to respond to outstanding ARRTC questions/comments. SSB to provide a list of all publications (including abstracts) to ARRTC in SSB's report for each meeting. SSB-ERA to provide an update on projects against the KKN project list. ARRTC to review: (i) Secretariat support for future meetings; and (ii) meeting structure to ensure there is sufficient time for consideration of technical and strategic matters in order for the Committee to provide considered advice. ERWG to discuss outcomes of the Review of the Ranger Revegetation Strategy and Supporting Information and provide a summary of the discussion to ARRTC.
09/05/19	Stakeholder business update	Jabiru Health Center	• Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
09/05/19	MERRG	SSB	Monitoring	Ongoing consultation	None minuted
08/05/19	Stakeholder business update	SSB	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted

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02/05/20	ARRAC 51	ARRAC members & observers	ERA provided an update on its operations, including health and safety, environmental performance, water management, closure planning and rehabilitation. SSB provided a strategic overview of SSB's work in stakeholder engagement and the progress of KKNs, mine rehabilitation activities and assessments, monitoring program, supervision activities and external engagement activities undertaken by the SSB. The NT DPIR provided an overview of mining activity in the Alligator Rivers Region. Parks Australia provided update including some background on his role as Assistant Security Kakadu and Strategic Priorities, and an update on the $216 million funding package for Kakadu National Park and the future of Jabiru.	ECNT noted that there is a need to focus on progress on milestones of assessment timelines and provide details. DPIR noted the importance of having confidence in the scaling of rehabilitation efforts, and the need for early understanding of, and resolution of, critical issues. ECNT and DPIR commented on the incident related to radiation clearance of a crane at Ranger Mine. NTEPA expressed an interest in the RMCP and how rehabilitation works progress through to completion.	ERA committed to providing more details outlining the sufficient assurance for rehabilitation milestones.
30/04/19	Stakeholder business update	Jabiru Area School teaching staff	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
29/04/19	MERRG	SSB	Monitoring	Ongoing consultation	None minuted
29/04/19	Stakeholder business update	West Arnhem Regional Council, local businesses/organisatio ns	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
26/03/19	ERWG	ERWG members	Ecosystem similarity	Species composition discussed.	General agreement that more detailed and clearer information from all parties is required.
15/03/19	RCCF	ERM, DPIR, DIIS, GAC NLC, SSB	• Findings and proposed method for updating background COPC in groundwater • General Ranger update and metrics • Pit 3 Subaqueous deposition trial update • HDS update Developing a restoration trajectory for Ranger mine	None minuted	Track seed gathering progress against target with information provided in ERA Revegetation Seed Stock documents presented by P Lu. ERA to present closure schedule sections relating to studies and KKNs.
06/03/19	Presentation to the Darwin Mining Club	Darwin Mining Club	• Presentation about ERA's achievements over 40 years and the importance of Ranger rehabilitation as a significant project	None minuted	None minuted
March 19	Visit by Mirarr Traditional Owners and rangers to the Trial Landform	Traditional Owners and rangers	Non-minuted	Non-minuted	Non-minuted

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11/02/19	ERWG	ERWG members	• Plant available water (PAW) and Pit 1 water balance; Soils and Fauna Revegetation strategy- e.g. single pass establishment or staged.	General consensus around the modelling presented by ERA. The modelling shows that there would be sufficient PAW to support a community similar to the reference with 67% (or less) rock and 4+ m of substrate. However PAW water is likely to be deficient if the substrate is above 72.5% rock. Potential/Planned Future Studies: • Additional WAVES modelling. • Spatial variability of the fine earth fraction. • Sensitivity analysis regarding the rate of weathering. • Potential effects of climate change. General consensus that an “incidentally consolidated horizon” is not a barrier to plant roots and may assist in preventing macro- pores and hence is not considered a concern. Pit 1 monitoring details: General consensus around the broad strategy. Agreement from ERA that they are open to input from group members on the detail of monitoring and research methods. Ranger Ecosystem Restoration Trajectory Project: Ecosystem similarity and novel substrate issue can be discussed by this group in a meeting prior to the project workshop 29-30 April. Discussion was held around novel substrate and that there is as yet no evidence it cannot support a community similar to the reference site.	ERA to provide further information– including longer data set and modelling a dry climate scenario. Form a sub-group to discuss what monitoring should be undertaken for Pit1- Committed to undertaking additional work on particle size distribution on the trial landform.
07/02/19	MTC	MTC members	ERA provided an update on closure activities including: • Ranger closure schedule • Minor project statues • Water inventories • Site water balance – assumption tracking • Activities updates • Brine squeezer for process water • Pit 1 backfill and tailings consolidation • Tailings management • Pit 3.	None minuted	None minuted
18/01/19	RCCF	ERM, DPIR, DIIS, GAC NLC, SSB	• Findings and proposed method for updating background COPC in groundwater • General Ranger update and metrics • Pit 3 Subaqueous deposition trial update • HDS update • Developing a restoration trajectory for Ranger mine • The nursey and closure schedule were discussed	None minuted	Track seed gathering progress against target with information pr ovided in ERA Revegetation Seed Stock documents presented by P Lu. ERA to present closure schedule sections relating to studies and KKNs.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
14/12/18	MTC	MTC members	ERA provided an update on Current closure activities including: • Closure schedule • Minor project status • Pond and process water management • Pit 1 backfill • Tailings management • Mine Closure Plan • Pit 1 final landform application • Pit 1 update • Pit 3 backfill and tailings deposition • ERA provided an update on the subaqueous deposition trail	None minuted	None minuted
13–14/11/18	ARRTC 41	ARRTC members & observers	ERA provided an update on the Mine Closure Plan and the Restoration Operational Plan. The Supervising Scientist provided an overview of SSB's mine closure plan assessment report.	The ARRTC noted/queried: • The timeline regarding assessment of the 2018 MCP. Whether ERA has considered climate change risk.	A standing agenda item be added to review the status of research, supervision and/or monitoring activities being conducted for other uranium sites in the broader Alligator Rivers Region.
11/10/18	RCCF	Rio Tinto, DPIR, DIIS, GAC, NLC, SSB	• General update and metrics • Feasibility study update • FS Demolition and Disposal • Seed harvest, Storage and Nursery update • Water Flowchart • Pit 3 CPT testing update SSB update on current revegetation studies	• None minuted	Track seed gathering progress against target with information provided in ERA Revegetation Seed Stock documents presented by P Lu Pit 1 decant geochemistry report (P Brown) to be uploaded to the Ongoing Ranger Closure Workspace when available Contaminated sites and Pit 3 Tailings deposition plan to be discussed in the feasibility update at next forum Water treatment model to be run for a current water treatment scenario (no additional water treatment) vs a planned water treatment scenario Information to be provided on floating pipeline behaviour and design Floating pipeline diameter to be confirmed and sent to DPIR ERA to use CSIRO CFD modelling, CPT test results and bathymetry to assess and validate trial modelling Revegetation to be the theme for the next forum
13/09/18	AARAC 50	AARAC members	• ERA presented a presentation outlining the contents of the MCP and a closure update • SSB assessment report on the MCP	None minuted	ARRAC to request AARTC for its consideration of the Ranger Mine Closure Plan.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
12/09/18	MTC	MTC members	ERA provided an update on current closure activities including: • Closure critical path • Minor project status • Pond and process water management • Site water balance • HDS plant • OPSIM assumption tracking • Brine management • Pit 1 backfill • Tailings management • Pit 3 bathymetric survey • Pit 3 Backfill and Tailings Deposition Update.	The Mine Closure Plan has been reviewed. SSB have made their Assessment Report publicly available on 11 September 2018. SSB explained the rationale for several of their recently distributed Rehabilitation Standards. DIIS stated that they will follow the process outlined in Annex B of the Authorisation to request comment from NLC/GAC. Version 5 Final landform digital elevation model will be provided to SSB on 21 September 2018. SSB expect long term landform modelling to take a few months. SSB will provide further comment to ERA on the Pit 1 application next week.	None minuted
04/09/18	Ranger Progressive Rehabilitation Monitoring Workshop Meeting	SSB, DPIR, IGS, UQCLMR, NLC, DIIS	• Overview of the Progressive Rehabilitation Schedule. A copy of the rehabilitation schedule and draft execution schedule was provided. • Closure criteria themes and associated monitoring commitments. Current operational monitoring includes water (Pit 1, Pit 3, TSF) and sediment, radiation, flora and fauna, soils and cultural heritage.	Monitoring requirements per theme including groundwater, ecosystem restoration, radiation and landform.	• Run-off monitoring requirements and methods for Pit 1 should be determined ASAP collaboratively by SSB and ERA to fit into the design. • For radiation dose assessment, opportunistic collection and analysis of fruits would be very useful from a stakeholder-assurance perspective. • SSB to distribute notes from meeting – both overall and group findings. ERA to use notes as a basis for developing monitoring programs and is encouraged to work collaboratively with SSB as required.

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24/08/18	RCCF	CSIRO, Rio Tinto, DPIR, DIIS, GAC, NLC, SSB	Topics discussed included: • Nursery • Pit 1 decant geochemistry report • Feasibility • Water treatment model • Sub aqueous discharge trial • Revegetation	None minuted	• Track seed gathering progress against target with information provided in ERA Revegetation Seed Stock documents presented by P Lu • Pit 1 decant geochemistry report (P Brown) to be uploaded to the Ongoing Ranger Closure Workspace when available • Contaminated sites and Pit 3 Tailings deposition plan to be discussed in the feasibility update at next forum • Water treatment model to be run for a current water treatment scenario (no additional water treatment) vs a planned water treatment scenario • Information to be provided on floating pipeline behaviour and design • Floating pipeline diameter to be confirmed and sent to DPIR • ERA to use CSIRO CFD modelling, CPT test results and bathymetry to assess and validate trial modelling • Revegetation to be the theme for the next forum
25/07/18	MTC	MTC members	ERA provided an update on current closure activities including: • Tailings dam activity • Pit 3 backfill and tailings deposition • Closure critical path • Minor projects status • Pond and process water management • Site water volume • OPSIM assumptions tracking • OPSIM do nothing scenario • Volume of brines injected • Pit 1 backfill material placement • Pit 1 settlement monitoring • Pit 1 decant • Tailings transfer	None minuted	• ERA to include future contingencies and mitigations for identified impact resulting from tailings disposal in the Mine Closure Plan and the tailings deposition application. • ERA to provide a schedule of all activities related to Pit 3. • ERA to provide a presentation of the outcomes of the finalised Feasibility Study. • ERA to provide clarification on the calculations for brines volumes. • ERA to provide MTC with a compilation of reports summarising the progress of tailings consolidation in Pit 1 and Pit 3. • ERA to provide MTC with an application for subaqueous tailings deposition in Pit 3, providing the supporting relevant information progressively prior to the finalised application.
13/06/18	MTC	MTC members	• ERA provided an update on current closure activities.	SSB raised their previous concerns from November 2017 and the January Pit 3 Workshop about the need to update tailings properties in the consolidation modelling to reflect segregated tailings. There was discussion between SSB and ERA about SSB's concerns for resourcing, personnel, and timeframes on this issue (and other environmental management areas like revegetation). NLC and GAC also raised these concerns.	• ERA to provide the upper limit of the proposed HDS plants treatment capacity, the capacity of the plant, and the ability to subsequently dispose of the treated water.

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25/05/18	RCCF	Rio Tinto, DIIS, DPIR, SSB	Topics discussed included: • HDS • Magnesium Closure Criteria • Nursery • TSF Eastern Wall Notch • Pit 1 decant geochemistry progress • Surface water model Radiation	None minuted	• HDS plant restart update to be provided at next forum • MI to meet with SSB to discuss HDS approval status, testing and monitoring needs to support notification/proposal prior to restart • Knowledge Management Committee being formed as part of Phase 3 of the water quality framework project should be treated as a MTC Technical Working Group. • MI to send Phase 3 project proposal to MTC members. • MTC to discuss at next meeting. • Align framework of Magnesium Closure Criteria project to cumulative surface water risk assessment. • Create a metric to track seed gathering and storage • MI to load full Paul Brown presentation and relevant references to Ranger Closure SharePoint as way of sharing information on the process water characterisation. • Surface water model technical memo to be sent to stakeholders before 23 March 2018. Model runs pending stakeholder response to memo. K Tayler to send ERA an internal SSB internal report on radiation doses to Aboriginal people from the operation of the Ranger uranium mine. Not for distribution outside of ERA.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
16-17/05/18	ARRTC 40	ARRTC members & observers	• ERA provided an update on its Pit 3 tailings deposition strategy and rehabilitation commitments and schedule. ERA provided a review of its draft closure criteria for flora and fauna, including its justification and rationale for each's outcome and parameter. • ERA presented an overview of the key historical work conducted to date on revegetation trials and other related activities informing the key elements of its revegetation strategy. • ERA provided an update on, and results of, its research project to investigate plant water use at analogue and waste rock sites and whether the waste rock substrate of the Ranger final landform can supply sufficient plant available water to sustain a local native woodland. • ERA updated the ARRTC on: its knowledge related to locations and concentrations of contamination from the decommissioned site; further modelling to improve these predictions; and how the predicted concentrations compare to water quality that has (i) been irrigated on woodland species in the land application areas, and (ii) to which plants at the edge/on bunds of wetland filters, ponds and sumps have been exposed for several decades • SSB provided an update on its key tasks and key assessments for 2018, a summary of its 2017-18 wet season water quality and biological monitoring results, a progress report on its 2017-18 research projects, an update on the status of the Supervising Scientist's Rehabilitation Standards, and an outline of its proposed 2018-19 work program. • SSB provided an update on the KKNs for groundwater, a comparison of current projects against the related KKNs, and research gaps. • SSB provided a briefing on the development of the Supervising Scientist's draft flora Rehabilitation Standard. • SSB provided the results of a historical study on the effect of magnesium sulfate on the germination of 20 plant species native to KNP (Malden, J.S. 1995). • SSB provided a briefing on SSB's Remote Piloted Aircraft System platforms, and short videos	It was noted by DPIR and ARRTC that the proposed substrate for the final landform is of concern when considering achieving 'an environment similar to the adjacent areas' (ER 2.1), though demonstrated growth of trees on the TLF is encouraging. The ARRTC made the following specific comments on the draft closure criteria: 1. For fauna, that these appear to have been considered belatedly, and are inadequate in their current form. For example, the criteria need more information on specific population demography, density and so on 2. For flora, that these are insufficient and need more information on demonstrating sustainability, e.g. reproduction, prescriptive demographic profiles (including age structure of trees for example). 3. There is a lack of consideration to soil microbiology. ERA pointed out there are nutrient cycling criteria and microbiology is implicit in this. ARRTC requested ERA adopt more explicit (clear) language in its strategy report, and better reference and cite throughout the empirical evidence upon which it is based. ERA stated this information would be provided in the RMCP.	ARRTC to consider the consolidated KKNs and provide any comments or advice on same to the Supervising Scientist by end July 2018. ARRTC to provide ERA with a list of reports it wishes to obtain from ERA on past revegetation trials, for the ARRTC restoration sub-group's consideration, in particular of the scientific evidence underlying ERA's revegetation strategy. ARRTC restoration sub-group to work out what additional information and evidence the ARRTC needs and report back to ARRTC. To do this, the sub-group will: • Gather the information it can, and cross-check this with the KKNs, and consider whether any more KKNs (knowledge gaps that must be addressed) should be proposed; • Look at the current project list and cross-check this with the KKNs, and proposed any amendments as necessary; and • Advise on exactly what specific projects ARRTC thinks are required to address key questions and knowledge gaps ARRTC to provide ERA with a list of its concerns with the PAW project. • ERA to provide ARRTC with requested reports related to the project, and ARRTC to provide SSB with its advice on the matter.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
06/04/18	MTC	MTC members	ERA provided an update on the draft mine closure plan and the Pit 3 Tailings Deposition Schedule ERA provided an update on closure activities including: • BC distillate production; • Process water volume balance • Dredged tailings movement • Pit 1 backfill material placement • Pit 1 settlement monitoring • Pit 3 MOL • OPSIM central estimates • Free process water versus total treated water • Closure critical path • Closure schedule with approvals	DIIS discussed key closure document (MCP and Annual Plan of Rehabilitation) status / relationship. 4. The MTC agreed that ERA could continue backfill placement using Grade 1s waste rock material until 6Mt remains to be placed for the final landforms per previous conditions. The placement of the final 6Mt is contingent upon resolution of a number of issues including traditional owner aspirations and the ability to support vegetation.	• ERA to provide as much detail as possible on OPSIM assumptions. • SSB and ERA to organize a workshop to discuss a long-term monitoring plan for revegetation and pit 1. • MTC is to review process water levels in Pit 3 at the end of the 2017/18 wet season. • ERA to present the value ranges associated with inputs and outputs for OPSIM. • ERA to provide definition of post closure monitoring terminology. ERA to provide the new date for the Pit 1 Final Landform application.
16/03/18	RCCF	DIIS, DPIR, SSB, GAC, NLC, JRHC	General update and metrics Feasibility study update Air quality and radiation dose assessment Closure plan update Approvals (status): • Pit 1 Final landform and revegetation plan • Pit 3 Sub-aqueous discharge • TSF Notch east wall • TSF Northern ramp • High Density Sludge (HDS) plant • Brine squeezer Ranger mine Magnesium closure criteria project phase 3 Rehabilitation - Nursery update Status of KKN's • Pit 1 decant geochemistry progress	None Minuted	• HDS plant restart update to be provided at next forum • MI to meet with SSB to discuss HDS approval status, testing and monitoring needs to support notification/proposal prior to restart • Knowledge Management Committee being formed as part of Phase 3 of the water quality framework project should be treated as a MTC Technical Working Group. • MI to send Phase 3 project proposal to MTC members. • Align framework of Magnesium Closure Criteria project to cumulative surface water risk assessment. • Create a metric to track seed gathering and storage • Surface water model technical memo to be sent to stakeholders before 23 March 2018. Model runs pending stakeholder response to memo. • K Tayler to send ERA an internal SSB report on Radiation doses to public completed by ERISS as part of a Cancer study. Not for distribution.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
09/02/18	MTC	MTC members	The closure schedule was presented.	• SSB queried if the Closure Schedule for revegetation would be completed by 2026, referring to presentation at ARRTC showing understorey planting will occur after 2026. • ERA responded that revegetation activities will be occurring post 2026 and terminology used by ERA refers to as "post closure monitoring" includes monitoring, maintenance and revegetation activities. Currently the FS plans for 25 years. • ERA will provide the Post Closure Monitoring activities and schedule in The Feasibility Study, due July 2018. • Integrated water and tailings study commenced Dec 2018, expected to be a 12-month study. With an aim to increase dredge capacity and productivity. SSB requested ERA highlight changes to the closure schedule in future presentations.	• ERA to provide the new date for the Pit 1 Final Landform application. • ERA to update graphs for rehabilitation metrics to show a rolling 12 months. • ERA to present probability curves for OPSIM. • ERA to present the values associated with input and outputs for OPSIM. • ERA to provide definitions of Post Closure Monitoring terminology. • ERA to highlight changes to the Closure Schedule with Approvals.
5-6/12/17	ARRTC 39	ARRTC members & observers	• ERA report and closure update • Landform design • Environmental outcomes • KKNs • Tailings deposition Revegetation	• Importance of information for reducing uncertainty in relation to KKNs • Mechanisms for sharing information with indigenous communities • Potential for pit subsidence post-closure- ERA noted consolidation being monitored in pit 1 and shows conformance with the modelling • Revegetation, including understory – ERA noted learnings from trial landform revegetation and Jabiluka will be applied to Pit 1 and the monitored and adapted as necessary across site. • Deposition method and potential related impacts • Consolidation modelling sensitivities • Magnesium plume and Magela Creek • Groundwater and surface water interactions • Landform impacts • Runoff and erosion from proposed access tracks • Correlation between various closure criteria	• ERA to provide ARRTC with its updated hydrogeological report for Pit 3 for comment • ERA to provide an update on the Pit 3 tailings deposition strategy and relevant reports • ERA to provide backfill cross sections for Pit 1 and Pit 3, which include the nature of layers (rock types) and location of sulphide risks • Regarding water balance, ERA to provide advice on root depths of vegetation from the water extraction profile • ERA to present to ARRTC its state of knowledge in relation to vegetation recruitment • ERA to provide ARRTC with its weed strategy
28/11/17	MTC	MTC members	• ERA presented an update on the status of Ranger rehabilitation and closure activities, including the current closure schedule for major rehabilitation activities.	• SSB reiterated previous advice that closure criteria should be numeric, not a process. SSB would support the use of the process that has been proposed by ERA if it was used to develop specific, numeric closure criteria.	• ERA to include tailings pore water volumes in the process water inventory for future presentations
15/09/17	MTC	MTC members	ERA provided the draft plan on 21/12/2016. SSB provided their initial adequacy review on 7/4/17. DPIR provided a response letter on initial review and NLC and GAC have provided ERA their initial adequacy response on 26/4/17. DPIR provided comments on 31/7/17 and SSB provided their assessment report on this date. NLC/GAC provided further comment on 21/8/17. The next version of the Plan is hoped to be submitted prior to the end of 17.	ERA provided the MMP on 16/3/17. Comments for this plan are due by the extended date of 5/5/17. Additional information was requested 23/5/17 and provided on 23/6/17. This MMP was approved on 23/8/17.	SSB will circulate a draft attachment to the Authorisation for ERA to periodically report on closure metrics.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
14/09/17	ARRAC 48	ARRAC members & observers	ERA report and closure update (including tailings deposition methods)	Queries regarding impact of deposition strategy on closure timeline	ERA to provide an update on the underbed drain and dewatering bore in Pit 3.
16-17/05/17	ARRTC 38	ARRTC members & observers	• ERA report and closure update (including tailings deposition methods) • CCLAA to Gulungul Creek Upper Tributary groundwater plume delineation • GCT2 interception system update • Landform flood modelling to inform sediment/erosion management Revegetation research update and Vegetation understorey trial.	• Concerns presented by GAC about lack of (i) specific KKNs for cover design parameters to ensure successful revegetation, (ii) detail on same in Ranger Closure Plan, and (iii) recent research and monitoring programs to support design criteria. Support from members and stakeholders for proposed sediment and erosion controls and planned understorey trial.	• Minutes of meeting publicly available. Next ARRTC meeting is to focus on these issues.
03-05/09/17	(SSB led) groundwater workshop	SSB (and various consultants to SSB: SA Department of Environment, Water and Natural Resources, Office of Water Science, Geoscience Australia; DJ), GAC, NLC, DPIR, DIIS, INTERA	• Response to stakeholder questions and discussion on the Ranger conceptual model and solute transport (from Pits 1 and 3) models.	• Fractures, faults and subsurface pathways, sensitivity of model; geochemical source term, temporal resolution. • A summary of the workshop was provided to ARRTC 37	• INTERA provided 2.5 days of presentations addressing questions provided in advance and during the meeting. • Conceptual Model report updated with response to major concerns raised. • Additional work scoped to update solute egress modelling to address outstanding concerns. Scope of works provided to stakeholders for input.
10-11/08/17	ARRTC 36	ARRTC members & observers	• ERA report and closure update (including tailings transfer from TSF, Pit 1 active rehabilitation) Ranger conceptual model	• Issues discussed with inputs and sensitivities of conceptual model and geochemical source term.	• SSB convening a groundwater workshop to review Conceptual Model and models of solute transport from the pits.
25/07/17	ERA consultants (BMT WBM) and Closure criteria water and sediment technical working group (TWG)	CCTWG members	• Preliminary findings/data of Mg guideline exceedance review and framework for assessing detrimental impact of such exceedances in terms of Environmental Requirements. • This work is undertaken by Consultants BMT WBM.	Discussion centred around: • The number of water types to be considered • the definition of 'different' in the context of biological attributes • the use of taxa richness as a measure of environmental impact • the definition of detrimental impact level of modelling accuracy	ERA provided a copy of the draft consultant's report to stakeholders for review on 16 August 2017.
16/06/17	MTC	MTC members	• ERA presented an update on closure activities and a level 1 schedule with a critical path. • Progressive rehabilitation metrics were presented. • Update was provided on the Osmoflow brine squeezer.	• MTC requested ERA provide details of the assumptions of the OPSIM model outputs and include key assumptions as rehabilitation metrics.	• SB will circulate a draft attachment to the Authorisation for ERA to periodically report on closure metrics; • ERA will provide quarterly updates on OPSIM trance and include actual process water volumes over time and details of key assumptions; and ERA will include details of key OPSIM assumptions in the rehabilitation metrics.
09-10/05/17	ERA consultants (BMT WBM) and Closure criteria water and sediment TWG	SSB, DPIR, GAC	• Initial consultation on developing a framework for assessing detrimental impact of guideline value exceedances in terms of Environmental Requirements	Non-minuted	• Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
03/05/17	Ranger rehabilitation and closure workshop	DIIS, DPIR, NLC, GAC, SSB, Geoscience Australia	• The DIIS presented a draft preliminary framework for the assessment and approval of rehabilitation implementation at Ranger. • GAC raise additional matters including: the time-limited nature of the existing regulatory framework and the issue of survivability; critical pathway analysis to track works and contingency; assessment timeframe(s) and facilitation of stakeholder participation. • ERA presented on its needs and schedule for decommissioning and rehabilitation, closure strategy for each domain of the RPA and closure objectives. • DPIR presented on the pars of the Mining Management Act relevant to rehabilitation and closure. SSB presented on its role in the rehabilitation and closure process. It is aware of time limitations but must ensure that the ERs are not compromised	Emerging issues were broad ranging, including but not limited to: • DIIS plans for close-out to be a separate process to rehabilitation approvals. • Acknowledgement that the NLC and GAC are consulted throughout the regulatory process via the Minesite Technical Committee. • The NLC questioned the robustness of the consultation process if its views could be disregarded under ER 9.4. The resolution of ambiguities in the interpretation and application of ER 9.2 was marked as a critical issue for follow-up. • Amendments to the draft rehabilitation applications table to include Ranger 3 Deeps, and approvals timeframes. • The level of required technical detail in the separate applications to ensure key elements are adequately addressed. • Establishing synergies between the Mining Management Plan and the Mine Closure Plan, as annual updates to both documents is unsustainable. Decision-making process flowchart needs to include a "stop the clock" mechanism. DPIR would be primary approver of any request during assessments. Intergovernmental processes within the framework need to include a set timeframe.	Issues emerging from this workshop particularly relating to the proposed decision-making process, are subject to ongoing stakeholder discussions. The next workshop is scheduled for 13 September 2017.
20/04/17	ARRAC 47	ARRAC, DPIR, SSB	• Rehabilitation and KKNs	• Groundwater quality and seepage matters were raised • Concern over the future of Jabiru was raised	ERA to provide bore monitoring results
19/04/17	MTC	MTC members	ERA provided an update of progressive rehabilitation for Pit 1, Pit 3, dredging and brines injection.	• SSB requested confirmation that studies for plant available water are being undertaken for assessment for the final land form. • SSB suggested that a clause for ERA to periodically report on closure metrics is to be included in the authorisation.	SSB will circulate a draft attachment to the authorisation for ERA to periodically report on Closure metrics.
10/02/17	MTC	MTC members	The Draft Mine Closure Plan was provided on 21/1/17.	• There was discussion regarding the future approach and how the Mine Closure Plan is expected to change and be reviewed over time.	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
29-30/11/16	ARRTC 37	ARRTC members & observers	• Groundwater drilling program • Surface water model • Closure milestones • Jabiluka revegetation • Trial landform vegetation • Final landform version 5 Closure criteria as presented in the Closure Plan	• ARRTC noted a lot of the concerns it has raised over the years around groundwater were being addressed; and noted the release of the Ranger Conceptual Model and Ranger Groundwater Workshop as major advances forward in this regard. ARRTC noted there may still not be 100 per cent agreement around certain groundwater issues, but believed there is now a clear and manageable way forward to resolving these. ARRTC commended the work of INTERA on the Ranger Conceptual Model (groundwater). ARRTC sought clarification on the relationship between the SSB's Rehabilitation Standards and ERA's closure criteria. SSB explained that the Rehabilitation Standards represent the Supervising Scientist's view of what is required to achieve the environmental objectives detailed in the Ranger Environmental Requirements. They represent advice and are not mandatory. In contrast, it is ERA's responsibility to propose closure criteria for the rehabilitation, which, once approved by the relevant Minister, become mandatory. ERA may or may not elect to align its closure criteria with the SSB's Rehabilitation Standards. The relevant Minister will make a decision on whether the closure criteria are approved and, as part of this, will consider the advice of the Supervising Scientist	Minutes of meeting publicly available. ERA committed to provide ARRTC with a copy of the draft Closure Plan, which includes closure criteria (Chapter 6), once all feedback was addressed, and invite comments from members. Future work committed to by ERA: • Additional work to update groundwater models. Surface water modelling to be undertaken by external experts.
18/11/16	MTC	MTC members	• Report from Mine Closure working group presented.	• None minuted	• None minuted
11/11/16	CCWG meeting 8 2016	CCWG members	All closure criteria.	• Landform: SSB requested validation process for modelling, suspended sediment criteria will only be possible to monitor following the completion of active management as ERA will be actively trapping sediments (therefore turbidity is not a true reflection of erosion). ERA disagreed. • Water and sediment: Discussion over the use of decision trees to demonstrate that objectives are met. Fauna and flora: weed criteria wording to be modified. Further work required regarding fauna criteria. SSB is not satisfied with the current wording of ground cover criteria.	Each organisation to send interpretation of ER 1.1(d) and 1.2(d) to DIIS along with any other ER where there is a material difference of interpretation. Email overview of the ERA closure risk assessment to CCWG. ERA to discuss radiation criteria with SSB and finalise.
28/10/16	CCWG meeting 7 2016	CCWG members	Update on development of closure criteria all themes.	• Cultural criteria: All the cultural health index criteria have been updated to match that proposed by GAC, the visual connection criteria has been added and a criterion on plant available water has been included in the flora and fauna table. • Water criteria: have been modified to include decision trees. The criteria for 'on the Ranger Project Area' have also changed to that requested by SSB in the Sept 30 meeting to be an 'As Low as Reasonably Achievable' (ALARA) assessment. Finally, wildlife drinking water criteria have been removed following a risk assessment process that has been presented in the closure plan.	ERA to meet with GAC and NLC to review criteria proposed by GAC.

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13/10/16	CCWG meeting 6 2016	CCWG members	• Interpretation of ER 1.1(d) and 1.2d. • Update on development of flora and fauna criteria. • Update on development of landform criteria. Interpretation of ER 1.1(d) and 1.2 (d) is ongoing regarding the definition of detrimental impact.	• Interpretation of ER 1.1(d) and 1.2d: Each organisation to send interpretation of ER 1.1(d) and 1.2d to DIIS along with any other ER where there is a material difference of interpretation. • Update on development of landform criteria: generally accepted by all present	Two new cultural criteria added. These relate to plant/water holding capacity and soil edaphic features.
30/09/16	CCWG meeting 5 2016	CCWG members	• Uncertainty in construction of the landform • Update on water and sediment closure criteria – health, ecosystem protection on and off the RPA, wildlife drinking water. • Update on cultural closure criteria	• Uncertainty in construction of the landform: uncertainty in the landform construction is approximately 1-2 metres. This uncertainty relates to the swell factor that will occur during reclamation and placement of waste rock. Uncertainty may require small changes to topography that will be made in areas that will not impact on the drainage or erosion characteristics. • Update on water and sediment closure criteria: o Health – accepted as a good framework for progression. Noted that some metals are already higher than tolerable intake levels via natural processes o ecosystem protection off the RPA – confusion existed over the interpretation of the outcome. Disagreement between SSB and ERA as to the location where the highest level of protection is applied, the confluence of Magela and Gulungul Creeks or the section of Gulungul Creek between the Gulungul Creek lease boundary and the confluence. o Ecosystem protection on the RPA - Disagreement between SSB and ERA reading the application of ALARA to species protection on the RPA • wildlife drinking water- discussion regarding the purpose for the criteria on wildlife drinking water.	All to review proposed cultural criteria and provide comments back to GAC

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15/09/16	CCWG meeting 4 2016	CCWG members	• Closure plan progress update and content review • Best Practicable Technology (BPT) overview • Criteria for each theme • Groundwater abstraction restrictions	Criteria: general discussion on each criterion • Radiation - Clarification needed on screening levels vs final value for assessment; SSB to finalise. • Landform – what is the acceptable level of error for landform execution, centimetres or metres? ERA to clarify. • Water and sediment – discussion around the wording and effects to wildlife from sumps. SSB request that there is no detrimental affect however ERA state that this is not possible. • Flora and fauna: further work required on the impact of fire. • Soils: noted that soils criteria only apply to contaminated soils. Nutrient cycling and other soil properties pertaining to the development of a sustainable ecosystem are included in flora and fauna criteria o Cultural criteria: GAC to review and provide comments.	• ERA to discuss radiation closure criteria with SSB and finalise • ERA to clarify the uncertainty in landform construction that is likely and place this into the landform CC • ERA to present on the status of water and sediment closure criteria at the next meeting. ERA to present on the status of Flora and Fauna closure criteria at the next meeting.
08/09/16	ARRAC 46	ARRAC members & observers	• ERA presented an overview of closure planning and stages.	• The drivers of rehabilitation relate to the things that are protected in the Alligator Rivers Region. Surface water is the main pathway of contamination so a set of water quality limits have been established to denote levels of contaminants that are considered acceptable. Considerable additional work is also occurring on predicting the effects of the rehabilitated landform on the surrounding environment. Groundwater is the main pathway in the situation and modelling have been focusing on Pit tailings and peak solute loads. The models apply for ten thousand years but become quite coarse the further out you go, so more detailed modelling is current ion development to show how ground and surface water will interact. Closure criteria describe a target. More challenging ids describing the pathway to that target, how the landform will perform and the implications for vegetation etc. SSB's entire focus is now on these matters.	• None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
01/09/16	CCWG meeting 3 2016	CCWG members	• Closure risk assessment presentation • Closure strategy and schedule • Objectives and outcomes all closure themes Reporting of closure activities	• Closure Risk Assessment Presentation: high risks (Class 3) highlighted. Some risks required further studies as the controls are ranked as less effective. • Closure strategy and schedule: general discussion regarding the extent that the closure plan covers all closure applications and approvals. Issue to be raised with MTC. • Objectives and outcomes all closure themes: Objectives for each theme were discussed. ○ To avoid duplication, tailings outcomes are to be reviewed for incorporation into other outcomes. ○ Flora and fauna outcomes have been changed to align to the ER objective ○ Soils are to follow the general NEPM process ○ Outcomes for the cultural criteria have been taken from the Murray Garde report and cultural health indices. Cultural criteria will be a subjective, not objective measure. Reporting of closure activities: ERA to provide regular update on closure progress, with parameters, to the MTC.	• Findings from the closure feasibility study scheduled to commence in September 2017, will be incorporated into future iterations of the Ranger Mine Closure Plan. The Ranger Mine Closure Plan, provides a table of additional closure applications and approvals appended to Chapter 1. Chapter 6, provides the most up-to-date view based on current knowledge, studies and stakeholder feedback.
09/09/16	MTC	MTC members	• Report from Mine Closure working group presented.	• Supervising scientist is drafting Rehabilitation Standard for Ranger. SS is also drafting an associated Communication Strategy. • There was discussion of the roles of SS and other stakeholders regarding the final approval for closure by the Australian Government under the *Atomic Energy Act 1953* (Cth). There was also discussion on the process to review future closure plans and site relinquishment.	• It was proposed to rename the overarching Closure Criteria Working Group. This will require a change in the terms of Reference of the working group. GAC to consider the issue further and report back.
19/08/16	CCWG meeting 2 2016	CCWG members	• Closure plan review and update • Update on progress of criteria development SSB rehabilitation standard	• Closure plan: outline of plan presented with a matrix of closure milestones. ERA seeking endorsement of the steps listed in the milestone matrix. General discussion around the feasibility study, scheduled to commence 2017. • Closure Criteria development: Most TWGs are progressing well. • SSB rehabilitation standards: Draft of SSB rehabilitation standards are being progressed, due in September 2016.	• Closure plan: The closure feasibility study is scheduled to commence September 2017. Findings of the feasibility study to be incorporated into later iterations of the closure plan. • Closure criteria development: The Ranger Mine Closure Plan, Chapter 6, provides the most up-to-date view based on current knowledge, studies and stakeholder feedback. SSB rehabilitation standards: Draft rehabilitation standards for radiation dose (humans), radiation dose (environment), magnesium, uranium and manganese surface water were issued to stakeholders for initial feedback on 1 August 2017.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
05/08/16	Flora and fauna TWG	FFTGW members	• Discussion on the flora and fauna closure criteria, particularly species composition, canopy architecture, tree distribution, weed composition and abundance, and fauna	• Species composition: Requires further discussion with run further scenarios given *Eucalyptus miniata* does not have a high success rate on TLF but *Corymbia foelschiana* fills the niche. • Canopy architecture: Needs to include a canopy cover and ground cover index within the range of the natural analogue sites. Dependent on the water retention in the soils. • Weeds: Needs to include introduced species not just declared spp. For example, annual *Pennisetum sp.* and red natal *Melinis repens* are both major issues on the RPA, but neither are declared species. • Fauna: Presence/absence is not strong enough. TWG must be able to established measurements.	• These emerging issues are addressed in the Ranger Mine Closure Plan, Chapter 6, Section 6.5.
26/06/16	Closure criteria water and sediment TWG meeting 2016-02	CCTWG members	• Magnesium field effects data to set closure criteria • Guideline values for drinking water, wildlife, recreation and livestock Science supporting local toxicity guideline values	• Magnesium field effects data to set closure criteria: SSB have not yet delivered their SSB Mg field effects paper. • Guideline values for drinking water, wildlife, recreation and livestock: All guideline values are compared against all water types. Suggestions put forth to improve the closure plan in regards to water. • Science supporting local toxicity guideline values: SSB to supply information on ecotoxicology guideline values and confidence intervals from the species sensitivity distribution curves and assess what information can be supplied on the confidence in field threshold effects GV	Emerging issues continue to be addressed in iterations of the Ranger Mine Closure Plan. The Ranger Mine Closure Plan, Chapter 6, Section 6.4 provides the most up-to-date view based on current knowledge, studies and stakeholder feedback.
06/06/16	Closure criteria water and sediment TWG meeting 2016-01	CCTWG members	• Develop a report for each COPC for which closure criteria are being recommended. • Relevance of KKNs to closure criteria. • Potential generation of acid sulfate sediments and subsequent environmental consequences • Nutrients from tailings/ process water (NH_3) and explosive residues in waste rock (NO_3). • Herbicides, hydrocarbons and other metals.	• Magnesium in surface waters: Discussion on use of field and laboratory tests to derive a guideline value for ecosystem protection for magnesium in surface waters. SSB to provide a report of science underpinning Mg closure criterion. • Uranium in surface waters: Discussion on appropriate U limit for surface waters taking into account the binding nature of dissolved organic carbon and expectations of traditional owners. SSB to provide report on science underpinning proposed uranium closure criterion. • Total Ammonia Nitrogen: Discussion on need for closure criterion for TAN given its high variability in nature. SSD to provide finalised paper to TWG. • Turbidity: Discussion on the use of drinking water guidelines to devise a limit for turbidity. • Stakeholders also provided comment on nutrients from tailings and metals	Emerging issues continue to be addressed in iterations of the Ranger Mine Closure Plan. The Ranger Mine Closure Plan, Chapter 6, Section 6.4 provides the most up-to-date view based on current knowledge, studies and stakeholder feedback. • Nutrients from tailings: ERA to assess and report on eutrophication risks from mine derived nutrients and suitable criteria/guidelines for preventing eutrophication if required. Metals: ERA to calculate and report on predicted metal concentrations transported to surface waters from tailings and process water in closed pits.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
27/05/16	MTC	MTC members	• An update on the Closure criteria Development Process was presented.	• None minuted	• ERA to schedule a Mine Closure Criteria working group. • ERA to assemble a schedule of expected notifications and applications for closure activities.
24/05/16	Landform TWG meeting	CCTWG members	Development of suspended sediment parameters.	No minutes available	• No minutes available
06/05/16	Flora and fauna TWG closure criteria workshop	CCTWG members	• Reporting on revegetation species list • Use of dissimilarity matrix to assess revegetation's similarly to analogue sites. • Presentation and discussion on draft closure criteria. • Reports on trajectory work. Discussion on closure criteria for fauna.	No minutes available	No minutes available
28/04/16	ARRAC 45	ARRAC, SSB, NTDME	• Closure criteria	None minuted	None minuted
08/04/16	MTC	MTC members	• Report from Mine Closure working group presented. ERA provided an updated on the Closure Criteria Development process.	SS requested that ERA ensure the closure and operational activities are closely aligned. ERA noted.	None minuted
04/03/16	CCWG meeting 1 2016	CCWG members	• Proposed changes to closure criteria objectives. • Update on progress of closure criteria development.	Cultural criteria: discussion held about the proposed cultural criteria and appropriateness as a measure of final close out. Consensus could not be reached. Flora and Fauna criteria: GAC requested the inclusion of edaphic criteria as an indicator of successful rehabilitation. Flora and fauna group to consider edaphic criteria. SSB noted that the weeds criteria needed simplification Guidance and focus for TWGs: SSB asked for TWGs to focus on the purpose of the technical groups as: • Set the end state or target for the objective • Develop the monitoring program or measurement method • Develop the method to reach the end state Expectations on closure criteria: SSB notified the group that they are firming up their position on what it expects for closure criteria.	ERA to update Landform, Flora and Fauna and Radiation objectives and report back to technical groups. ERA to check with ERISS to determine what depth should apply to radiation criteria and update parameter description. ERA to consult with GAC on the draft cultural health indices to determine how they would like them applied and request that Murray Garde be allowed to present on the proposed program. ERA to request that the flora and fauna group consider edaphic criteria.
23/02/16	Landform TWG workshop	Landform TWG members	• Setting allowable gully size for the various erosion zones. • Setting criteria for other parameters. • Review of landform evolution modelling results to identify areas of potential erosion and agreement on the erosion zones for monitoring and criteria setting.	Agreement could not be reached regarding allowable gully size. Two options were debated: • Some gully erosion is acceptable. Use modelling to determine gully formation location and size and then this would be the basis for the criteria and monitoring program; or No gully erosion is acceptable.	None minuted
12/02/16	MTC	MTC members	No meetings of the Mine Closure working group had been held. A flora and fauna closure had been held. • A radiation landform closure criteria working group meeting was held.	• None minuted	Closure criteria working group meeting scheduled for March 2016.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
11/12/15	Landform TWG meeting	Landform TWG members	• ERA presentation on current proposed landform and general closure planning • ERA overview of proposed landform criteria • Discussion on the proposed measurement endpoints (outcomes or targets) • Discussion of parameters of relevance to targets Agreement on actions to progress	General agreement that landform objectives were appropriate. Objective 1: Maintain a stable landform that will not expose tailings through erosion processes for at least 10000 years Outcomes identified to address Objective 1: • Gully erosion: Landform Evolution Model to be used to identify locations of potential gully erosion and a monitoring program then developed for these areas. • Land Slip: Agreement that risk is low due to flat terrain however a risk assessment will be undertaken and a monitoring program developed. • Movement of Magela creek impacting toe of landform: this may cause mass movement therefore it was incorporated into the risk assessment for land slip. Objective 2: Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved do not vary significantly from comparable landforms in surrounding undisturbed areas Outcomes identified to address Objective 2: • Sediment loads: Post-mining suspended sediment loads will temporally and spatially decrease to match background rates of the surrounding areas • Bedload: Sediment or sand does not cause the accelerated infilling of billabongs with sand and silt Denudation: Erosion/denudation rate is comparable to background erosion rates in 10,000 years.	None minuted
30/11/15	CCWG meeting 3 2015	CCWG members	• Overview of landform v5. • Discussion around CCWG setting the closure criteria objectives.	• None minuted	• Species list needs to be agreed • Review and endorse analogue work subject to timeframe • Agreed to use analogue approach with variability shown by Renee work • Identify the likely vegetation communities on site (3?) • Structure, function, resilience - measurement parameters, then numerical values • Weeds in KNP and ferals • Fauna criteria Preliminary work on trajectories for next meeting
30/11/15	Flora and fauna TWG closure criteria workshop	Flora and fauna TWG members	• ERA presentation on the status of current closure planning. • ERA presentation on ecosystem re-establishment and species list. • Discussion on proposed measurement endpoints. • Identification of future actions to obtain agreement on measurement endpoints.	None minuted	• None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
23-25/11/15	ARRTC 35	ARRTC members & observers	• INTERA update on groundwater modelling and response to the perceived knowledge gaps in groundwater research. • Outline of the current closure schedule. • Development of cultural health indices criteria • Ranger post closure land use statement • Coonjimba Billabong ASS risk assessment 2015 sampling • analysis of U concentration in LAAs • collation and description of water quality • re-vegetation monitoring. • Summary of the KKN requirements for the critical and high risks for the ecological risk assessment.	• INTERA update: SSB agreed to consider making surface flow and water quality data sets available to INTERA subject to a formal request from ERA. • Magela Creek: Addressed by INTERA in the site wide model due for completion in early 2016. It was also noted that INTERA have reported that sensitivity studies indicate that the current model is insensitive to changes in the hydraulic conductivity of the Magela sand bed. Ongoing from ARRTC 32. • Seismic events: Minutes from FEPS workshop indicated there had been a discussion which had led to agreement that seismic events were not an issue for Ranger rehabilitation. • ARRTC suggested work should be done to quantify the risk based on historical records and given the mine is sitting on the edge of a regional fault zone and seismic activities have potential to influence overland and sub-surface flows; then note that seismic events cannot be mitigated. ERISS advised that the conceptual models for the risk assessment had captured seismic events.	• Seismic Events: ERA noted that the issue of seismic events was assessed as "low" in the context of the disposal of tailings in Pit 3. Tailings were being buried in a pit, and an assessment had identified this as best practice and the Ranger Authorisation had been updated to require this. The landform will be built to the required standards; ERA queried the justification for doing additional work to quantify the risk of an earthquake when there are no additional mitigations that can be adopted to protect against such an event. ERA advised that a 1997 study had looked at extreme events in the ARR. The relevant section of the report would be provided to ARRTC members. Ongoing.
13/11/15	MTC	MTC members	• No meetings of the Mine Closure working group had been held.	• Supervising scientist requests that ERA reconvene working groups with more project management, resources and personnel assigned. • There was discussion on the process of producing closure criteria and the requirement of working groups and closure criteria. One day workshops are proposed for each working group prior to closure.	• Two workshops are proposed prior to the end of December 2015.
10/09/15	MTC	MTC members	Report from Mine Closure working group presented.	• None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
09/09/15	ARRAC 44	ARRAC members & observers	Overview of $400 M spent on rehabilitation to date, including: • Installation and commissioning of the brine concentrator. • Outline of the $30 M rehabilitation spend forecasted for 2015. • Transfer line for tailings from the mill to Pit 3. • Pumping system for dewatering of Pit 3. • Progress on the Pit 1 capping – the majority of the pit has a lateritic cover, remainder of capping within the next two months; bulk backfill and subsequent revegetation will commence in 2017, pending approvals. • Completion of civil works in Pit 3 to allow the pit to receive tailings and process water, including the installation of a horizontal bore that will be used to extract seepage and the installation of reinjection bores for storage of process water brines. • Impending commissioning of brine injection bores. Launch of tailings dam dredge; now in the commissioning phase. These accomplishments collectively form the last steps towards implementation of the ITWC management processes that will be required for mine closure. The dredge is estimated to move 5-6 Mt of tailings each year to 2020, which will enable final consolidation of material in Pit 3 prior to closure and rehabilitation.	Minutes not available	Minutes not available
12/08/15	CCWG meeting 2 2015	CCWG members	• Discussion on ERA proposed closure criteria.	None minuted	None minuted
17/07/15	CCWG meeting 1 2015	CCWG members	Update on plan to progress closure criteria.	• Tier 2 project: SSB announced it will be setting up a Tier 2 project on Ranger Closure. Tier 2 is a mid-level project that requires regular reporting to the Executive Board. SSD will be getting a resource to establish this project. It will be requiring regular updates from ERA on the progress of closure criteria development. • New purpose for TWGs: Agreement that the TWGs would now be used for the review of tabled criteria. Coonjimba billabong: KT noted that SS has some questions about the fate of Coonjimba billabong. It has been historically subjected to sedimentation during construction and is now a lot shallower than pre-mining and there are notable acid events. The question was asked if GAC could provide feedback as to what would be an acceptable state for this billabong on closure.	Prepare SOW for TWG and circulate before next CCWG meeting Obtain clarification from SS of the questions to be asked regarding the billabong then organise appropriate consultation with the Mirarr (through Murray Guard if needed)
10/07/15	MTC	MTC members	Report from Mine Closure working group presented.	• None minuted	None minuted
22/05/15	MTC	MTC members	Report from Mine Closure working group presented.	None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
18-20/05/15	ARRTC 34	ARRTC members & observers	• ITCW closure roadmap including information on 8 closure strategies and 4 main options. • Update on the installation of the wicks in Pit 1 and preloading. • Update on the arrival of the tailings dredge. • Pit 3 rehabilitation and the construction of the underfill. • Progress of the tailings and brine management project and various strategies. • Outcomes based on 113 years of climate data on soil water deficit and plant available water. • Closure/rehabilitation related knowledge requirements and outline of the current closure schedule. Outcomes of the environmental risk assessment.	• Regional groundwater: Supervising Scientist and ERA to ensure the regional groundwater context is explicitly addressed and considered as part of proposed review of KKNs next meeting • Magela Creek subsurface profile: Supervising Scientist and ERA to keep ARRTC informed on identification of appropriate methodologies to investigate subsurface profile of Magela Creek sand channels and assess potential for solute migration. Seismic events.	• Regional groundwater: Completed. • Magela Creek subsurface profile: ERA advised the report is still in draft but the recommendations had been considered as part of recent sediment work. Report to be circulated once finalised. Ongoing. Seismic events: ERA to provide ARRTC with the basis on which seismic events were excluded from the risk assessment process. See response under ARRTC 35.
21/04/15	ARRAC 43	ARRAC members & observers	• Pit 1 closure works, including rock preload and laterite capping, prior to bulk backfill, landform shaping and rehabilitation. • Pit 3 closure preparation works, including backfilling and related civil works to enable tailings deposition.	• GAC sought 'stronger' reassurance from ERA regarding the security of future funding for rehabilitation of Ranger.	• Since 2012, ERA has invested over $425 m in rehabilitation and water management projects, to meet statutory mine closure requirements and stakeholder expectations.
10/04/15	MTC	MTC members	• Report from Mine Closure working group presented.	Discussion was on the objectives and priorities of various closure criteria.	None minuted
13/02/15	MTC	MTC members	Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	None minuted	ERA to provide DME with further information on mine closure criteria working group
10/12/14	Closure criteria water and sediment TWG meeting 2014-05	CCTWG members	• Discussion paper on detrimental impact. • Update on diet review • Update on cultural values and criteria. • Discussion paper on the recommended closure criteria for Objective 3 for water and sediment theme. Drinking water, recreation and wildlife drinking water criteria.	• Detrimental Impact: presentation by SSB on the term 'detrimental impact'. SSB position is that any change detected in the biological program is a detrimental change. To be applied outside of the RPA. All TWG members to review paper. • Discussion paper – closure criteria for water and sediment theme: Discussion paper supplemented with a presentation on turbidity criteria. Discussion revolved around monitoring frequency. Frequency will be informed by modelling predictions. • Turbidity pH and sedimentation in Coonjimba Billabong	• Detrimental Impact: Definition is currently being addressed by consultants BWT WBM. • Turbidity criteria to be developed for sediment load and turbidity in the water column in billabongs and creeks. • ERA and SSB to compile information on Coonjimba Billabong water quality. MI to follow up with Murray to prioritise sharing updated diet information earlier than report finalisation.
07/11/14	MTC	MTC members	• Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented. Murray Garde has completed consultation with Mirarr and will submit a report in December 2014. Flora and fauna technical working group to commence prior to 2015.	• None minuted	• None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
04-06/11/14	ARRTC 33	ARRTC members & observers	Updates on the following ERA and collaborative closure studies: • Overview of CCWG recent work and outputs. • Status of groundwater solute transport modelling indicating negligible flow going through the deep bedrock system, suggesting no need for concern that linear faults with enhance transport of solutes. • 5th year of erosion and chemistry studies on the trial landform confirming rapid decline in material leaving the site post construction. • Revised direction and work plan for aquatic ecosystem establishment. Outline of the key 14 steps associated with Ranger's revegetation strategy, and the learnings and risks associated with each of the 14 steps.	None minuted	None minuted
03/11/14	Closure criteria water and sediment TWG meeting 2014-04	CCTWG members	Technical presentations including: • Review of operational water quality monitoring parameters, method and trigger values. • Parameter review, predicted metal loads from Pit 3. • Annual additional load limits (AALL) and dietary intake review for metals. • Sediment baseline review. • Water quality closure criteria. • Toxicity and guideline values for U in billabong sediments. • Toxicity of NH_3 in local freshwater biota.	Additional Annual Load Limits (AALL) and dietary intake review for metals: • All agreed that the 1985 approach for diet assessment and AALL for metals and radionuclides is no longer appropriate • Concentration criteria appear to be more restrictive than AALL except for manganese. Supervising Scientist agreed to remove or review the diet based AALL in the Authorisation. • Query raised as to whether the background diet for the BRUCE database is not influenced by mining in last 30 years. Evidence required that this is the case. • Toxicity and guideline values for uranium in billabong sediments. Discussion paper to be produced describing the data and providing recommendation on approach and value to adopt for interim closure criteria.	None minuted
17/10/14	CCWG meeting 2 2014	CCWG members	• TWG updated on landform. • Water and sediment TWG update.	Landform TWG proposed to separate two distinct phases in landform objectives into two criteria, landform design based criteria and landform monitoring based criteria.	None minuted
12/09/14	MTC	MTC members	• Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	None minuted	None minuted
09/09/14	ARRAC 42	ARRAC members & observers	Closure planning update: • Pit 3 initial backfill is nearing completion: 8.3 Mt of waste material moved during the first half of 2014 taking the total to 31.1 Mt at end of June 2014. • Tailings management work progressing on schedule and budget. Brine concentrator meeting water quality specifications and throughput has progressively increased.	None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
15/08/14	Closure criteria water and sediment TWG meeting 2014-03	CCTWG members	• Defining terms such as parameter, measurement endpoint, criteria. • Report on all candidate ecological processes (from world literature). • Defining “change”. • Considering water quality measures and points – e.g. spatial variations billabong v creek.	• Defining change: TWG reminded that change definitions are covered in the discussion paper Acceptable Limits of Change/Detrimental Impact that was previously distributed to the TWG. TWG has been asked to use the Limits of Acceptable Change approach when developing criteria. • Water quality comparative measures: spatial and temporal differences discussed such as stream vs billabong and wet season vs dry season. Measurement methods of concentration vs load were discussed. • Water quality values: discussion regarding the information to be compiled in table format to assist in the decision-making process on water quality criteria. COPC from tailings and brine: Current solute transport models for the tailings and brine do not include predicted loads and concentrations of metals. ERA to calculate the predicted loads and concentrations from the pit tailings and brines based on current solute models. Compare the predicted concentrations and loads to ecosystem protection data and appropriate health limits.	SI to check with SP if Murray Guard is asking TOs about drinking water sources. Road test approach on Mg from Pit modelling. ERA to consult an expert on Manganese dietary risks ERA to provide predictions of loads and concentrations of the metals that are identified (Brown et al 1985) as being of mill or ore origin and compare the prediction concentrations and loads to ecosystem protection data and appropriate health limits. Communicate compiled information supporting the biological effects data and recommendations for criteria.
14/08/14	CCWG meeting 1 2014	CCWG members	• Industry comments on closure criteria objectives and agreement on changes to *"Detrimental Environmental Impact"* paper. • Acceptance of report as starting point for progression by the TWG closure criteria report. • Update on TWGs; presentations from water and sediment TWG.	• Detrimental Environmental Impact: ERA presented a paper proposing the use of the RAMSAR wetland “limits of acceptable change” as a way to incorporate the scientific and cultural/social aspects into a measurable outcome. Paper put forward as a ‘starting point’ and referred to the water and sediment TWG for progression. • Closure Criteria Report: Discussion surrounding the need for groundwater criteria and a groundwater monitoring program. • Water and Sediment Group points of discussion: • Natural acid events in creeks and billabongs mobilising solutes stored in sediments originating from the rehabilitated landform • The use of load limits or concentrations to enable comparison between modelling output	Update the closure objectives to include comments from Industry. Final comments on the detrimental impact paper to be sent to ERA. Incorporate relevant cultural criteria work conducted by Murray Guard into the detrimental impact paper before finalising. update the closure criteria report to include more details on groundwater being used as a means to confirm that model predicted are on the predicted trajectory. Assess potential for impact of water quality from sediment loads form the landform. Update last water and sediment objective to replace "ecosystem function" with a more appropriate term. Review the diet implications for the AALL suit, including historically removed values, to be in line with the most recent diet and data collected by ERISS Conduct more research into the Mn human health effects to obtain a better indication of risk.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
14/07/14	Closure criteria water and sediment TWG meeting 2014-02	CCTWG members	• Standardisation of ecological nomenclature. • Preparation of recommended interim water quality criteria for Magela Creek and Coonjimba Billabong. • Seeking feedback on acceptable limits of change discussion paper. • Review of risk assessment models an output for Pit 3 closure interim criteria. • Review of constituents of potential concern (COPC) 1985 to present.	Water quality limits and contaminants of concern for Magela Creek were presented to group by ERA •	Standardisation of ecological nomenclature referred to CCTWG for interpretation.
11/07/14	MTC	MTC members	• Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	None minuted	None minuted
17/06/14	Closure criteria water and sediment TWG meeting 2014-01	CCTWG members	Kick-off meeting for the TWG outlined 6 objectives and 7 specific tasks. Agreement on endpoints, interpretation of ERs, for example on quality of rehabilitation of the site needed for inclusion into KNP, evidence of decisions to support recommendations to the CCWG and MTC.	• Discussion of closure and approvals timelines relevant to water and sediment criteria. • Interpretation of environmental requirements including the spatial extent to which the criteria will apply. All members to review the Limits of Acceptable Change paper which includes the spatial context of interpreting the ERs • TWG agreed on the following priority tasks in order to progress the Pit 3 application. These were: ○ Determining measurement endpoints Setting parameter values and trajectories	Inconsistent terms used in the objectives eg: “ecological values” in Objective 3 versus “ecological function” in Objective 6 (slide 6). Seek direction from CCWG on interpretation of these terms. Prepare presentation recommending interim WQ closure criteria for Magela Creek and CB billabong. Include references and rationale in notes panel of presentation so it can act as a standalone report. Review risk assessment models and outputs when developing presentation for Pit 3 closure interim criteria for next meeting.
09/05/14	MTC	MTC members	Report from Mine Closure working group presented. Draft version of detrimental impact was sent out to MTC members.	None minuted ○	MTC to respond with comments to the draft version of detrimental impact definition.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
07-08/05/14	ARRTC 32	ARRTC members & observers	Updates on the following ERA and collaborative closure studies: • ITWC study including: Pit 1 preload and capping; outcomes of the monitoring of the barrier integrity. • Prioritisation of key environmental studies to inform closure criteria. • Interpreting "detrimental environmental impact". • Rehabilitation-closure risk assessment outcomes and initial implications for KKN revisions. • Water retention capacity of waste rock substrate to support a functional tropical woodland. Natural colonisation and seasonal responses of emergent aquatic plant in constructed sumps.	• Magela Creek: appropriate methodologies to investigate subsurface profile of Magela Creek sand channel and assess potential for solute migration. Also discuss rationale and recommendations with SSB. • Groundwater modelling: sensitivity • Pit 3 closure • Water retention of waste rock • Emergent aquatic plants: ERA/SSB to run a workshop prior to ARRTC 33 to determine the types of water bodies that need to be assessed, what are the risks, what is known, what are the knowledge gaps and the applicability of the sumps to studies. • Risk assessment: ERA to run a qualitative risk assessment process for decommissioning.	• Magela Creek: ERA to identify appropriate methodologies to investigate subsurface profile of Magela Creek sand channel and assess potential for solute migration. Also discuss rationale and recommendations with SSB. Addressed during ARRTC meeting 35 – INTERA presentation. • Groundwater modelling: ERA to advise if modellers are exploring the sensitivity of the model to geological structures using broad (i.e. hydro stratigraphic unit wide) variations in hydraulic conductivity, or are they looking at preferential flow through linear structures as well? If not, what has been done to systematically assess the presence and characteristics of linear geological structures to act as a potential transport pathway for contaminants to the surface? Completed and addressed further with presentation by INTERA during ARRTC meeting 33. • Pit 3 closure: ERA to draft and distribute a table of contents for Pit 3 tailings application in addition to making early input data available to members. Completed. • Water retention of waste rock: : ERA to provide update on the implications of eco-hydrology study for Pit 1, including advice on how to explore lessons for Pit 1's future. Completed. Addressed during ARRTC meeting 34 via ERA presentation. • Emergent aquatic plants: completed prior to ARRTC meeting 33. Risk assessment: Ongoing ARRTC meeting 34.
09/04/14	ARRAC 41	ARRAC members & observers	Closure planning update: • Progress on the backfilling of Pit 3 ahead of schedule. • Completion of the ITWC study which outlines the optimal rehabilitation plan for the RPA.	• GAC and NLC comfortable with statuses of Pit 1 rehabilitation. • Australian Conservation Foundation sought clarification regarding a statement in the ERA 2013 Annual Report that was interpreted as linking approval of R3D as a prerequisite for rehabilitation of the RPA. • GAC and Environment Centre NT (ECNT) queried sufficiency of funding for rehabilitation. ECNT tabled report titled 'Reconsidering Ranger – a brief on social, environmental and economic cost of uranium mining in Kakadu'.	• R3D Statement: The wording of the statement interpreted to link R3D approval to successful rehabilitation could not be clarified during the meeting. However, the Ranger 3 Deeps project and infrastructure was placed into care and maintenance in June 2015, following the ERA board decision that the project should not proceed to final feasibility study in the current operating environment. • Rehabilitation Funds: Commonwealth Department of Industry and NT Department of Mines and Energy responded to bond queries. The different types of bonds were clarified and assurances provided to GAC that the departments were satisfied with the value of the bonds.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
28/03/14	MTC	MTC members	• Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	• None minuted	Draft version of detrimental impact definition has been completed – ERA will circulate to MTC. • MTC to respond with comments to the draft version of detrimental impact definition.
17/02/14	MTC	MTC members	Report from Mine Closure working group presented. Update on Pit 1 presented.	None minuted	Draft version of detrimental impact definition has been completed – ERA will circulate to MTC.
27-28/11/13	ARRTC 31	ARRTC members & observers	Updates on the following ERA and collaborative closure studies: • Status of ITWC study activities for 2014, including: Pit 3 initial fill, tailings transfer and brine management, Pit 3 preload, seepage studies and associated engineering designs, progressive rehabilitation works on LAAs. • Status of Pit 1 preload and validation of consolidation predictions, and wick performance. • Status of the Pit 3 underfill for subsequent brine management. • Tailings and brine management project- Phase 1. • Update on Phase 1 (problem formulation) of the ecological risk assessment. • Water quality closure criteria (for natural water bodies) adjacent to Ranger. • Revegetation focussing on MLAAs remediation strategies. • Groundwater and solute modelling around Pit 1 and Pit 3. • Implications for surface water from the Pit 3 groundwater modelling. • Key findings of the Pit 1 contaminant transport modelling. Status of planning and scientific knowledge for development of closure criteria and trajectories.	None minuted	ERA and SSD to provide an update on the status of the development of closure criteria (including trajectories). Addressed during ARRTC meeting 32.
15/11/13	MTC	MTC members	• Report from Mine Closure working group presented.	None minuted	None minuted
03/10/13	CCWG meeting 4 2013	CCWG members	• Final comments and agreement on closure criteria objectives • Final comments and issues of TWG scope of works. Update of closure project priorities.	• Closure criteria objectives • Phrasing of water and sediment objectives discussed particularly in reference to the risks to fauna when drinking on site water and the impact of creek and billabong sediment loads on ecological function. Cultural objectives require further consultation.	It was agreed that SP will update and send out the objectives for final agreement out of session, this item will all be progressed under the current open action items. The SOW document will be updated and sent out with a table of comments received and how they have been addressed. Final comments and confirmation on both the objectives and SOW required in 2 weeks to enable the TWG to start work. CH to provide further details of higher level information required to be included in the scopes of work.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
17/05/13	MTC	MTC members	• Report from Mine Closure working group presented.	• None minuted	None minuted
06/09/13	MTC	MTC members	Report from Mine Closure working group presented. The working group has developed the scope of work for the technical working groups for each theme.	None minuted	None minuted
05/09/13	ARRAC 40	ARRAC members & observers	Closure planning update (Pit 1): • Preload of rock fill has been approved but the final height of consolidation is still to be determined. • Preload will assist with model validation and enable a better understanding of how closely current models are representing reality. • ERA is strongly committed to determining a final consolidation level which is acceptable to stakeholders. Pit 1 rehabilitation marks the beginning of a broader scale rehabilitation approach across the site.	None minuted	None minuted
16/07/13	CCWG meeting 3 2013	CCWG members	• Update on closure criteria objectives, including risk assessment conceptual models. • Update of closure project priorities; outline of the scope of works for the TWGs. • Update on ecosystem trajectories.	• Water and sediment objectives: Drinking and recreational water use values used instead of ecological values as drinking and recreation will also be values applicable to the area. • Fauna objectives: recommendation from SSB to reference stock drinking water values. • Radiation objectives: recommendation from SSB that wording is changed to clarify that radiation exposure is ALARA rather than applying dose limits. • Closure project priorities: general consensus with draft outline. • TWG: technical working groups to be kept small. • Ecosystem trajectories: SSB clarified the two types of ecosystem trajectories as: • Management trajectory to track progress towards achieving criteria. • Trajectory to track progress to a point before achieving the objective as the final objective will not be achieved within a reasonable timeframe Definition for ecosystem trajectories are to be developed by ERA.	Include explanation of water and sediments objectives (as discussed at meeting) in technical working group SOW Provide comments on the objectives and SOW to ERA in 2 weeks Update project list with comments from meeting and add conditional formatting to highlight lagging projects. Develop project Gant chart for closure projects. Develop definition of trajectories and other higher level issues for inclusion in SOW

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
21-22/05/13	ARRTC 30	ARRTC members & observers	• Update on ITWC study looking at the best options for solving tailings and water disposal and mitigating associated impacts; preparation of Pit 3 for the successful rehabilitation of the tailings dam. • Update on research informing the development of closure criteria for agreed themes: Landform, radiation, water and sediment, flora and fauna and soils. • Update on aquatic ecosystem proposal. • Status of Pit 1 rehabilitation and final landform. • Outcomes of the collaborative Ranger closure ecological risk assessment workshop.	• ITWC PFS: ARRTC commended ERA on the high quality of their scientific work and presentations to this meeting. • Ecological risk assessment: ARRTC requested that a status report (including the results from the screening phase) be provided to next meeting. • Groundwater: ERA asked to provide an update on groundwater modelling activities (including associated boundary conditions) to next meeting. • Revegetation: ERA asked to present on the eco-hydrology research, status (and scientific basis for) the proposed vegetation strategy and closure trajectories. • Landform: ERA and SSD asked to provide an update on the status of erosion modelling for Ranger.	None minuted
02/05/13	Technical workshop	MTC members, CSIRO, Geoscience Australia, ATC Williams, Rio Tinto T&I	• Technical workshop on Pit 1 closure and subsequent submission of a notification on 17/05/13 for the Pit 1 preload phase.	• DPIR (former DME and supervising authority) could see no obvious show stoppers with pre-loading.	Consensus from the technical workshop attendees that the pre-loading phase for Pit 1 should proceed.
24/04/13	CCWG meeting 2 2013	CCWG members	• Update on closure project priorities Update on the composition of proposed technical working groups (TWGs) for each closure criteria theme.	Review of changes suggested for the closure criteria report: • Groundwater abstraction: agreement by all that groundwater abstraction must be prohibited in certain areas across site • Cultural aspects of landform: agreement by all to reword Objective 8 to reflect cultural aspects of water bodies, namely the requirement to ensure that the number of water bodies on site after rehabilitation be the same as before mining. Sentinel wetlands: agreement by all to remove the term ‘sentinel wetland’ from the plan due to confusion as to its definition.	Include as task in the Flora and Fauna technical working group scope of works to define what is meant by “local native plant species”. Also include any information received back from Ping Lu and Steve Winderlich. Review closure objectives to include Assessment Endpoints from conceptual model. Include words in the report to highlight the need for capturing the historical mining heritage and keep heritage as a theme out of scope. Reword landform objectives to include links to cultural aspects. Remove the term “sentinel wetland” from the glossary and record this decision in Appendix C ERA to review the project priority list with regards to U in sediment to determine if criteria will be required for Pit 1 approvals or if some modelling can be done to demonstrate these criteria will not be required
22/03/13	ARRAC 39	ARRTC members & observers	• Backfilling of Pit 3 and the ITWC PFS progressing. • Rehabilitation of the Magela LAA and adjoining borrow pit is scheduled to commence this year. • Planning for Pit 1 rehabilitation well advanced; over 7,000 wicks installed and preparatory works are expected to be completed by the time Pit 3 backfill is completed.	• None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
15/03/13	MTC	MTC members	• Report from Mine Closure working group presented. The group has prioritised the formation of technical working groups for theme, with Georgetown Billabong criteria and radiological criteria as being identified as being required initially to fit in with the timeframe for projected works on site.	None minuted	None minuted
07/03/13	CCWG meeting 1 2013	CCWG members	• Discussion on CCWG planning for the year. Discussion on closure ecological risk assessment and development of conceptual models.	• Detrimental Impact: definition provided by SSD that there should be no observable biological effect as determined by an appropriately designed monitoring program. This raised further questions surrounding the definition of 'biological effect'. • Technical working groups: agreement that these groups need to be formed within the next month. Key tasks include finalising objectives, reviewing the list of environmental studies and doing a gap analysis, commenting on the proposed time lines to determine if they are achievable, documentation of baseline conditions or how they can be calculated and developing the methods for determining closure criteria. Ecological risk assessment and conceptual models: presentation given by ERA summarising recent workshop in conceptual models. Outcomes of risk assessments to be provided to the technical working groups.	• Technical working groups were established and have contributed significantly to the closure criteria outlined in the Ranger Mine Closure Plan, Chapter 6. • The definition of detrimental impact is currently being addressed by consultants BMT WBM. • Ecological risk assessment and conceptual models were developed by SSB in collaboration with stakeholders. No new actions identified
08/02/13	MTC	MTC members	• Report from Mine Closure working group presented.	• None minuted	ERA to nominate closure criteria meeting schedule for 2013 (carried over from last meeting).
07/12/12	MTC	MTC members	Report from Mine Closure working group presented.	None minuted	ERA to nominate closure criteria meeting schedule for 2013.
05-06/12/12	ARRTC 29	ARRTC members & observers	• Current status of studies on radiation protection of the environment (non-human biota). • Recommendations from the independent surface water working group. • Status of the trial rehabilitation in the Magela LAAs. • Soil erosion and water quality on the trial landform. • Radon exhalation from the trial landform. • Update on the characterisation of groundwater flows and associated solute source strength and duration, form Pit 3 solutes to Magela Creek. • Systems analysis of Ranger closure process. • Developing billabong closure criteria for solutes. • Potential integration of aquatic ecosystem establishment into the broader rehabilitation/closure process. Overview of progressive rehabilitation pilot projects on the RPA 2012 – 2017.	• Pit 1 Aquatic ecosystems: ARRTC requested that a more detailed project proposal be provided to next ARRTC meeting. Closure criteria: ERA to provide further information on the status of research informing the development of closure criteria for Ranger to next meeting.	ERA to provide a presentation on Pit 1 rehabilitation status and proposed final landform to next meeting. Completed. Addressed at ARRTC meeting 30.
05/10/2012	MTC	MTC members	• Report from Mine Closure working group presented.	• None minuted	None minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
05/10/12	CCWG meeting 5 2012	CCWG members	Discussion on the post closure land use; defining "detrimental impact".	• Detrimental Impact: SSD provided summary of their interpretation of the definition of 'detrimental impact'. Notes that a scientific view of impact may differ from the traditional owner's perspective. SSD will provide a written interpretation for review by the working group. Technical working groups: General discussion held regarding the development of technical working groups for each closure theme.	Prepare a list of proposed members for each of the technical working groups and circulate to CCWG members. Prepare a paper outlining the scope of works for the technical working groups and send out for review by the CCWG out of session. Then form the technical working groups to commence work. Identify appropriately qualified personnel in the NT government that will be used by DME to review the technical working group findings. These people will then be added to the consultation list to make sure they are satisfied with the progress.
06/09/12	ARRAC 38	ARRAC members & observers	• Progressive rehabilitation discussed including installation of wicks in Pit 1 and application of trial landform rehabilitation successes across site. ERA presented a conceptualisation of the Pit 3 brine injection and tailings management closure strategy.	• The resistance of wick installation at a depth of 20 m was discussed.	In 2012, ERA successfully installed 7,554 prefabricated vertical wick drains into Pit 1, to assist with dewatering the pit, ahead of capping and rehabilitation. The wicks were installed within the top 40 m of the tailings mass in Pit 1. The purpose of the wicks is to dewater the upper level of the tailings and promote tailings consolidation, thus establishing a stable surface upon which to commence backfill activities.
27/08/12	CCWG meeting 4 2012	CCWG members	• Discussion on the post closure land use; defining "detrimental impact".	• Definition of 'detrimental impact' taken from the ERs and added to the closure criteria report. SSD to review and provide a position paper. Post-closure land use document tabled by GAC for review by next meeting.	ERA to continue the update of table 10.1 priorities and include the entire list of project required for closure criteria. All to review entire CC document and provide feedback by next meeting Update the "Post Closure land use" document and circulate for CCWG members for comment SSD have tabled some words to interpret what is meant by the Detrimental Impact definition in the ER's. All groups to go away and review these words and either provide comment or their own interpretation for discussion at the next meeting Complete Radiation section on closure criteria derivation method and circulate to working group for review and agreement. Once agreed this will then be distributed to each ERA closure criteria theme owner as the template to be used as information required.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
23/07/12	CCWG meeting 3 2012	CCWG members	• Ongoing discussion and progression of closure criteria for the RPA. • Emphasis on a review of the terms of reference and the closure criteria report. General discussion on the structure of closure criteria.	• Discussed inclusion of Parks NT in CCWG meetings and the structure of closure criteria discussed.	Parks invited to attend meetings. Attendance began in March 2013. Review and provide feedback on the “Rehabilitation and Closure Objectives” section of the CC report in order to reach agreement at next meeting. Inform the ISWWG of the CCWG need to determine the most appropriate location for post closure monitoring ERA to meet with Parks (Anna Morgan) to provide context on the CCWG and discuss their attendance at future meetings and general involvement in the development of closure criteria. Add a new section to the Closure Criteria report that outlines the specific areas of concern for closure. Provide the updated “Post Closure land use” section to the CCWG at the next meeting. Expand Section 7.1 (Objectives for closure) to include the ERs word for word and then put ERA’s interpreted objectives underneath the relevant heading. Review and provide feedback on the updated objectives to reach agreement. Put together a closure criteria priorities table and include at an appropriate location within the document. ERA to liaise with CH about the timeline for producing a document for comment on the development of billabong water criteria. Cross channel Magela Creek channel analysis being done by Kate Turner to be presented at the next meeting.
20/07/12	MTC	MTC members	• Report from Mine Closure working group presented.	None minuted	None minuted

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Cover photograph: Partridge Pigeon (*Geophaps smithii smithii*) [Vulnerable] on Trial Landform

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Environmental Requirements	The Ranger Environmental Requirements are attached to the S.41 Authority and set out Primary and Secondary 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.
Minesite Technical Committee (MTC)	The Minesite Technical Committee, convened in accordance with Attachment A of the Working Arrangements for the Regulation of Uranium Mining in the Northern Territory dated 30 May 2005, is tasked with: • Reviewing proposed and existing approvals and decisions under NT legislation. • Reviewing technical information in relation to Ranger Mine, including monitoring data and environmental performance. • Collaboratively developing standards for the protection of the environment. • Developing strategies to address emerging issues. The MTC consists of the representatives of the Northern Territory Department of Industry, Tourism and Trade, the Supervising Scientist, ERA and the Northern Land Council. Representatives of the Commonwealth Department of Industry, Science, Energy and Resources may also attend MTC meetings.
Mirarr	Mirarr is a patrilineal descent group. Descent groups are often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Ranger Project Area (RPA)	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976.*
WA Guidelines. WA Guidelines for Preparing Mine Closure Plans	Guidance documentation provided by the Western Australia Department of Mines, Industry Regulation and Safety for the development of mine closure plans.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As low as reasonably achievable
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ASNO	Australian Safeguards and Non-Proliferation Office
BPT	Best Practicable Technology
Cth	Commonwealth
DITT	Department of Industry Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
EIS	Environmental Impact Statement
EMS	*Environmental Management System*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPIP Act	*Environmental Protection (Impact of Proposal) Act 1974*
ER(s)	Environmental Requirements
ERA	Energy Resources of Australia Ltd
GISTM	Global Industry Standard on Tailings Management
IAEA	International Atomic Energy Agency
ICMM	International Council on Mining and Metals
ICRP	International Commission on Radiological Protection
OBS	Osmoflow Brine Squeezer
MCP	Mine Closure Plan
MMP	Mine Management Plan
MTC	Minesite Technical Committee
NLC	Northern Land Council
NGO	Non-Government Organisations
NOHSC	National Occupational Health and Safety Commission
NP	National Park
NT	Northern Territory
NTP	Northern Territory Portion
RPA	Ranger Project Area
S41	Section 41
SSB	Supervising Scientist Branch
WA	Western Australia

3 CLOSURE OBLIGATIONS AND COMMITMENTS

This section provides an overview of the closure obligations and commitments that are applicable to Energy Resources of Australia Ltd (ERA) in relation to the Ranger Project Area (RPA). An outline of the primary Commonwealth (Cth) and Northern Territory (NT) legislative framework is provided, including descriptions relating to rehabilitation and closure activities. Relevant external guidelines, standards, codes of practice and stakeholder input, along with internal corporate policies and standards, have also been addressed as relevant to the Mine Closure Plan (MCP).

As this MCP is appropriately addressing the requirements of the Mining Management Plan (MMP), this section also covers MMP statutory and non-statutory requirements.

It is implicit that ERA will comply with all necessary legal obligations and uphold internal standards during closure to ensure the ongoing preservation of cultural values, the protection of the environmental values in the surrounding Kakadu National Park (Kakadu NP), and the health and safety of the community.

Chapter 3.1 provides an overview of the ERA regulatory framework and includes a list outlining ERA key legislative instruments and agreements. Key legislation and agreements specific to Ranger Mine operations, including closure, together with explanation are included in Appendix 3.1. A compliance register of specific obligations is included in Appendix 3.2.

3.1 Legislative framework

Rehabilitation and closure of the Ranger Mine are governed by both Commonwealth and Northern Territory legislation and regulations.

3.1.1 Applicable legislation and agreements

The following Acts and Regulations are relevant to closure activities[2] at the Ranger Mine:

- *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (Cth)
- Aboriginal and Torres Strait Islander Heritage Protection Regulations 2017 (Cth)
- *Aboriginal Land Act 1978* (NT)
- *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth)
- Aboriginal Land Rights (Northern Territory) Regulations 2007 (Cth)
- *Atomic Energy Act 1953* (Cth)
    - ‘Government Agreement’ between the Commonwealth, ERA and the Atomic Energy Commission (under the *Atomic Energy Act 1953*)
    - ‘Section 41 Authority’ under the *Atomic Energy Act 1953*

[2] Exploration, mining and milling activities have ceased

  - 'Mining Agreement' (the Ranger uranium mining project agreement between the Northern Land Council (NLC) and ERA)
- *Australian Radiation Protection and Nuclear Safety Act 1998* (Cth)
- *Building Act 1993* (NT)
- Building Regulations 1993 (NT)
- *Bushfires Management Act 2016* (NT)
- *Control of Roads Act 1953* (NT)
- *Corporations Act 2001* (Cth)
- Customs (Prohibited Exports) Regulations 1958 (Cth)
  - Permit to export
- *Dangerous Goods Act 1998* (NT)
- Dangerous Goods Regulations 1985 (NT)
- *Electrical Workers and Contractors Act 1978* (NT)
- *Electricity Reform Act 2000* (NT)
- Electricity Reform (Safety and Technical) Regulations 2000 (NT)
- *Environmental Offences and Penalties Act 1996* (NT)
- Environmental Offences and Penalties Regulations 2011 (NT)
- *Environment Protection (Alligator Rivers Region) Act 1978* (Cth)
- *Environment Protection and Biodiversity Conservation Act 1999* (Cth)
- Environment Protection and Biodiversity Conservation Regulations 2000 (Cth)
- *Environment Protection (Northern Territory Supreme Court) Act 1978* (Cth)
- *Environmental Offences and Penalties Act 1996* (NT)
- Environmental Offences and Penalties Regulations 2011 (NT)
- *Fair Work Act 2009* (Cth)
- *Fire and Emergency Act 1996* (NT)
- Fire and Emergency Regulations 1996 (NT)
- *Fisheries Act 1988* (NT)
- *Hazard Waste (Regulation of Exports and Imports) Act 1989* (Cth)
- Hazardous Waste (Regulation of Exports and Imports) Regulations 1996 (Cth)
- *Heritage Act 2011* (NT)
- International Atomic Energy Agency Regulations for the Safe Transport of Radioactive Material

- *Industrial Chemicals Act 2019* (Cth)
- *Mineral Titles Act 2010* (NT)
- Mineral Titles Regulations 2011 (NT)
- *Mining Management Act 2001* (NT)
- Mining Management Regulations 2001 (NT)
    - Ranger Authorisation Variation 0108-18
- *Northern Territory Aboriginal Sacred Sites Act 1989* (NT)
- Northern Territory Aboriginal Sacred Sites Regulations 2004 (NT)
- *Nuclear Non-Proliferation (Safeguards) Act 1987* (Cth)
    - Permit to possess
    - Permit to decommission
- *Radiation Protection Act 2004* (NT)
    - Licences for radiation equipment
- *Radioactive Ores and Concentrates (Packaging and Transport) Act 1980* (NT)
    - Licence to transport and store U_3O_8
- Radiation Protection Regulations 2007 (NT)
- Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council (under the *Atomic Energy Act 1953*)
    - Ranger Uranium Mining Project Agreement between the Northern Land Council and ERA (2013)
- *Territory Parks and Wildlife Conservation Act 1976* (NT)
- Territory Parks and Wildlife Conservation Regulations 2001 (NT)
- Territory Parks and Wildlife Conservation By-Laws 1984 (NT)
- *Waste Management and Pollution Control Act 1998* (NT)
- Waste Management and Pollution Control (Administration) Regulations 1999 (NT)
- *Water Act 1992* (NT)
- Water Regulations 1992 (NT)
- *Weeds Management Act 2001* (NT)
- Weeds Management Regulations 2006 (NT)
- *Work Health and Safety (National Uniform Legislation) Act 2011* (NT)
- Work Health and Safety (National Uniform Legislation) Regulations 2011 (NT).

3.1.2 Commonwealth

The Commonwealth Government approved the Ranger Mine project on 9 January 1979. This approval followed the recommendations of the first and second reports of the Ranger Uranium Environmental Inquiry, which had been initiated under the *Environmental Protection Impact of Proposal Act 1974 (EPIP Act)* termed 'the Fox Inquiry' and assessed the potential impacts of uranium mining in the Alligator Rivers Region (Fox *et al.* 1976, 1977; Hart & Jones, 1984).

The Fox Inquiry provided the following recommendations relevant to rehabilitation and closure:

- 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 be fully secured at all times; and
    - 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 Mine project be permitted to commence only if there is a firm, legally binding undertaking by Ranger Mine to place in one or the 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 Mine's operating procedures (the Minesite Technical Committee (MTC) was formed as a result).

Title to the RPA was granted to the Kakadu Aboriginal Land Trust in 1978, in accordance with the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* (*Aboriginal Land Rights Act*). Prior to the Commonwealth Minister approving the Ranger Mine, the Commonwealth Government entered into the Section 44 Agreement with the NLC under the *Aboriginal Land Rights Act*. The original mining authorisation of the Ranger Mine was granted on 9 January 1979 under Section 41 of the *Atomic Energy Act 1953* (Cth) (*Atomic Energy Act*). Known as the S41 Authority, this approval provides the key tenure and land access approval required for the mine.

The section 41 Authority (Cth) established fundamental Environmental Requirements (ERs), which are inclusive of rehabilitation obligations applicable to the Ranger Mine. The ERs were appended to the main Commonwealth authority issued under Section 41 of the *Atomic Energy Act*. In general, the ERs set out environmental objectives that establish the principles by which the Ranger Mine operation is to be conducted, closed, and rehabilitated and the standards that are to be achieved. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation.

The closure and rehabilitation of Ranger Mine is not subject to the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* because the action started prior to the commencement of the Act on 16 July 2000 and is therefore exempt under Section 43(a) of the *EPBC Act*.

3.1.3 Northern Territory

The key regulatory instrument that governs operations at the Ranger Mine on a day-to-day basis is the NT Authorisation 0108 (the Authorisation), which was issued under the NT *Mining Management Act 2018* (*Mining Management Act*). The Department of Industry Tourism and Trade (DITT), formally the Department of Primary Industry and Resources (DPIR), regulates ERA in accordance with the Ranger Authority under the *Mining Management Act*. Key closure obligations included within the Ranger Authorisation have been incorporated into the Closure Legal Obligations Register (Appendix 3.2).

Schedule 2.1 of the Ranger Authorisation provides the primary basis for operations, and states:

> *2.1 In addition to the obligation under the Environmental Requirements, the Operator is authorised to operate in accordance with the conditions and requirements set out in this Authorisation. In particular, the Operator is authorised to:*
>
> *2.1.1 conduct mining operations and rehabilitation activities in accordance with the latest approved Mining Management Plan, Water Management Plan and Mine Closure Plan and all subordinate plans referenced therein, submitted in accordance with the processes set out in the Annexes.*

The overall objective for rehabilitation and closure is based on the rehabilitation goals outlined in the Authorisation and the ERs. Annex A of the Authorisation includes the ERs, which makes specific references to the ERA obligations for environmental protection (Clause 1), rehabilitation (Clause 2) and the Rehabilitation Plan (Clause 9). The Variation of the Ranger Authority includes Annex B which addresses the requirements for submission and assessment of the MCP. ERA is now undertaking and pursuing final rehabilitation and closure of the Ranger Mine via the existing statutory review and assessment mechanisms.

Several legislative instruments relevant to environmental protection within the NT apply unless specific exemptions for the Ranger Mine have been made. These obligations are identified within the Closure Legal Obligations Register in Appendix 3.2.

3.1.4 Land and tenure

The Kakadu NP surrounds the RPA and was declared in three stages between 1979 and 1991 under the then *National Park and Wildlife Conservation Act 1975*, later replaced by the *EPBC Act* in 2000. Land tenure surrounding the RPA is a combination of Aboriginal and Commonwealth Government freehold land managed through several leasing, governance and service arrangements. Each stage of Kakadu NP includes Aboriginal land declared under the *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth) and is either leased to the Director of National Parks or subject to a claim to traditional ownership under the Act.

The Mirarr are the Traditional Owners of the land within the RPA. The Mirarr estate includes the RPA, Mining Lease (MLN1), Jabiru and parts of Kakadu NP. The Mirarr exercise their rights as Traditional Owners under two Aboriginal Land Trusts and benefit from fee simple title (a form of freehold ownership legislated by the NT Government) to most of the estate. Aboriginal freehold title exists across most of the land in the RPA, with the titles held by the Kakadu Aboriginal Land Trust. The Kakadu Aboriginal Land Trust was handed an Aboriginal freehold title over NT Portion 7127 (currently Portion 2273) under the *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth) on 16 August 2013.

Land in the NT is subject to cadastral divisions, called Northern Territory Portions or Parcels (NTPs) for the purposes of identification and security of land ownership. Land tenure in the region, relevant to the RPA, includes NTPs 2273, 2376, 1656, 1657, 1662, 1685 and 1686. The majority of NTP 2376 is declared as Kakadu NP and leased back to the Director of National Parks (with current lease expiration date of 31 December 2077); the remaining part of NT Portion 2376 is within the boundaries of the RPA. The RPA also includes NTPs 1656, 1657, 1685, 1686 and part of NTP 1662 (Figure 3-1).

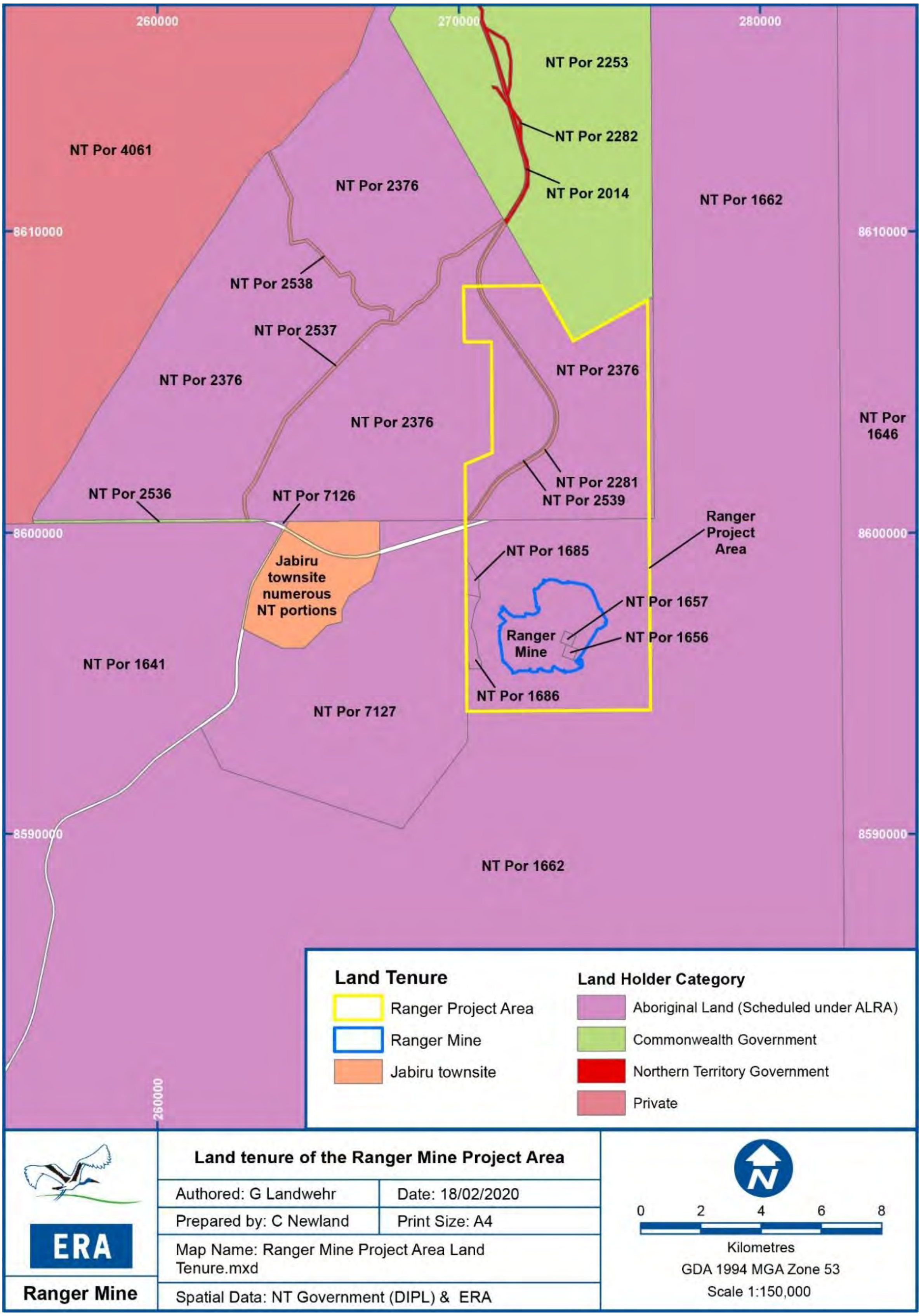

Figure 3-1: Post-closure tenure and land access

In accordance with schedule 5.1 of the S41 Authority, ERA ceased all mining operations on 8 January 2021. Schedule 3 of the S41 Authority requires ERA to comply with the Mining Agreement (Ranger Uranium Mining Project Agreement) established between the NLC and ERA, which requires the RPA to be vacated on cessation of mining operations, other than for the purposes of undertaking rehabilitation as required by the S41 Authority (Schedule 5.2). The current rights of ERA to access and occupy the RPA, under the current S41 Authority, continues until 8 January 2026.

Gundjeihmi Aboriginal Corporation (GAC), the NLC and ERA have been working collaboratively with relevant Government departments on the rehabilitation of the RPA and the proposed amendment to the *Atomic Energy Act*. The GAC and NLC, together with ERA have written to the relevant Minister to confirm that they jointly support the introduction of legislation to amend the *Atomic Energy Act* to allow ERA to apply for a new S41 Authority to access the RPA to complete rehabilitation of the site beyond January 2026. At the time of writing this 2022 MCP, the amendments had just been presented to Parliament and are not yet finalised.

The S41 Authority requires ERA to undertake a monitoring program 'following cessation of operations until such time as a relevant close-out certificate is issued.' Following the completion of rehabilitation works, rehabilitated areas will undergo stabilisation and monitoring as the site progresses towards development of a long-term stable landform and viable ecosystem that meets closure objectives. ERA assumes monitoring will continue for up to 25 years after the closure phase is completed.

The rehabilitation obligations of ERA will cease once the close-out certificate has been issued by the Minister, subject to the Supervising Scientist and the NLC agreeing that the specific part of the RPA has met the aims and objectives for rehabilitation. Close-out will be granted at the point at which the rehabilitation requirements have been met or are assured, appropriate regulations and standards have been met and the site is suitable for the intended future land use. Following close-out, a separate process will be required to formally relinquish the RPA.

3.2 Standards, codes of practice and guidelines

The following external standards, codes of practice, and guidelines are relevant to closure activities at the Ranger Mine:

- Australian Code for the Transport of Dangerous Goods by Road and Rail (ADG Code) 7th Edition
- Australian Guidelines for Water Quality Monitoring and Reporting – Summary 2000
- Code of Practice – Safe Transport of Radioactive Material (ARPANSA 2019)
- Code of Practice & Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (ARPANSA 2005)
- Western Australia (WA) Government Guidelines for preparing Mine Closure Plans (DMIRS 2020a, 2020b)
- National standards for the practice of ecological restoration in Australia. Second Edition. (SRG 2018)

- International Council on Mining and Metals (ICMM) (2019) Integrated Mine Closure: Good Practice Guide (2nd Edition)
- ACARP Management of waste tyres in the mining industry C8037 (2000)
- NTEPA Guidance Note - Asbestos disposal in the NT – information on the requirements for the disposal of Asbestos in the Northern Territory (2018).

ERA has closely followed the ICMM (2019) best practice for mine closure and has adopted the elements of closure planning (Figure 3-2).

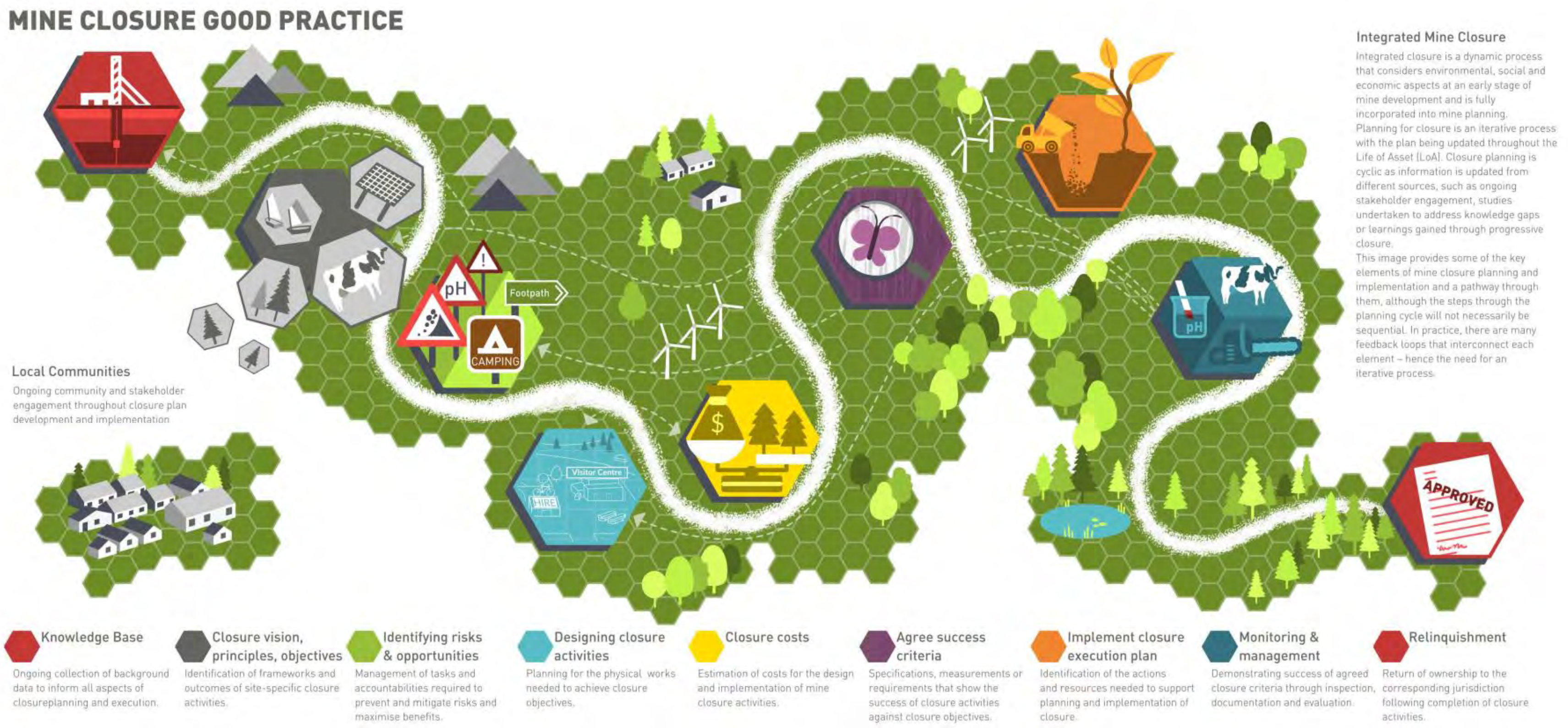

Figure 3-2 Integrated mine closure good practice framework (ICMM 2019)

3.2.1 Corporate policies and standards

ERA and Rio Tinto both have a number of Health, Safety and Environmental and Community (HSEC) policies and standards. The Closure Standard is an element of the Rio Tinto sustainable development framework, designed and developed to incorporate the ICMM Sustainable Development Framework (Rio Tinto 2014, ICMM 2015).

The Rio Tinto Closure Standard (HSEC-B-27) requires each Rio Tinto operation (globally) to develop and implement a plan for closure that achieves the requirements of the Closure Standard. The plan must be based on comprehensive and up-to-date knowledge base of the regulatory, socio-economic, cultural and environmental context in which the site operates; and all reasonable options for post-closure land use(s) must be identified and evaluated.

One of the core ERA values for the Ranger Mine closure is that the natural and cultural values of the surrounding World Heritage-listed Kakadu NP must continue to remain protected. To achieve this ERA has made it a business priority to care for country and deliver the best-in-class rehabilitation. The ERA Environmental Policy sets the underlying commitments required from employees and the company to ensure the environment remains protected and specifically commits to:

- respect all agreements with the NLC and Aboriginal Traditional Owners;
- comply with, and endeavour to exceed, all applicable legislation and commitments;
- rehabilitate land on which ERA operates, to establish an environment similar to the adjacent areas of Kakadu NP;
- conduct research to develop environmentally sound closure strategies; and
- ensure sound environmental decision making through collaboration with leading research providers, using best practicable technologies and engaging qualified suppliers.

3.2.2 Statutory and Non-Statutory Obligations

ERA has a system to identify, manage, assess and report against legal compliance requirements. This system includes Environmental Management System (EMS) procedures, checklists, inspections and audits. Legal compliance is monitored on a continual basis from analysis of monitoring and other data, maintenance of compliance checklists, and a system of regular audits and inspections. As part of this system, areas of non-compliance are promptly identified and actioned.

Inspections may also be conducted on an ad hoc basis by government authorities to assess, among other matters, performance against legal and other requirements.

Consistent with EMS procedures, any changes to legal requirements such as new approvals or changes to legislation are monitored. These changes may be identified from research, industry contact and correspondence from Non-Government Organisations (NGOs), government notifications, subscriptions, media reports and legal advice. ERA's EMS framework, and procedural and training documentation, is also reviewed on an ongoing basis and is updated as required to reflect changes in legal requirements.

3.2.2.1 Statutory Requirements

Operations and closure at Ranger are governed by both Australian and NT legislation and regulations as discussed above. ERA maintains a Compliance Obligation Register to identify and manage compliance with the relevant Acts and Regulations (Appendix 3.2).

As a uranium mining and milling facility, international guidelines relating to radiation protection apply to the Ranger Mine. The system of radiation management is based on the justification, optimization and limitation principles established by the International Commission on Radiological Protection (ICRP), standardized by the International Atomic Energy Agency (IAEA) and adopted in a joint Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and National Occupational Health and Safety Commission (NOHSC) document.

3.2.2.2 Non-Statutory Obligations

ERA complies with the environmental management and sustainability requirements of its major shareholder, Rio Tinto. Rio Tinto has implemented Environmental Standards that aim to manage environmental risk at a consistent level across all Rio Tinto operations.

Several agreements are in place to support the function of ERA's regulators and the relationships between ERA and key stakeholders. Relevant agreements include:

- An agreement between the Commonwealth of Australia and the NT in relation to the principles to be applied in the regulation of uranium mining in the Northern Territory.
- A Memorandum of Understanding commonly referred to as the 'Working Arrangements' which establishes procedures for consultation between the Australian Government's Office of the Supervising Scientist and the Northern Territory Department of Primary Industry and Resources (DPIR) now the Department of Industry, Tourism and Trade (DITT) in the performance of their legislative functions. The 'Working Arrangements' also set out the functions of the Minesite Technical Committee (MTC).
- The GAC, NLC, ERA and the Commonwealth Government finalised the suite of agreements governing operations at the RPA, including a Mining Agreement in January 2013.

Ranger's Safety Management System and EMS has been certified to AS4801 and ISO14001 standards respectively since December 2003. The system is audited by an accredited external party on an annual basis to ensure compliance to these standards.

3.2.3 Supervising Scientific Branch (SSB) rehabilitation standards

The SSB published nine rehabilitation standards for the RPA (Department of Agriculture, Water and the Environment, 2021), which are based on over 40 years of research and monitoring in the area surrounding the Ranger mine. The SSB rehabilitation standards are reviewed and updated as required.

These standards are respected by ERA, along with the overarching corporate standards, to promote desired outcomes for environmental protection.

3.3 Western Australia Mine Closure Plan guidelines

Annex B of the Ranger Authorisation and the Rio Tinto internal requirements frame the content and structure of the MCP. At the request of the Commonwealth Government, and in the current absence of NT specific closure plan guidelines, this MCP has been prepared with reference to the WA Guidelines for Preparing Mine Closure Plans (the WA Guidelines) (DMIRS, 2020b). The WA Guidelines outline a general mine closure planning process. ERA has followed this mine closure planning process throughout its operation and addresses each component of this process in detail throughout this MCP.

The Annex B requirements align with the WA Guidelines, which recognise that closure planning is a progressive process and that mine closure plans are living documents that undergo ongoing review, development, and continuous improvement throughout the life of a mine. This is consistent with the requirement to update and submit the MCP annually as per the Authorisation. The level of information required recognises the stage of mine development (i.e. exploration, planning and design/approvals, construction, operations, decommissioning, post-closure maintenance and monitoring), with detail increasing as the mine moves through closure.

The WA Guidelines also include requirements for radiation management for uranium mines, such as the ‘as low as reasonably achievable’ (ALARA) principle and the ‘best practicable technology’ (BPT) principle, defined by the International Commission on Radiological Protection (ICRP), and endorsed by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (ARPANSA 2005, DMIRS 2020a, 2020b). These principles are discussed in detail in *Section 6, Best Practicable Technology.*

3.3.1 Other closure and rehabilitation resources

Beyond the guiding documents identified above, there are several other sources of information that are useful to the mining industry for the management of rehabilitation and closure. These documents provide a baseline to cross-check whether the ERA closure practices are conforming to industry standards and that the necessary planning and management aspects are being considered. The following documents have been considered:

- A guide to leading sustainable development in mining (Australian Government 2011);
- Mine closure – leading practice sustainable development program for the mining industry (Australian Government 2016a);
- Mine rehabilitation – leading practice sustainable development program for the mining industry (Australian Government 2016b);
- Guidance for the assessment of environmental factors – rehabilitation of terrestrial ecosystems. No. 6. (EPA 2006);

- A framework for developing mine-site completion criteria in Western Australia. [endorsed by the Department of Mines, Industry Regulation and Safety] (Young *et al*. 2019); and
- Kakadu Management Plan 2016 - 2026 (Director of National Parks 2016).

3.4 Closure permits and approvals

ERA obtained a 'Permit to Decommission Facility' on 8 January 2021 under the *Nuclear Non-Proliferation (Safeguards) Act 1987* from the Australian Safeguards and Non-Proliferation Office (ASNO). Decommissioning works proceeded following the receipt of, and in accordance with the permit.

The annual update and approval of the MCP will cover a range of closure activities undertaken on-site as the Ranger mine transitions from its operational phase into closure. However, stand alone applications will be required for activities that require amendment of the Ranger Authorisation, cause or have potential to cause disturbance to intact or undisturbed areas of the RPA, or are likely or have the potential to impact downstream values.

In 2019, during further discussions on the amendments to the Ranger Authorisation, Ministers agreed that the following matters (the matters agreed in writing) will require consultation with the Commonwealth Minister pursuant to subsection 34(3) of the *Mining Management Act 2001* (NT):

- the making of substantial changes to the Ranger Authorisation;
- assessment of the MCP and the process for assessing the MCP;
- assessment of the Ranger Mining Management Plan in so far that it addresses the requirements of the Environmental Management Report referenced in clause 18 of the Environmental Requirements, noting that most elements of the management plan are now more relevant for inclusion within the MCP and will be captured in the 2022 MCP; and
- applications for the approval of significant rehabilitation and closure activities including, but not limited to, the final Pit 1 and Pit 3 landform, the Ranger 3 Deeps exploration decline, deconstruction of the Tailings Storage Facility and/or processing plant and the final landform over the Ranger Project Area.

The following applications require Commonwealth Ministerial approval:

- **Pit 3 Closure** (submitted February 2022): this application was submitted to the MTC for assessment on 7 April 2022 and seeks approval for the method of Pit 3 closure up to, but excluding, the final landform layer of 6m. The application details the most recent tailings consolidation modelling, planned capping layer, wicking, geotextile, bulk material movement (waste rock) and waste disposal within the bulk material. All associated studies have also been included in the application to inform the environmental risk and potential mitigation strategies. Feedback on the application has been received and a revised document to address this feedback is being developed.

- **Ranger Water Dam Deconstruction and Final Landform** (forecast submission Q1 2024): ERA completed mill operations in the first quarter of 2021 and has transitioned into rehabilitation and closure of the mine. The tailings in the above-ground Ranger Water Dam (RWD) floor and confining embankments have now been transferred to Pit 3. The RWD will be used for water storage during Pit 3 capping construction and for on-site water balance needs. The RWD decommissioning schedule will be dependent on the proposed deconstruction methodology and when water storage is no longer a constraint. ERA are now commissioning engineering study works to develop a selected Best Practicable Technology conceptual design for the RWD deconstruction, as well as Coonjimba and Gulungul Catchments reconstruction to meet ERs in the S41 of the Authorization for the regulatory decommissioning and final landform application compliant with ANCOLD guidelines and Global Industry Standard on Tailings Management (GISTM). The outcomes of this study will be combined with outcomes of all other relevant studies in the final landform application. This application will document the activities planned to achieve the final landform, how this final landform will achieve the ERs, the risks and controls associated with achieving the ERs, and contingency measures that would be applied if required.

Beyond the two major stand-alone applications noted above, the MTC is responsible for reviewing 'minor' applications and advising on matters for consideration as part of the Regulatory Authority's approval. This process will generally occur when information is not available at the time of MCP submission, or due to the complexity of the supporting information.

The current applications that are to be submitted to the MTC for approval in 2022 are:

- An application to change the release criteria for BC distillate. In addition to a request to increase the threshold for electrical conductivity of distillate permitted to be directed to release water storages, this application will also request that near-spec distillate be able to be directed to RP2.
- An application to treat and release process water through the upgraded Osmoflow Brine Squeezer (OBS). ERA is in the process of upgrading the OBS through the addition of a pre-filtration section, similar to that in the existing pond water treatment plants that will enable the Brine Squeezer to treat process water through to a high quality permeate by reverse osmosis. The upgraded Brine Squeezer will provide additional process water treatment capacity to the existing Brine Concentrator.

No areas outside of the RPA footprint are planned to be disturbed during closure.

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APPENDIX 3.1: OVERVIEW OF PRIMARY LEGISLATION, AGREEMENTS AND AUTHORISATIONS

Act	Administering Authority	Overview of the Act
Aboriginal Land Act 1978 (NT)	Minister for Aboriginal Affairs Department of the Chief Minister and Cabinet Department of Industry Tourism and Trade (DITT)	Authorises a Land Council to grant certain permits to access Aboriginal land but Land Councils are not able to grant permits that would interfere with the use or enjoyment of the owner of another interest, such as the s.41 Authority, granted under the *Atomic Energy Act.*
Aboriginal Land Rights (Northern Territory) Act 1976 (Cwlth)	Minister for Indigenous Australians s44 Agreement The Attorney-General's Department The Department of the Prime Minister and Cabinet	The Act establishes the process for licensing use of Aboriginal Land, Aboriginal Land Trusts and the Land Councils to manage the Land Trusts. The relevant Australian Government Ministers have entered into an agreement under section 63 of the Act, which determines how much of the royalties that ERA pays to the Australian Government go to the traditional owners. ERA has approval (s44 Agreement) under the *Aboriginal Land Rights (Northern Territory) Act* to mine and explore the Ranger Project Area, which is on land belonging to the Kakadu Aboriginal Land Trust.
Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (Cwlth)	Attorney-General's Department Department of Climate Change, Energy, the Environment and Water	The *Aboriginal and Torres Strait Islander Heritage Protection Act* is designed to be a last resort for protection of both significant Aboriginal objects and areas. It allows the Commonwealth Minister for the Environment to make a declaration to protect significant Aboriginal objects and areas in certain defined circumstances.

Atomic Energy Act 1953 (Cwlth)	Department of Industry, Science and Resources	This Act vests title of all "prescribed substances" in the Commonwealth which includes uranium oxide (section 5). The Act establishes the process for authorising mining as well as recovering, treating and processing prescribed substances. The Act does not exclude or limit the operation of any Territory law that is capable of operating concurrently. Part III of the Act specifically addresses the Ranger Project Area (RPA) and refers to the definition of the RPA as stated in the *Aboriginal Land Rights Act.*
Environment Protection (Alligator Rivers Region) Act 1978 (Cwlth)	Department of Climate Change, Energy, the Environment and Water	The *Environment Protection (Alligator Rivers Region) Act* establishes the functions and responsibilities of the Supervising Scientist and the Environmental Research Institute of the Supervising Scientist (ERISS), as well as establishing the Alligator Rivers Regional Advisory Committee (ARRAC) and the Alligator Rivers Region Technical Committee (ARRTC). The SSB is required to provide advice to the Commonwealth Minister, NT Minister and or the Supervising Authority (per Ranger Authorisation).
Environmental Protection (Northern Territory Supreme Court) Act 1978 (Cwlth)	Attorney-General's Department	This Act gives the Supreme Court of the NT jurisdiction to make orders for the enforcement, in relation to uranium mining operations in the Alligator Rivers Region, of any requirement that relates to the environment in that region.

Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)	Department of Climate Change, Energy, the Environment and Water	The *Environment Protection and Biodiversity Conservation Act* ("EPBC Act") provides a national scheme for environment and heritage protection and biodiversity conservation. Under the EPBC Act, actions likely to have a significant impact on a matter of national environmental significance (MNES) are assessed. Matters considered to be of national environmental significance include for example; world heritage values (Kakadu National Park), wetlands of international importance, migratory species, and nuclear actions (including uranium mining). The Criminal Code applies to offences under the Act and breaches of the Act can result in prosecution. The Act prohibits a number of activities from being conducted as set out in the Regulations.
Heritage Act 2011 (NT)	Minister for Arts, Culture and Heritage Department of Territory Families, Housing and Communities	The *Heritage Act* protects Aboriginal archaeological objects and places. The archaeological objects covered are relics pertaining to the past occupation by Aboriginal or Macassan people, being: an artefact or thing of any material given shape to by man; a natural portable object of any material sacred according to Aboriginal tradition; or human or animal skeletal remains.
Mining Management Act 2001 (NT)	Minister for Mining and Industry Department of Industry, Tourism and Trade	The *Mining Management Act* is the primary legislation governing mining in the NT and specifically addresses environmental management, health and safety on mine sites. The Act also covers control of the mine site, the issuing of Authorisations to mine, requirements for Mining Management Plans and offences under the Act. The Act requires the Ranger Authorisation to incorporate or adopt by reference the Ranger Mine ERs.

Northern Territory Aboriginal Sacred Sites Act 1989 (NT)	Minister for Arts, Culture and Heritage Aboriginal Areas Protection Authority	Establishes a procedure for the protection and registration of sacred sites and establishes the Aboriginal Areas Protection Authority (AAPA) as an independent statutory organisation to oversee protection. The Act establishes offences for entry onto, work on or, desecration of, sacred sites without appropriate Authority Certification or in contravention of the certification. The Act does not derogate from the provisions of the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* or the *Aboriginal Land Rights (NT) Act 197*6.
Protection of Movable Cultural Heritage Act 1986 (Cwlth)	The Department of Infrastructure, Transport, Regional Development, Communications and the Arts	For a declared heritage place or object, a conservation management plan is required for a person to carry out work of any sort, to damage, demolish, destroy, desecrate or alter or, for the object to be moved. ERA and the Gundjeihmi Aboriginal Corporation (GAC) maintain a secure database of archaeological sites on the Ranger Project Area to ensure that no harm comes to those sites.
Radiation Protection Act 2004 (NT)	Minister for Health NT Department of Health	The Radiation Protection Act repealed the Radiation (Safety Control) Act 1978 (NT). The Act applies to the manufacture, sale, acquisition, possession, use, storage, transport and disposal of a radiation source but can include any activity that is connected with radiation practices.
Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste	Australian Government - Australian Radiation Protection and Nuclear Safety Agency	The Code establishes requirements for radiation protection for the mining industry and protection of human health and the environment from the effects of radioactive waste generated. As part of its Authorisation, ERA is required to abide by the provisions in the Code of Practice (1987). This

Instrument	Governing Body/Parent Instrument	Description
Management in Mining and Mineral Processing (2005)	(ARPANSA)	Relates to preparing an approved Radiation Management Plan, Radioactive Waste Management Plan, cessation of operations and rehabilitation.
Memorandum of Understanding between the Commonwealth of Australia and the NT regarding Working Arrangements for the Regulation of Uranium Mining in the NT (1975)	Commonwealth Minister for Resources and Minister for Northern Australia Northern Territory Minister for Mining and Industry; Minister for Northern Australia and Trade	The Commonwealth of Australia and the NT share regulatory responsibility for uranium mining via the Memorandum commonly referred to as "the Working Arrangements". The purpose is to establish procedures for consultation between the Australian Government's Office of the Supervising Scientist and the NT Department of Primary Industry and Resources (DPIR) in the performance of its legislative functions with “maximum efficiency and minimum duplication”. The Working Arrangements establish the functions of the Ranger MTC; make provision for ad hoc Technical Working Groups comprised of the same representatives (and others as necessary); and reiterate the functions of the Alligator Rivers Region Advisory Committee (ARRAC) and refer to the Alligator Rivers Region Technical Committee (ARRTC); and establishes that the NT Supervising Authority (NT Department of Primary Industry and Resources).

Agreement between the Commonwealth of Australia and the NT in relation to principles to be applied in the regulation of uranium mining in the NT (2000)	Commonwealth Minister for Resources and Minister for Northern Australia Northern Territory Minister for Mining and Industry; Minister for Northern Australia and Trade	As per the *Mining Management Act* the NT Minister must consult with the Commonwealth Minister (administering the Atomic Energy Act) about matters agreed in writing between them relating to the mining of uranium or thorium; and, must act in accordance with any advice provided by the Australian Government Minister. The 'matters agreed in writing between' the Australian and NT Ministers (referred to above) are principally contained in this Agreement. The NT Minister is the Supervising Authority for the Ranger Mine ERs, the Australian Government Minister has the primary decision-making role.
s41 Authority (Jan 1979) New s41 Authority (November 1999)	Commonwealth Minister for Resources and Minister for Northern Australia *Atomic Energy Act 1953* (Cwlth)	The Australian Government Minister granted ERA an authority (s.41 Authority) under the *Atomic Energy Act 1953* (Cwth) authorising ERA to mine, recover, treat and process uranium oxide (a "prescribed substance") at Ranger Mine. The Environmental Requirements (ERs) are attached to the s.41 Authority and form a condition of the Authority. The s.41 Authority also states that ERA must comply with the "Complementary Agreement", "Government Agreement" and "Mining Agreement". Under this Authority, the supervising authority is required to approve the MCP (also approved by Cwth) with advice from SSB. The original s41 Authority under the *Atomic Energy Act* applied for 26 years (21 years mining and 5 years rehabilitation) between 1979 and 2000.

s41 Authority - Environmental Requirements (ERs)	Commonwealth Minister for Resources and Minister for Northern Australia *Atomic Energy Act 1953* (Cwlth)	The Ranger Mine ERs are attached to the s.41 Authority and set out Primary and Secondary Environmental Objectives which establish the principles by which the Ranger Mine operation is to be conducted, closed and rehabilitated and the standards that are to be achieved.
s44 Agreement	Minister for Indigenous Australian	The Commonwealth was required to enter into an agreement with the NLC under the then section 44 (2) of the *Aboriginal Land Rights Act* prior to authorising the s41 Authority under the *Atomic Energy Act.* This agreement continues in force under transitional provisions. The s44
between the Commonwealth of Australia and theNorthern Land Council (November 1978) Renegotiated s44 Agreement (January 2013)	Northern Land Council *Aboriginal Land Rights (NT) Act 1976* (Cwlth) (Attorney-General's; Prime Minister and Cabinet)	Agreement was established to address payments to be made to the NLC and conditions for operating the Ranger Mine.

Instrument	**Governing Body/Parent Instrument**	**Description**
Extension Agreement between the Commonwealth of Australia and the Northern Land Council (March 1999)	Minister for Indigenous Australians Commonwealth Minister for Resources and Minister for Northern Australia Northern Land Council s44 Agreement	For ERA to continue operations beyond 2000, the Commonwealth was required to negotiate a new s44 Agreement with the NLC before it could grant a new s41 Authority. An agreement was unable to be successfully negotiated between 1996 and 1998. This resulted in an arbitration process and concluded with the parties entering into an "agreement to agree" in the form of a Deed (“Extension Agreement”). This extends the s.44 agreement for a *further* 26 years (21 years mining, 5 years rehabilitation) and required the parties to agree on a new s.44 agreement.
Complimentary Agreement between the Commonwealth of Australia, the Northern Land Council and ERA (March 1999)	Commonwealth Minister for Resources and Minister for Northern Australia Minister for Indigenous Australians Northern Land Council s44 Agreement	ERA, the Commonwealth and NLC entered into a "Complementary Agreement" to complement the terms of the extension agreement. This contemplated that: a) The Commonwealth and NCL would renegotiate the terms of the extended s44 Agreement; b) The NLC and ERA would negotiate the Mining Agreement; and c) The Commonwealth and ERA would amend the Government Agreement to reflect the renegotiated s44 Agreement and was consistent with the Mining Agreement. In addition, under this complementary agreement, ERA has agreed to enter into a "mining agreement" with the NLC.

Instrument	Governing Body/Parent Instrument	Description
Ranger Uranium Project Deed of Assignment Commonwealth of Australia and Australian Atomic Energy Commission to Energy Resources of Australia LTD (September 1980)	Commonwealth of Australia	Commonwealth agreed to sell and assign its shares of Concentrates of Ranger Uranium Ore and certain other rights to ERA. Further the AAEC agreed to to sell and assign the whole of the AAEC enterprise, it rights, obligations and duties and the whole of its interest in the Authority. ERA agreed to purchase and take those assignments on the conditions within this Deed.
Ranger Uranium Project - Government Agreement between Commonwealth of Australia and Energy Resources of Australia LTD (September 1979) (Amended 1982, 1990, 1992, 1993, 1995, 1999 & 2013)	Commonwealth Minister for Resources and Minister for Northern Australia Section 41 Authority	The Commonwealth entered into a separate agreement, in October 1974, with ERA's predecessor (Peko-Wallsend Operations Ltd, Electrolytic Zinc Company of Australasia Ltd) which referred to the development and mining of ranger deposits. The parties entered into a Memorandum of Understanding in 1975, which was later foreshadowed by the "the Government Agreement" and included the AAEC. In 1980 Peko, EZ and the AAEC sold the whole of their interests and rights under the Government Agreement to ERA and the s41 Authority was transferred to ERA.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Mining Agreement between the Northern Land Council and ERA (January 2013)	s44 Agreement Extension Agreement	The Mining Agreement is executed contemporaneously with the deed of amendment and restatement that varies the Extended s44 Agreement to create the Renegotiate s44 Agreement. The Commonwealth Minister consented to the NLC entering the Mining Agreement pursuant to the *Land Rights Act*. ERA entered into the Mining Agreement as consideration of the NLC entering into the Renegotiated s44 Agreement and in order to comply with its obligations under the Complementary Agreement.
Ranger Authorisation and Annex to Authorisation Variation of Authorisation 0108-18 (June 2018)	NT Department of Industry, Tourism and Trade (DITT) *Mining Management Act 2001* (NT)	The NT maintains an Authorisation for the Ranger Mine operations which fulfils the requirements of the Mining Management Act 2001 (NT). The Annex of Authorisation contains the key terms of ERA's licence to operate and reflects the ERs.

APPENDIX 3.2: CLOSURE LEGAL OBLIGATIONS REGISTER

ERA Closure Obligations Register up to 30 June 2022

This register contains the environmental and cultural legal obligations applicable to ERA in relation to the closure of the Ranger Mine.
The obligations below represent a subset of the overarching obligations and compliance requirements applicable to all operations.
The list compiled below is not limiting and all efforts have been made to identify commitments that either generally or specifically apply to the mine closure timeline, objectives and activities.

Instrument	Title	Section	Obligation
Legislation	*Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (Commonwealth)*	Section 20 - Discovery of Aboriginal remains	If ERA discovers anything suspected to be Aboriginal remains, details of the remains and their location must be reported to the Minister.
Legislation	*Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (Commonwealth)*	Section 22(2) & 23 - Offences & Penalties	ERA will be guilty of an offence if it engages in conduct that contravenes the terms of a declaration relating to significant Aboriginal object(s) (see section 12). This is an indictable offence. (Penalties: Max: 250 Penalty Units).
Legislation	*Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (Commonwealth)*	Section 22(3) - Offences & Penalties	If ERA does not report the discovery of remains suspected to be Aboriginal to the Minister (see section 20), it will be guilty of an offence. (Penalty: a fine not exceeding 5 Penalty Unit).
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 4(1) - Entry onto Aboriginal land or road	ERA shall not enter onto/remain on Aboriginal land or use a road unless it has been issued with a permit to do so. A permit also allows ERA to use a road that is bordered by that Aboriginal land. (Penalty - Max: 8 Penalty Units).
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 4 - Entry onto Aboriginal land or road and Section 21 - No prosecution except on authority of Land Council	It is an offence to enter onto Aboriginal land or use a road without a permit. A complaint against this offence shall not be heard unless it is supported by a notice in writing by the relevant Land Council. (Penalty: Max: 8 Penalty Units).
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 5 - Issue of permits	The Land Council for the area in which the Aboriginal land or road is situated or the Traditional Aboriginal Owners of an area, may issue a permit to a person to enter onto and remain on that Aboriginal land or use that road subject to conditions specified by the Land Council/Traditional Aboriginal Owners. The permit must be in writing and can be cancelled by the Land Council or the Traditional Aboriginal Owners.

Instrument	Title	Section	Obligation
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 5A - Administrator may issue permits to use roads in certain circumstances	Where the Land Council or those Traditional Aboriginal Owners refuse to issue the permit to use the road, within a reasonable time, then the person may apply to the Administrator who may issue the permit to use the road subject to the conditions set out in the permit.
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 22(1) - Vehicles may be stopped and questions asked	A police officer may require an ERA employee, where they are about to enter Aboriginal land or open road, to produce a permit or state his name and address.
Legislation	*Aboriginal Land Act 1978 (NT)*	Section 23 - Offence to refuse to produce permit	It is an offence not to produce a permit or state your name and address if ERA is required to do so under section 22(1). (Penalty: 8 Penalty Units).
Legislation	*Aboriginal Land Rights (Northern Territory) Act 1976*	Section 48D- Payments in respect of mining under Acts	ERA is not authorised to enter or remain on the land or do any act on the land unless the Commonwealth has entered into an agreement for the payment of specified amounts by the Commonwealth to the Land Council. An agreement was made on 3 November 1978 and extended on 19 March 1999.
Legislation	*Aboriginal Land Rights (Northern Territory) Act 1976*	Section 69 - Sacred Sites	Unless authorised under the Act, ERA is guilty of an offence if it enters or remains on a Northern Territory sacred site. It is a defence if ERA had no reasonable grounds to suspect that the land concerned was a sacred site. (Penalty: $1,000 Penalty Units).
Legislation	*Aboriginal Land Rights (Northern Territory) Act 1976*	Section 70 - Entry on Aboriginal Land	Unless authorised under the Act, ERA is guilty of an offence if it enters or remains on Aboriginal Land. The defence of necessity applies. (Penalty: 10 Penalty Units).
Legislation	*Atomic Energy Act 1953 (Commonwealth)*	Section 41 - Authority to mine prescribed substances on behalf of, or in association with, the Commonwealth	The Minister may authorise ERA to mine for prescribed substances in the Ranger Project Area, subject to any specific conditions or restrictions, and: (a) enter with workmen, b) bring on machinery and vehicles, c) take possession of whole/part of the land, d) carry on, upon or under that land operations for discovering prescribed substances, and for mining, recovering, treating and processing prescribed substances and other minerals in order to obtain prescribed substances, e) erect or install buildings, structures and machinery for mining operations, f) cut and construct water races, drains, dams, tramways and roads for mining operations, g) bore or sink for water, and pump, raise or use water, or mining operations, h) demolish or remove buildings, structures and machinery erected or installed, i) remove persons who enter the land without consent or by law, j) pass over, or authorize persons and things to pass/be carried over the land, and k) do all other things necessary for the exercise of ERA's powers. ERA must also comply with the Ranger Uranium Project Government Agreement that was made on 9/1/1979 between the Commonwealth, Peko-Wallsend Operations Ltd., Electrolytic Zinc Company of Australasia Limited and the Commission.

Instrument	Title	Section	Obligation
Legislation	*Atomic Energy Act 1953 (Commonwealth)*	Section 41A - Revocation and variation under Section 41	ERA may apply for the authority to mine to be cancelled. This may not occur unless an action for the rehabilitation of the area affected by operations has been observed. By prior written notice, the Minster may impose additional conditions or restrictions on ERA if they refuse or fail to comply with an existing condition or restriction. This may prevent mining operations for a specific period or indefinitely.
Legislation	*Atomic Energy Act 1953 (Commonwealth)*	Section 41C - Further Authority under section 41 in respect of Ranger Project Area	(4) If the agreement is extended as mentioned in that or a further agreement is entered into the Minister shall; a) as soon as practicable, after consulting with the applicants, determine the conditions and restrictions to which the new authority is to be subject, being conditions and restrictions that: i) include conditions and restrictions that the Minister is satisfied will ensure the rehabilitation, in the manner and to the extent provided by the current authority, of the area affected by operations carried on under the current authority; b) as soon as practicable, but not later than 6 months before expiration of the mining period, give to the applicants a notice in writing setting out those conditions and restrictions.
Legislation	*Atomic Energy Act 1953 (Commonwealth)*	Section 41D - Offences relating to breach of condition	It is an offence to refuse/fail to comply with a condition or restriction subject to which an authority has been granted to the company. (Penalty: 100 Penalty Units).
Legislation	*Atomic Energy Act 1953 (Commonwealth)*	Section 41E - Offences relating to breach of condition	It is an offence to enter into a land without the consent of the person in possession of the land or without the right or power conferred by law. (Penalty: 10 Penalty Units).
Legislation	*Australian Radiation Protection and Nuclear Safety Act 1998 (CTH)*	N/A	Codes of practice relevant to ERA include: - Code of Practice and Safety guide: Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005) - Code of Practice for the Safe Transport of Radioactive Material (2001) still applies)
Legislation	*Biological Control Act 1986 (NT)*	N/A	Under the Act ERA can make an application to Northern Territory Biological Control Authority for an organism which is causing harm to the Territory to the Northern Territory Biological Control Authority. The Authority can declare the organism to be a target organism and implement biological control measures which includes either reducing the numbers or preventing an increase of the numbers of the organism. Under the Act, ERA can also nominate an organism to be declared an agent organism if it believes its release would control a target organism. The Act is not directly applicable to the operations of ERA therefore further information has not been included.

Instrument	Title	Section	Obligation
Legislation	*Bushfires Management Act 2016 (NT)*	Section 68 - Requirement to establish firebreaks	Owner or occupier of land must have a firebreak around the perimeter of the land, or another approved position or close to, the land within a fire protection zone. (Penalty - Max: 20 Penalty Units and 2 Penalty Units for each day during which the offence continues).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 70(1),(5)/81(5) - Property fire management plans	Owner of land within a fire protection zone may be required to prepare and submit to the executive director a property fire management plan for the land. The executive director may return the plan and request amendments to be made.
Legislation	*Bushfires Management Act 2016 (NT)*	Section 72 - Offence to light small fire near flammable material	ERA must not light small fire: (a) within a fire protection zone or a fire danger zone during a fire danger period or (b) less than 4 m away from bush or other flammable material. (Penalty - Max: 100 Penalty Units).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 73 - Offence to light fire unless authorised by permit	ERA must not intentionally lights a fire (other than a small fire) in the open air within a fire protection zone, or within a fire danger area during a fire danger period. (Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 75 - Matter not to be thrown	ERA must not throw from a vehicle or otherwise, within 4 m of any bush or other flammable material, a thing that is burning or smouldering within a fire protection zone, or within a fire danger area during a fire danger period. (Penalty - Max:100 Penalty Units).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 76 -Spark arresters	ERA must not start an engine which sparks, flames or burning material from the engine's exhaust, on the land that is within a fire protection zone, or within a fire danger area during a fire danger period.(Penalty - Max:100 Penalty Units).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 84 - Property fire management plans	Owner of land within a fire management area must perform all the acts specified in the fire management plan and within the stipulated period as specified by the executive director.
Legislation	*Bushfires Management Act 2016 (NT)*	Section 86(1) - Prohibition on fires in fire ban areas	ERA must not intentionally light a fire in the open air in a fire ban area during a fire ban period. (Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 90 - Duty of owner or occupier to control fires	An owner or occupier of land must take all reasonable steps to protect property on the land from fire and prevent fire spreading from one land to other land. If unable to control a fire on the land, the owner/occupier must take all reasonable steps to notify fire control officer or fire warden and the occupier of or a person apparently over the age of 16 years present on land to which the fire is likely to spread. (Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).
Legislation	*Bushfires Management Act 2016 (NT)*	Section 91 - Duty of person who lights fire to control it	If a fire is lit, ERA must protect property on the land from the fire and prevent the fire spreading from the land to other land. If a person who lights a fire is unable to control the fire, they must take all reasonable steps to notify as per Section 90. (Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).

Instrument	Title	Section	Obligation
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	Section 2.7.1 - Radiation Management Plan	Before the commencement of any stage of an operation to which this Code applies, a Radiation Management Plan (RMP) for that stage must be devised and presented to the relevant regulatory authority for approval. The Plan must be directed towards meeting the objectives of this Code and must be in accordance with the best practicable technology and take into account the potential dose delivery pathways.
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	Section 2.8.1 - Radioactive Waste Management Plan	A Radioactive Waste Management Plan (RWMP) must be developed to provide for the proper management of radioactive waste arising from operations. Before the commencement of any stage of an operations, a RWMP for that stage must be presented to the relevant regulatory authority (see Annex A) for approval. The Plan must be directed towards meeting the objectives of this Code and must be in accordance with best practicable technology and take into account the potential dose delivery pathways.
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	Section 2.9.4 - Approvals and Authorisations	An operator must not commence decommissioning or rehabilitation of any part of a mine, processing plant or waste management facility to which this Code applies without authorisation from the relevant regulatory authority.
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	Section 2.9.5 - Approvals and Authorisations	The relevant regulatory authority must be informed of any proposal for significant changes to an operation to which an approved Radiation Management Plan or Radioactive Waste Management Plan applies.
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	3.7.4 Cessation of Operations	Cessation of operations constitutes a 'significant change' under Clause 2.9.5 of the Code, and the relevant regulatory authority (see Annex A) should be notified. The operator should continue all relevant monitoring, inspection and rehabilitation programs until approval to discontinue is received from the relevant regulatory authority. b) Permanent Closure - Prior to the permanent closure of all or part of an operation, plans for decommissioning and rehabilitation will need to be updated or prepared, and submitted for approval. Such plans will form part of the relevant RMP and RWMPs. Again, the relevant regulatory authority will require assurance that the site remains in an acceptable condition until rehabilitation is complete, and that deterioration which might prejudice final rehabilitation does not occur.
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	3.7.5 Authorisation to Rehabilitate	The waste management plan should contain proposals for rehabilitation of the project as a whole and for individual components (for example tailings dams reaching their capacity). On decommissioning, these plans will need to be updated and engineering detail finalised. Requirements and responsibilities for continuing monitoring and surveillance of the site, and of any remedial work that may become necessary, will need to be determined.

Instrument	Title	Section	Obligation
Legislation	*Dangerous Goods Act 1998 (NT)*	Section 9(1) - Safe handling of dangerous goods	A person handling dangerous goods must ensure as far as practicable, that all dangerous goods are handled safely. (Penalty: 2160 penalty units and where an offence results in death or serious harm to a person – 40320 penalty units)
Legislation	*Dangerous Goods Act 1998 (NT)*	Section 9(2) - Safe handling of dangerous goods	ERA will be guilty of an offence, if it is involved in the handling of dangerous good and fails to ensure that: (a) the goods are handled in a manner or in circumstances that the goods will not:(i) endanger or be likely to endanger the safety or health of a person or (ii) damage or be likely to damage any property or (b) the goods are not abandoned.
Legislation	*Dangerous Goods Act 1998 (NT)*	Section 9(3) - Safe handling of dangerous goods	ERA may be guilty of an offence, if it is in charge of dangerous goods and fails to ensure: (a) the safety and maintenance in safe condition of the plant or a container, vehicle, building or structure, used in the handling of the goods; (b) plant, containers and substances used, handled, stored or transported for goods in a safe manner or (c) a system is in place which provides and ensures: (i) the safe management of the goods; (ii) the identification of hazards, assessment and control of risks; (iii) safe work practices; (iv) that appropriate information, training, instruction and supervision are provided for safe handling of the goods; and (v) that appropriate information for safe handling of the goods is provided to other persons affected, or likely to be affected.
Legislation	*Dangerous Goods Act 1998 (NT)*	Section 15 - Goods too dangerous to transport	ERA must not transport any dangerous goods or cause or arrange to transport, dangerous goods that the Regulations specify are too dangerous to transport (Penalty - 2160 penalty units).
Legislation	*Dangerous Goods Act 1998 (NT)*	Reg 5D - Possession of explosives	ERA must not have any explosives (other than safety cartridges, distress signals or propellant for firearms) in its possession except in accordance with the-terms and conditions of a licence (Penalty - Max: 40 penalty units).
Legislation	*Electricity Reform Act 2000 (NT)*	Section 35 - Surrender of License	An electricity entity must give 6 months prior written notice to Utilities Commission before the surrender of the licence.
Legislation	*Environmental Offences and Penalties Act 1996 (NT) and Environmental Offences and Penalties Regulations 2011 (NT)*	Section 4 - Penalty for environmental offence level 1, i.e., where the offence causes 'serious environmental harm'	If ERA is found guilty of a level 1 environmental offence, a penalty of not less than 1924 penalty units and not more than 19240 penalty units is applicable.
Legislation	*Environmental Offences and Penalties Act 1996 (NT) and Environmental Offences and Penalties Regulations 2011 (NT)*	Section 5 - Penalty for environmental offence level 2, i.e., where the offence causes 'material environmental harm'	If ERA is found guilty of a level 2 environmental offence, a penalty of not less than 770 penalty units and not more than 7700 penalty units is applicable.

Instrument	Title	Section	Obligation
Legislation	*Environmental Offences and Penalties Act 1996 (NT) and Environmental Offences and Penalties Regulations 2011 (NT)*	Section 6 - Penalty for environmental offence level 3, i.e., where the offence causes 'environmental harm'	If ERA is found guilty of a level 3 environmental offence, a penalty of not less than 385 penalty units and not more than 3850 penalty units is applicable.
Legislation	*Environmental Offences and Penalties Act 1996 (NT) and Environmental Offences and Penalties Regulations 2011 (NT)*	Section 7 - Penalty for environmental offence level 4, i.e., where the offence occurs, but no environmental harm is caused	If ERA is found guilty of a level 4 environmental offence, a penalty of not more than 385 penalty units is applicable.
Legislation	*Environmental Offences and Penalties Act 1996 (NT) and Environmental Offences and Penalties Regulations 2011 (NT)*	Section 8 - Infringement notices	If ERA appears to have committed a level 3 or 4 environmental offence and is served with an infringement notice, ERA may pay as an alternative to the prescribed penalty under this Act: a) level 3 environmental offence, 8.8 penalty units, or b) level 4 environmental offence, 4.4 penalty units.
Legislation	*Environment Protection (Alligator Rivers Region) Act 1978 (CTH)*	Section 27 - Power of Supervising Scientist to obtain information and documents	ERA to provide the information and documents within the time limit and manner as specified, if the notice in writing furnished by the Supervising Scientist for providing such information and documents.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 3: Section 12 - Requirement for approval of activities with a significant impact on a declared World Heritage property	A person must not take an action that: (a) has or will have a significant impact on the world heritage values of a declared World Heritage property, or (b) is likely to have significant impact on the world heritage values of a declared World Heritage property (Civil Penalty - Max: 50,000 penalty units).
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 3: Section 15A - Offences relating to World Heritage Properties: Section 17B - Offences relating to declared Ramsar wetlands : Section 18A - Offences relating to listed threatened species etc : Section 20A - Offences relating to listed migratory species	(1) A person is guilty of an offence if: (a) the person takes an action; and (b) the action results in or will result in or is likely to have a significant impact on either the world heritage values of a property, the ecological character of a wetland or a species or ecological community; and (c) either the property is a declared World Heritage property, the property is declared a Ramsar wetland, the species is a listed threatened species, the community is a listed threatened ecological community or the species is a listed migratory species. Strict liability applies to paragraph (c) (Civil penalty - Max: 50,000 penalty units). (Penalty - Punishable on conviction by imprisonment Max: 7 years, a fine - Max: 420 penalty units, or both. Additionally, Penalty - Max 2,100 penalty units (Section 4B(3) Crimes Act, 1914)).

Instrument	Title	Section	Obligation
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 3: Section 25 - Requirement for approval of prescribed actions Reg 12.20 Taking plants into Commonwealth reserve	A person must not cause or allow a plant to be taken into, or possess a plant in, a Commonwealth reserve. Penalty: 20 penalty units ($2,200). This does not apply to a) taking into the Jabiru township a plant included on the Director's list of plants, b) taking a specified plant into a Commonwealth reserve to cultivate or propagate the plant on land held under a lease or licence granted by the Director, or c) taking a plant into a Commonwealth reserve as food. It does not apply to a person who takes a plant into, or possesses a plant, in a reserve if the plant is confined in a vehicle on a road or in a vessel on a watercourse. This regulation does not apply to specified pest species.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Reg 12.19A Offences in relation to non-native species and Reg 12.19B Offences in relation to native species Reg 12.19C Complying with a direction in relation to native species	It is an offence if a person takes an action and do not comply with the directions in relation to native species in a Commonwealth reserve that results in the a) death or injury of a member of a non - native and native species in the reserve; or b) involves taking, trading, keeping or moving a member of a non-native and native species in the reserve; or c) cause disturbance or harm to a member of a native species in the reserve; ord) cause disturbance or harm to the habitat of a native species in the reserve. (Penalty: 50 Penalty units).Note: The above regulation (a) and (b) are not applicable on person who is permitted by these regulations to take action.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 3: Section 25 - Requirement for approval of prescribed actions Reg 12.21 Cultivating plants	A person must not cultivate or propagate a plant in a Commonwealth reserve. (Penalty: 30 penalty units). Note: This does not apply to: a) in the Jabiru township if the plant is a native species and included in the Director's list of plants or b) on land that is not in the township but held under a lease or licence granted by the Director which specifies the plant may be cultivated or propagated. This regulation does not apply to specified pest species.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 3: Section 26 - Requirement for approval of activities involving Commonwealth land	A person must not take on Commonwealth land an action that has/will have/is likely to have a *significant impact* on the environment. A person must not take outside Commonwealth land an action that has/will have/is likely to have a significant impact on the environment. (Penalty: 10,000 penalty units).
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 4: Section 43A - Actions with prior authorisation	(1) A person may take an action described in a provision of Part 3 without an approval under Part 9 (Approval of Actions) for the purposes of the provision if: (a) the action consists of a use of land, sea or seabed; and (b) before the commencement of this Act, the action was authorised by a specific environmental authorisation; and (c) immediately before the commencement of this Act, no further specific environmental authorisation was necessary to allow the action to be taken lawfully ;

Instrument	Title	Section	Obligation
			and (d) at the time the action is taken, the specific environmental authorisation continues to be in force.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Section 211 Killing or injuring member of listed migratory species 211A Strict liability for killing or injuring member of listed migratory species	A person commits an offence if: (a) the person takes an action; and (b) the action results in the death or injury of a member of a species; and (c) the member is a member of a listed migratory species; and (d) the member is in or on a Commonwealth area. (Penalty for aggravated offence - Max: Imprisonment for 2 years or 3,000 Penalty Units or both and Penalty in any other case - Max: Imprisonment for 2 years or 1,000 Penalty Units or both) Strict liability applies to (a) to (d) (Penalty aggravated offence - Max: 1,500 Penalty Units and Penalty in any other case - Max: 500 Penalty Units)
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Section 211B Taking etc. member of listed migratory species 211C Strict liability for taking etc. member of listed migratory species	A person commits an offence if: (a) the person takes, trades, keeps or moves a member of a species; and (b) the member is a member of a listed migratory species; and (c) the member is in or on a Commonwealth area. (Penalty for aggravated offence - Max: Imprisonment for 2 years or 3,000 Penalty Units or both and Penalty in any other case - Max: Imprisonment for 2 years or 1,000 Penalty Units or both) Strict liability applies to (a) to (c) (Penalty aggravated offence - Max: 1,500 Penalty Units and Penalty in any other case - Max: 500 Penalty Units)
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	211D Trading etc. member of listed migratory species taken in Commonwealth area 211E Strict liability for trading etc. member of listed migratory species taken in Commonwealth area	A person commits an offence if: (a) the person trades, keeps or moves a member of a migratory species; and (b) the member is a member of a listed migratory species; and (c) the member has been taken in or on a Commonwealth area. (Penalty for aggravated offence - Max: Imprisonment for 2 years or 3,000 Penalty Units or both and Penalty in any other case - Max: Imprisonment for 2 years or 1,000 Penalty Units or both) Strict liability applies to (a) to (c) (Penalty aggravated offence - Max: 1,500 Penalty Units and Penalty in any other case - Max: 500 Penalty Units). Strict Liability applies to (1)(b) (Penalty - Max: 5,000 Penalty Units).

Instrument	Title	Section	Obligation
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 15: Section 354 & 355 - Activities that may be carried on only under management plan	(1) A person must not do the following acts in a Commonwealth reserve except in accordance with its management plan: a) kill, injure, take, trade, keep or move a member of a native species, b) damage heritage, c) carry on an excavation, d) erect a building or other structure, e) carry out works, or f) take an action for commercial purposes. (Penalty - Max: (Body corporate) 5,000 penalty units). A person must not carry on mining operations in a Commonwealth reserve except in accordance with a management plan in operation for the reserve. (Penalty - Max: (Body Corporate) 5,000 penalty units) (1A) Subsection (1) does not apply in relation to the Kakadu National Park or the Antarctic.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 15: Section 387 - No mining operations in Kakadu National Park	A person must not carry out mining operations in Kakadu National Park. Note: This does not prevent, as prescribed by the regulations: a) the use, development or reconstruction of the town Jabiru, b) transportation of anything in Kakadu National Park along routes including air (see Part 1 of Schedule 9), c) the construction and use of pipelines and power lines in Kakadu National Park along routes (see Part 2 of Schedule 9), d) activities for the purposes of building or construction, or the supply of water, in Kakadu National Park as long as they are not connected with, or incidental to, mining operations and e) prescribed activities (i.e. the non destructive monitoring of the environment) in Kakadu National Park in connection with, or incidental to, mining operations outside Kakadu National Park.
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 17: Section 458 - Directed environmental audits	ERA may be directed by the Minister to undertake an environmental audit where the Minister suspects ERA is contravening/has contravened the Act
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 17: Section 490 - Providing false or misleading information in response to a condition on an approval or permit	The person is guilty of an offence the person is reckless as to whether information is false or misleading in a material particular which is provided in relation to a requirement of a condition attached to an environmental authority. (Penalty - Max: If ERA knew the information was false or misleading: 2yrs imprisonment and/or 600 penalty units). (Penalty – Max: If ERA was reckless as to whether the information was false or misleading: 1 yr imprisonment and/or 300 penalty units).

Instrument	Title	Section	Obligation
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 18: Section 499 - Commonwealth powers to remedy environmental damage and Section 500 - Liability for loss or damage caused by contravention	ERA must not take an action or make an omission that contravenes this Act or the regulations. This includes providing false or misleading information leading to the grant of an authority under the Act or the regulations. ERA is also liable to pay any affected party for any loss or damage suffered by that party as a result of the contravention. There is no limit to financial liability.
Legislation	*Environment Protection (Northern Territory Supreme Court) Act 1978 (Commonwealth)*	Section 4 - Jurisdiction of the Supreme Court	(1) The Supreme Court of the Northern Territory of Australia has jurisdiction, at the suit of the Director, the Commission or a Land Council, to make orders for or in relation to the enforcement, in relation to uranium mining operations in the Alligator Rivers Region, of any requirement of or having effect under a prescribed instrument, so far as the requirement relates to any matter affecting the environment in that region. (2) A Land Council is not entitled to maintain a suit by virtue of this section unless the matter in relation to which the requirement is sought to be enforced is a matter affecting the environment in a part of the Alligator Rivers Region that is included in the area for which that Land Council is established and is Aboriginal land within the meaning of the *Aboriginal Land Rights (Northern Territory) Act 1976* . (3) The Director or the Commission is not entitled to maintain a suit by virtue of this section unless the matter in relation to which the requirement is sought to be enforced is a matter affecting the environment in a part of the Alligator Rivers Region that is included in a Commonwealth reserve or conservation zone under Part 15 of the *Environment Protection and Biodiversity Conservation Act 1999* .
Legislation	*Fire and Emergency Act 1996 (NT)*	Section 30(6) - Granting a permit	On grant of a permit to light a fire in the open air in an emergency response area, ERA must not: (a) contravene a permit or a condition to which a permit is subject; (b) provide false or misleading information in respect of an application for a permit; or (c) except with the consent of the Director, alter a particular or condition shown on a permit. (Penalty - Max:100 penalty units or imprisonment for 2 years and an additional penalty not exceeding 5 penalty unit if the offence continues).
Legislation	*Fire and Emergency Act 1996 (NT)*	Section 33 - Occupier to extinguish fires	Where a fire is burning on land in an emergency response area and the lighting of the fire is not permitted, ERA must immediately on becoming aware of the fire regardless of who lit it: a) take all reasonable steps to extinguish or control the fire and b) as soon as is practicable report the existence and location of the fire to a member or a member of the Police Force.

Instrument	Title	Section	Obligation
			(Penalty - Max:100 penalty units or imprisonment for 2 years and an additional penalty not exceeding 5 penalty unit if the offence continues).
Legislation	*Fire and Emergency Act 1996 (NT)*	Section 34(1) and 34(2) - Power of occupier to enter land	An occupier of land in an emergency response area who believes a grass or bush fire which is burning within 1 kilometre of his or her land constitutes a fire risk to his land, may enter the land on which the fire is burning, take on to that land a vehicle or equipment for extinguishing or controlling the fire and take all reasonable measures to control the fire provided there is no notice of the intent to fire either orally or written by the person lighting it or by a member or a police officer unless occupier believes that the fire is unlawfully lit or is out of control. (Penalty - Max:100 penalty units or imprisonment for 2 years and an additional penalty not exceeding 5 penalty unit if the offence continues).
Legislation	*Fire and Emergency Regulations 1996 (NT)*	Regulation 3 - Firebreaks	ERA as an occupier or owner of the land in an emergency response area must ensure that a firebreak that complies with the regulation is created and maintained along the entire boundary of the land~~.~~ (Penalty - Max: 100 penalty units).
Legislation	*Fire and Emergency Regulations 1996 (NT)*	Regulation 4 - Accumulation of flammable or combustible material	ERA as an occupier or owner of the land must ensure that flammable or combustible material does not accumulate on the land in such a way that it constitutes a danger by fire~~.~~ (Penalty - Max: 100 penalty units).
Legislation	*Fisheries Act 1988 (NT)*	Section 11 ~~15(1)~~ - Requirement for permit	(1) Subject to this Act or to an instrument of a legislative or administrative character made under it a person shall not – (c) cause or permit a shock, sound, or other vibration, whether by percussion, the use of an explosive, or otherwise, where an effect of the shock, sound, or vibration is, or may be, that fish or aquatic life is stunned, injured, killed, or detrimentally affected; or (e) introduce a dangerous substance into waters of the Territory unless the person does so under and in accordance with a permit. (Penalty- Max: 500 penalty units or imprisonment for 2 years)
Legislation	*Heritage Act 2011 (NT)*	Section 111 - Causing damage to heritage place or object	ERA must not engage in a conduct that results in damage to a heritage place or object unless the conduct is in accordance with: a heritage agreement; a work approval; authorised work; repair order; or exempt work. (Penalty - Max: 400 penalty units or imprisonment for 2 years).
Legislation	*Heritage Act 2011 (NT)*	Section 112 - Removal of part of heritage place	ERA must not remove a part of a heritage place unless:(a) it is in the possession of a person/group who has the right to possess it and removes it in accordance with the Aboriginal tradition;(b) the removal is carried out in accordance with a heritage agreement or a work approval or a repair order; or(c) the removal is authorised under the declaration of the heritage place or object.(Penalty - Max: 400 penalty units or imprisonment for 2 years)

Instrument	Title	Section	Obligation
Legislation	*Heritage Act 2011 (NT)*	Section 113 - Removal of heritage objects from Territory	ERA must not remove a heritage object from the Territory unless: (a) it is in the possession of a person/group who has the right to possess it and removes it in accordance with the Aboriginal tradition; or (b) the removal is carried out in accordance with the CEO's approval. (Penalty - Max: 400 penalty units or imprisonment for 2 years)
Legislation	*Heritage Act 2011 (NT)*	Section 114 - Discovery of archaeological places and objects	ERA must, as soon as practicable, give the CEO a written report of the discovery of a place or object the person knows is an Aboriginal or Macassan archaeological place or object with the prescribed details. (Penalty - Max: 20 penalty units)
Legislation	*Mineral Titles Act 2010 (NT)*	Section 94(1) - Reports	The holder of a mineral title must give the Minister reports about the authorised activities conducted under the title, and other matters, as required by this Act or prescribed by regulation.
Legislation	*Mineral Titles Act 2010 (NT)*	Section 99(1) - Removal of equipment	No later than 3 months after a mineral title ceases to be in force, the person who held the mineral title immediately before the cessation must remove from the former title area all plant, machinery and other equipment placed there by the person.
Legislation	*Mining Management Act 2001 (NT)*	Section 13 - General obligation to take care	Every person on a mining site must take care of the environment.
Legislation	*Mining Management Act 2001 (NT)*	Section 16 – Obligations of operator	1) The operator for a mining site must ensure that the environmental impact of mining activities is limited to what is necessary for the establishment, operation and closure of the site. Operator must: (a) establish and maintain an appropriate management structure of competent persons for the site; and; (b) ensure that workers on the site are competent to perform their duties; and; (c) establish, implement and maintain an appropriate environment protection management system for the site; and; (d) provide adequate resources for the implementation and maintenance of the management system; and (e) ensure, by regular assessment, that the management system operates effectively. (3) The operator for a mining site must display in a prominent place on the site all written instructions of a mining officer relating to the site and make those instructions available to a contractor or worker on request.
Legislation	*Mining Management Act 2001 (NT)*	Section 29 – Operator must report environmental incident or serious environmental incident	ERA (as operator) must notify the CEO as soon as practicable If an environmental incident, or serious environment incident occurs, if ERA gives oral notice of a serious/critical incident to the CEO, written notice must also be given as soon as practicable. (Penalty - Max: 200 Penalty Units). A breach of either of the above is an offence of strict liability.

Instrument	Title	Section	Obligation
Legislation	*Mining Management Act 2001 (NT)*	Section 33 - No unauthorised release of waste or contaminant	(1) ERA commits an offence if: (a) the person releases waste or a contaminant that is from a mining site; and (b) the release is not authorised by the mining management plan for the site. (2) Abovementioned offence is an offence of strict liability (Penalty: 200 Penalty Units). Note: The above provisions applies regardless of whether the release occurs on or outside the mining site; or causes, or has the potential to cause, environmental harm
Legislation	*Mining Management Act 2001 (NT)*	Section 34(4) - Minister to have regard to mining interest etc.	In granting or varying an Authorisation that relates to the Ranger Project Area, the Minister must ensure that the Authorisation incorporates or adopts by reference (with the necessary modifications) the Ranger Project Environmental Requirements.
Legislation	*Mining Management Act 2001 (NT)*	Section 38 - Variation or revocation of Authorisation	ERA (as operator) may apply for a variation of an Authorisation. Variations will only be approved where they have the effect of improving the protection of the safety or health of persons or the environment. An application for a variation of an Authorisation must state the reasons for the application and include a revised Mining Management Plan.
Legislation	*Mining Management Act 2001 (NT)*	Section 40 - Mining management plan and required information	1) A mining management plan is a plan for the management of a mining site for which the operator requires an Authorisation to carry out mining activities. 2) A mining management plan must include the following: (g) a plan and costing for closure.
Legislation	*Mining Management Act 2001 (NT)*	Division 4 - Security and levy (Section 42A - Application of Division)	This Division does not apply in relation to the following: a) an operator who carries out mining activities under the Authorisation relating to the Ranger Project Area; b) an Authorisation granted in relation to the Ranger Project Area.
Legislation	*Mining Management Act 2001 (NT)*	Section 46 - Certificate of closure	1) On completion of the rehabilitation of a mining site to the satisfaction of the Minister, the operator for the site may apply to the Minister for a certificate of closure in respect to the site. 2) When the operator has met the closure criteria for the mining site, the Minister must: a) issue to him or her a certificate of closure in respect of the site; and b) return or relinquish any outstanding security provided by the operator. 3) In this section, **closure criteria** means the standard or level of performance, as specified in the mining management plan for the mining site, that demonstrates successful closure of the site.
Legislation	*Mining Management Act 2001 (NT)*	Section 83 - Minister may cause action to be taken on a mining site	(3) The Minister may cause action to be taken to complete rehabilitation of a mining site.

Instrument	Title	Section	Obligation
Legislation	*Northern Territory Aboriginal Sacred Sites Act 1989* (NT) and *Northern Territory Aboriginal Sacred Sites Regulations 2004*	Section 19B - Application for Authority Certificate	ERA must apply to the Authority for an Authority Certificate when performing or proposing to perform work or use land comprised in or in the vicinity of a sacred site.
Legislation	*Northern Territory Aboriginal Sacred Sites Act 1989* (NT) and *Northern Territory Aboriginal Sacred Sites Regulations 2004*	Section 33 - Entry onto sacred sites	A person shall not enter or remain on a sacred site. Penalty - Max: 1,000 penalty units
Legislation	*Northern Territory Aboriginal Sacred Sites Act 1989* (NT) and *Northern Territory Aboriginal Sacred Sites Regulations 2004*	Section 34 - Work on sacred site	A person shall not work on or use a sacred site. (Penalty - Max: 2,000 penalty units. It is a defence if it is proved that the defendant acted in accordance with the conditions of an Authority or Ministers Certificate permitting it to do so
Legislation	*Northern Territory Aboriginal Sacred Sites Act 1989* (NT) and Northern Territory Aboriginal Sacred Sites Regulations 2004	Section 35 - Desecration	A person shall not desecrate a sacred site. (Penalty - Max: 2,000 penalty units.

Instrument	Title	Section	Obligation
Legislation	*Nuclear Non- Proliferation (Safeguards) Act 1987* (CTH)	Section 13 - Permit to Possess Nuclear Material	ERA to comply with the restrictions and conditions associated with the permit in respect of one or more of the following: (a) the nuclear material, or the class of nuclear material, or the associated items or items, or the class of associated items; (b) the period for which the permit is to have effect; (c) the locations for which the permit is to have effect and the procedures to be followed if nuclear material or an associated item is to be transported from one location to another (including requirements for the giving of notice to the Minister, the Director or any carrier engaged by the holder of the permit); (d) the measures to be taken to ensure the physical security of nuclear material or an associated form; (da) the taking of measures that are consistent with Australia's obligations under the Physical Protection Convention (e) the persons, of class of persons, who are allowed to be allowed access to nuclear material or an associated item nd the conditions on which access to nuclear material or an associated item is to be allowed; (f) the steps to be taken, and the records to be kept, to account for nuclear material or an associated item; (g) the uses to which nuclear material or an associated item may be put; (h) the enrichment of nuclear material or the reprocessing of irradiated nuclear material; (i) the reports to be furnished, and the inspections to be permitted, in respect of nuclear material or an associated item; (k) the transfer by the holder of the permit to another person of property in, or possession or control of, nuclear material or an associated item; (m) if the permit is a permit to possess associated technology - the communication of the information contained in, or that may be obtained of deduced from, the associated technology; (n) the alteration, dispersal or disposal of nuclear material or an associated item; (o) if nuclear material or an associated item is to be held at a nuclear facility - the provision to the Director of information in order to allow inspectors or Agency inspectors to comply with health and safety procedures applicable at the facility. (Penalty - The permit/authority may be revoked by the Minister in case of contravention of the condition, failure to observe a restriction subject to which the permit or authority is granted, contravention of a direction given or an order made under Section 73 or convicted of an offence against this Act (Section 19)).

Instrument	Title	Section	Obligation
Legislation	*Nuclear Non- Proliferation (Safeguards) Act 1987* (CTH)	Section 16B - Permit to decommission facility	(1) The Minister may grant a written permit for work to be carried out to decommission the whole or a part of a facility described in paragraph 28A(1)(a), but only if the Director's report under paragraph 12(2)(b) relating to the application for the permit states that the Director is satisfied that: (a) the applicant for the permit has provided the Director with all information the applicant was required under paragraph 12(2)(a) to provide in relation to the application; and (b) appropriate procedures could be applied for the implementation of the Australian safeguards system in relation to nuclear material and associated items that, during the decommissioning, are to be removed from the facility or otherwise dealt with; and (c) adequate physical security could be applied to nuclear material and associated items that, during the decommissioning, are to be removed from the facility or otherwise dealt with. (2) The permit is granted subject to the restrictions and conditions specified in it. (3) The permit may specify restrictions and conditions in respect of: (a) inspection of the work and the facility by inspectors and Agency inspectors; and (b) reports relating to the work and the facility (including reports on incidents affecting the work or the facility).
Legislation	*Public and Environmental Health Regulations 2014 (NT) / Public and Environmental Health Further Amendment Regulation 2020 (NT)*	Regulations 55, 56, 72 Note: Reg 74, 75 and 78 were repealed in 2020 Amendment	ERA as an owner or occupier of a place must: (a) ensure there is no water at the place such that the water is or may become a breeding ground for mosquitoes (r55(1)); (b) ensure that no circumstances exists at a place such that water accumulates at the place and becomes a breeding ground for mosquitoes (r55(2)); (c) comply with the directions given by the authorised officer regarding accumulation of water which may become a breeding ground for mosquitoes (r56); (d) comply with the directions given by the CHO regarding installation of sanitary facilities (r72);

Instrument	Title	Section	Obligation
Legislation	*Radiation Protection Act 2004 (NT) and Radiation Protection Regulations 2007*	Parts 2 Division 1 Section 11, Division 2 Section 12, Subdivision 2 Section 13,15 Division 3 Section 16, 17, 18,19, Division 6 Section 24 and Part 3 Division 1 Section 25, 26, 27, 28 Part 5 Division 4 Section 68, 69	To ensure that radiation emitted from the source during the manufacture, possession, use, storage, transport, disposal or other dealing does not result in harm to health or safety of persons or the environment. For a person who deals with a radiation source, to take all measures that are reasonable and practicable to ensure that radiation emitted from the source during the dealing does not result in harm to the health or safety of persons or the environment. (Penalty - Max: 2500 penalty units) (s.11). To comply with the requirements of the act, including:- not to manufacture, sell, acquire, possess, use, store, transport, dispose of or otherwise deal with a radiation source other than in accordance with a licence (Penalty - Max: 1000 penalty units) (s12); - treated person does not receive a dose of radiation in an amount or in a way that does not comply with the request of the diagnostic procedure (Penalty - Max: 1000 penalty units) (s.13);-not to cause another person to receive a dose of radiation that is higher than the prescribed dose limit (Penalty - Max: 1000 penalty units) (s.15);- to ensure the owner of a radiation source holds a certificate of registration for the source (Penalty - Max: 5000 penalty units)(s.16);- to ensure the occupier of a place where a radiation source is used or stored holds a certificate of registration for the place (Penalty - Max: 5000 penalty units) (s.17);- not to carry out any work on a radiation source unless the holder of a certificate of accreditation (Penalty - Max: 1000 penalty units) (s.18);- not to issue a certificate of compliance for a radiation source unless the holder of a certificate of accreditation (Penalty - Max: 5000 penalty units) (s.19(1));- not to issue a certificate of compliance for a radiation place unless the holder of a certificate of accreditation (Penalty - Max: 5000 penalty units) (s.19(2));- not to possess or supply a radiation source that is prescribed by the regulations to be a banned radiation source (Penalty - Max: 5000 penalty units) ((s.24).To ensure that an application for a licence to possess a radiation source to carry out a radiation practice is accompanied by the proposed radiation protection plan for the radiation practice (s.25 - s.28).To comply with the requirements in relation to authorised officers to provide name and address (Penalty - Max: 100 penalty units) (s.68).To comply with the requirements in relation to authorised officers and give information about the offence. (Penalty - Max: Body Corporate 500 penalty units).To notify the Chief Health Officer of a dangerous event in the prescribed form (Penalty - Max: Body Corporate 5000 penalty units) (s.69).
Legislation	*Radiation Protection Act 2004 (NT) and Radiation Protection Regulations 2007*	Part 3A Section 47B - Monitoring of exposure to radiation	The operator for a mining site must conduct monitoring or testing in relation to exposure to radiation for each radiation worker who works on the mining site. (Penalty - Max: Body Corporate 1000 penalty units)

Instrument	Title	Section	Obligation
Legislation	*Radiation Protection Act 2004 (NT) and Radiation Protection Regulations 2007*	Part 3A Section 47B - Monitoring of exposure to radiation, Section 47C - Operator to keep personal radiation exposure records for radiation workers, 47D Reporting, 47F Access to records and information for radiation workers and Regulation ,9D - Monitoring requirements, 9E - Personal radiation exposure records, 9F - Reporting requirements	The operator for a mining site must: - prepare and implement a monitoring and dose assessment program and conduct monitoring or testing in relation to exposure to radiation for each radiation worker who works on the mining site (Penalty - Max: 1000 penalty units); - maintain an up to date personal radiation exposure record for each radiation worker (Penalty - Max: 500 penalty units); - keep a personal radiation exposure record for the period prescribed by the Regulations (Penalty - Max: 100 penalty units); - must give information as required to the CEO of ARPANSA within the meaning of the Australian Radiation Protection and Nuclear Safety Act 1998 (Cth) and the Chief Health Officer (Penalty Max: 500 penalty units); - give a person access to, or a copy of, radiation exposure information about the person on request (Penalty - Max: 500 penalty units).
Legislation	*Soil Conservation and Land Utilisation Act 1969 (NT)*	Section 20 - Landholder to reduce hazard	A landholder in an area that is declared to be an erosion hazard (under section 17) must take measures as specified by the Commissioner to reduce the hazard within a certain time. Prior to declaration, the landholder is notified and is able to make an objection to the proposal. (Penalty - Max: 0.8 penalty units).
Legislation	*Territory Parks and Wildlife Conservation Act 1976 (NT) and Territory Parks and Wildlife Conservation Regulations 2001*	Section 66 - Offences relating to protected wildlife	A person must not: (a) take or interfere with protected wildlife unless the person is authorised to do so; (a) have in his or her possession or under his or her control an animal that is protected wildlife or bring protected wildlife into, release protected wildlife in or take protected wildlife out of the Territory unless the person is authorised to do so under this Act. (Penalty - (a) Protected wildlife other than threatened wildlife – Max: 2,500 penalty units and (b) Threatened wildlife - 5,000 penalty units)
Legislation	*Territory Parks and Wildlife Conservation Act 1976 (NT) and Territory Parks and Wildlife Conservation Regulations 2001*	Section 67C - Offences relating to areas of essential habitat	It is an offence to alter, damage or destroy essential habitat or remove wildlife from an area of essential habitat unless authorised under the Act. (Penalty: 2,500 penalty units)

Instrument	Title	Section	Obligation
Legislation	*Territory Parks and Wildlife Conservation By-Laws 1984 (NT)*	Part 3 - Control of Activities By-laws 12 - 17	ERA must not:(a) deposit or discharge industrial waste or noxious, offensive or polluting substances or material elsewhere than in an area provided by means of a sign or other notification for the purpose (by-law 12).(b) carry on trade or commerce without a permit (by-law 13).(c) use or carry (i) a firearm or other weapon; (ii) a trap or snare; (iii) a net or spear gun; or (iv) ammunition or explosives; or lay a bait or poison, unless he has first obtained from the Commission a permit to do so (by-law 14).(d) use or carry a device manufactured for the purpose of detecting metals in a park or reserve except in accordance with a permit issued by the Commission (by-law 15).(e) disperse or lay (whether from an aircraft or in another way) a chemical substance in a park or reserve except in accordance with a permit issued by the Commission (by-law 16).(f) except in accordance with a permit issued by the Commission, damage, injure, destroy or otherwise interfere with wildlife that is an animal in a park or reserve (by-law 17).
Legislation	*Territory Parks and Wildlife Conservation By-Laws 1984 (NT)*	Part 3 - Control of Activities By-laws 18 & 27	ERA must not, in a park or reserve: (a) dig or otherwise interfere with any soil, stone or other material forming part of the park or reserve; or remove, mark, damage, deface or otherwise interfere with a: (i) rock or natural feature; or (ii) tree, shrub or plant whether or not planted by the Commission; except as provided in a plan of management in force under the Act. (by-law 18) (b) remove, interfere with or take an impression of an Aboriginal painting or historic painting, carving, object, structure or relic without the written approval of the Commission. (by-law 27)
Legislation	*Territory Parks and Wildlife Conservation By-Laws 1984 (NT)*	Part 3 - Control of Activities By-law 19	ERA must not except in accordance with the conditions of a permit issued by the Commission: (a) dam or divert a river or watercourse; or (b) pump or siphon off water from a lake, river, watercourse or natural water storage for use in an agricultural, industrial or other enterprise; or (c) foul or pollute a lake, river, watercourse or natural water storage. Maximum penalty: 40 penalty units and 8 penalty units for each day during which the offence continues. (by-law 19).
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Section 12 - General environmental duty	A person who conducts an activity that causes or performs an action which is likely to cause pollution resulting in environmental harm or that generates or is likely to generate waste must take all measures that are reasonable and practicable to prevent or minimise the pollution or environmental harm and reduce the amount of the waste.

Instrument	Title	Section	Obligation
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Section 14 - Duty to notify of incidents causing or threatening to cause pollution	(1) A person conducting the activity must notify the NT EPA, where an incident occurs in the conduct of an activity and the incident causes or is threatening or may threaten to cause, pollution resulting in material environmental harm or serious environmental harm as soon as practicable after (and in any case within 24 hours after) first becoming aware of the incident or the time he or she ought reasonably be expected to have become aware of the incident. (Penalty: environmental offence level 4). (2) A person must not intentionally fail to notify the NT EPA as soon as practicable and in any case within 24 hours after first becoming aware of the incident where an incident occurs in the conduct of an activity and the incident causes or is threatening or may threaten to cause, pollution resulting in material environmental harm or serious environmental harm. (Penalty: environmental offence level 3).
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Section 30 - Where approval or licence required	(1) A person must not, except under an environment protection approval, conduct an activity specified in Part 1, Schedule 2. Penalty: environmental offence level 4. (2) A person must not, except under an environment protection approval, modify/alter premises in/on which an activity specified in Part 1 or 2 of Schedule 2 is conducted/is to be conducted if: a) while the modification/alteration is carried out there is likely to be: i) significant increase/alteration in waste generated, stored, treated or disposed of or ii) significant increase in the risk of pollution resulting in environmental harm or b) at the premises modified/altered there is likely to be: i) significant increase/alteration in waste generated, stored, treated or disposed of or ii) significant increase in the risk of pollution resulting in environmental harm. Penalty: environmental offence level 4. (3) A person must not, except under an environment protection licence or a best practice licence, conduct an activity specified in Part 2, Schedule 2. Penalty: environmental offence level 4. (4) Subsections (1) and (2) do not apply to maintenance of premises in/on which an activity specified in Part 1 or 2, Schedule 2 is conducted/is to be conducted.
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Section 39 - Person must comply with approval or licence	(1) The holder of an environment protection approval or a licence must not intentionally contravene or fail to comply with it. Penalty: environmental offence level 3. (2) The holder of an environment protection approval or a licence must not contravene or fail to comply with it. Penalty: environmental offence level 4.

Instrument	Title	Section	Obligation
Legislation	*Waste Management and Pollution Control Act 1998 (NT)* and *Waste Management and Pollution Control (Administration) Regulations 1998*	Section 42 - Annual fee and Regulation 3B -Annual fee	(1) The holder of: a) an environment protection licence or b) a best practice licence that is granted for a period of 2 years or more must pay the annual fee specified on the licence each year/part of a year the licence remains in force. The annual fee is stated in the Regulations. The Chief Executive Officer may waive whole/part of the fee in relation to a best practice licence. The Chief Executive Officer may give written notice if the fee has not been paid. Failure to pay will result in licence suspension (s. 45).
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Section 43 - Notification of ceasing to conduct licensed activity and surrender of licence	(1) ERA must notify the NT EPA within 14 days after stopping an activity which the licence relates. Penalty: environmental offence level 4.
			(2) Subsection (1) does not apply to ERA if the NT EPA has approved the transfer of the licence to another person.
			(3) ERA may, with the approval of the NT EPA, surrender the licence.
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Schedule 2 Part 1 – Activities that require environment protection approval	1. Constructing, installing or carrying out works for premises disposing waste by burial other than: a) domestic waste from a domestic residence disposed of on the land the premises are situated on, b) domestic waste from temporary construction camps, c) waste generated by pastoral activities disposed of on the land the pastoral activities are carried out, d) waste rock, rubble and other inert materials used for reclaiming land; and e) waste of a prescribed class.
			2. Constructing, installing or carrying out works for premises, other than sewerage treatment plants, for the storage, re-cycling, treatment or disposal of listed wastes on a commercial/fee for service basis.
			3. Constructing, installing or carrying out works for premises processing hydrocarbons to produce, store and/or dispatch liquefied natural gas or methanol, where: a) the premises are designed to produce more than 500,000t/y of liquefied natural gas and/or methanol and (b) no lease, licence or permit under the Petroleum Act or the Petroleum (Submerged Lands) Act relates to the land which the premises are/will be situated.

Instrument	Title	Section	Obligation
Legislation	*Waste Management and Pollution Control Act 1998 (NT)*	Schedule 2 Part 2 – Activities that require licence	1. Operating premises for the disposal of waste by burial that service/are designed to service the waste disposal requirements of more than 1 000 persons. 2. Collecting, transporting, storing, re-cycling, treating or disposing of a listed waste on a commercial or fee for service basis other than in/for the purpose of a sewerage treatment plant. 3. Operating premises, other than a sewerage treatment plant, associated with collecting, transporting, storing, re-cycling, treating or disposing of a listed waste on a commercial or fee for service basis. 4. Omitted. 5. Operating premises for processing hydrocarbons to produce, store and/or despatch liquefied natural gas or methanol where: a) the premises are designed to produce more than 500,000 tonnes annually of liquefied natural gas and/or methanol and b) no lease, licence or permit under the *Petroleum Act* or the *Petroleum (Submerged Lands) Act* relates to the land which the premises are situated.
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 16 - Prohibition of pollution	ERA is prohibited (unless authorised) from allowing waste to come into contact with water or from allowing water to be polluted. It is an environmental offence to willfully cause (level 1) or to cause (level 2), either directly or indirectly, waste to come into contact with water or for water to be polluted causing serious environmental harm. It is an environmental offence level 3 to cause, either directly or indirectly, waste to come into contact with water or for water to be polluted causing material environmental harm. It is an environmental offence level 4 to cause, either directly or indirectly waste to come into c ontact with water or for water to be polluted. Evidence of a drain, pond, dump or other means where waste is capable of coming into direct/indirect contact with water will incur a penalty. In limited circumstances, the Regulator may authorise ERA to allow waste to come into contact with water or water to be polluted. (Maximum default penalty: 20 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 40 - Prohibition of unauthorised works - replaced in the 2018 Amendment to – Interfering with waterway without authorisation	ERA must not (unless authorised) engage in conduct that interferes with a waterway. (Penalty - Max: 500 units). ERA must not (unless authorised) intentionally engage in conduct that interferes with a waterway and the person is reckless in relation to the result. (Penalty - Max: 1,000 units or imprisonment for 2 years).
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 41 and Regulation 6 and 2018 Amendment - Grant of Construction Permit	ERA must apply for a Construction Permit if ERA wishes to interfere with a waterway. The application must be in accordance with the approved form.

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 42 as replaced in 2018 Amendment - Breach of term or condition of permit	If ERA holds a Construction Permit it must not contravene a term or condition of the permit. (Penalty - Max: 500 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 45 and Regulation 8 - Licence to take surface water	If ERA wants to take surface water, ERA must apply to the Controller for water extraction licence to take or use water. An application for a licence must be in the approved form.
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 46 repealed and replaced in 2018 Amendment - Breach of licence to take surface water	If ERA holds a licence to take surface water, it must not contravene a term or condition of the licence. (Penalty - Max: 500 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 48, 49 and Regulation 10(1), 48 repealed and replaced in 2018 Amendment - Drilling bore work without a licence	If ERA wishes to drill, construct, deepen, enlarge, remove, replace, alter or repair a bore or part of a bore, ERA must apply for a drilling licence in accordance with the approved form. (Penalty - Max: 500 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 55 & 56, repealed and replaced in 2018 Amendment – Power to require information about bore	ERA must provide to the Controller upon request, information in relation to any bores situated on the land, and provide the information within a specified time or as soon as practicable after the completion of bore work. Penalty – Max: 30 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 58, repealed and replaced in 2018 Amendment - Breach of permit to do bore work	If ERA holds bore construction permit it must comply with the terms and conditions of that permit. (Penalty: 500 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 59, 60 and Regulation 9, 59 repealed and replaced in 2018 Amendment – Taking groundwater without authorisation (59), Grant of	If ERA wishes to take groundwater it must have a ground water extraction licence from the Controller. The licence must be in accordance with the approved form. Penalty – Max: 500 penalty units if ERA takes water from a bore without authorisation. Max: 1,000 penalty units or imprisonment for 2 years if intentionally takes water from a bore without authorisation).

Instrument	Title	Section	Obligation
		licence to take groundwater (60)	
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 61, repealed and replaced in 2018 Amendment - Breach of licence to take groundwater	If ERA holds a licence to take water from a bore, ERA must comply with its terms and conditions. (Penalty: 500 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 62 - Prohibition of unlicensed waste disposal	ERA is not permitted to cause waste to be disposed of underground by using a bore. The prohibition is strict and applies regardless of whether the act was deliberate or caused environmental harm. In limited circumstances, the Minister/Controller may authorize disposal underground by using a bore. Environmental offence level 1 - person who wilfully causes waste to be disposed of underground by a bore causing serious environmental harm. Environmental offence level 2 - person who causes waste to be disposed of underground by a bore causing serious environmental harm. Environmental offence level 3 - person who causes waste to be disposed of underground by a bore causing material environmental harm. Environmental offence level 4 - person who causes waste to be disposed of underground by a bore. In proceedings for an offence against this section, proof of the existence on land of a way where waste is capable of being disposed of underground by a bore is evidence of contravention. (Maximum default penalty: 20 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT and Water Legislation Amendment Act 2018)*	Section 63 & 65 - Underground waste disposal licence	If ERA wishes to dispose of waste underground it must apply to the Controller for an underground waste disposal licence, in a form approved by the Controller. If a person wants to change the use of the bore, written consent must be obtained from the Controller. An offence against this section is an environmental offence level 3.
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 64 - Breach of term or condition of licence	If ERA holds a licence to dispose of waste underground, its terms and conditions must be complied with. Offence: An offence against this section is an environmental offence level 3. (Maximum default penalty: 20 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 74 and Regulation 9A - Grant of waste discharge licence	ERA may apply to the Controller to grant a waste discharge licence in the approved form to carry out an action which would otherwise be an offence against section 73 or because the action is not and cannot be (but for this section) authorised by or under this Act.
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 76 - Breach of terms and conditions of licence	The holder of a waste discharge licence must not contravene or cause, suffer or permit a person to contravene a term or condition to which the licence is subject. An offence against this section is an environmental offence level 3. (Penalty - Max: 20 penalty units)

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 79 and 2018 Amendment - Power to construct works	A person shall not, unless authorised by the Minister, or under and in accordance with this or any other Act, acquire, construct, maintain, repair, alter, operate or remove works for: investigating, observing, measuring or assessing waste or water, conserving water or protecting or enhancing its quality, irrigating or draining land, the use of water for recreation purposes, or controlling flooding. A person may not cause, suffer or permit another person to do so. (Penalty – Max: 200 penalty units or imprisonment for 2 years if intentional and reckless in relation to the result)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 98, repealed and replaced in 2018 Amendment - Destruction of works	ERA shall not intentionally engage in conduct that results in authorised works being damaged or destroyed, or benefits from the works being diminished. (Penalty - Max: 100 penalty units).
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT) and Water Legislation Amendment Act 2018*	Section 99, repealed and replaced in 2018 Amendment - Interference with rights	ERA shall not intentionally engage in conduct that results in materially diminishing another person's enjoyment of a right mentioned in section 10, 11 or 14 of the Act, or interferes with the performance of an act authorised under section 97. (Penalty - Max: 100 penalty units).
Legislation	*Water Legislation Amendment Act 2018*	Section 100 – Wasting water	ERA shall not intentionally engage in conduct that results in more water being used than is reasonably necessary for the immediate purpose for which the water is taken, water being taken without adequate control or supervision of its taking. (Penalty - Max: 50 penalty units).

Instrument	Title	Section	Obligation
Legislation	*Weeds Management Act 2001 (NT) and Weeds Management Regulations 2006 (NT)*	Section 9 - General duties	(1) ERA as owner and occupier of land must: a) take all reasonable measures to prevent the land being infested with a declared weed, b) take all reasonable measures to prevent a declared/potential weed on the land spreading to other land and c) notify an officer within 14 days of becoming aware of a declared weed that has not previously been/known to have been present on the land. (2) ERA must comply with a weed management plan relating to the weed. (3) ERA must dispose of the weed only on the land or at a designated weed disposal area. (4) ERA must not, except in accordance with a permit: a) bring a declared weed into the Territory, b) propagate or scatter a declared weed, c) sell or purchase a declared weed, d) hire any equipment, device or thing that contains or carries a declared/potential weed, e) store, grow or use a declared weed or any thing that contains or carries a declared weed or f) transport a declared weed except to deliver it to an officer. (Penalty: environmental offence level 3).
Legislation	*Weeds Management Act 2001 (NT) and Weeds Management Regulations 2006 (NT)*	Section 21 - Quarantine areas	ERA must not contravene or fail to comply with a restriction on the movement of persons, animals, vehicles, aircraft, boats, plants, fodder, soil or any other thing in, into or out of the quarantine area except in accordance with an access permit as specified in a notice. (Penalty - environmental offence level 3).
Legislation	*Weeds Management Act 2001 (NT) and Weeds Management Regulations 2006 (NT)*	Section 32 - Moving animals and vehicles on roads	ERA must not drive a vehicle that ERA knows/should reasonably know contains/carries a declared weed: a) on a public road or b) from the person's land to another person's land. An exception to this obligation is where the vehicle has been cleaned in accordance with a declared weed management plan or in compliance with the direction of an officer.(Penalty - environmental offence level 3)
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 2.3 - Termination	(a) This Mining Agreement will terminate on the earlier of: (i) 8 January 2026; (ii) the date this Mining Agreement is terminated by mutual agreement between the Parties; or (iii) the date of Final Close Out
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 2.4(a) - Actions Following Termination	On the Termination Date, ERA will immediately pay to the Commonwealth all monies then due and payable to the Commonwealth under the Government Agreement or the New s.41 Authority.

Instrument	Title	Section	Obligation
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 2.4 (b) - Actions Following Termination	On the Termination Date, ERA will immediately, or as soon as practicable, comply with any obligation or meet any liability which may have arisen or accrued prior to the Termination Date and which has not been complied with or met at the Termination Date.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 2.4 (c) - Actions Following Termination	On the Termination Date, ERA will vacate the Ranger Project Area unless otherwise lawfully authorised to undertake rehabilitation or revegetation after the Termination Date.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 3.1 - Operations	ERA will, in undertaking Operations, comply with: a) the New s.41 Authority, including the Environmental Requirements; b) Applicable Laws; c) the Government Agreement; and d) this Mining Agreement.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 3.2 (a)(i)(ii) - Cessation of Mining Operations	(a) ERA will cease Mining Operations on the Ranger Project Area on the earlier of the following: (i) the date that ERA is required to cease Mining Operations on the Ranger Project Area pursuant to clause 5.1 of the New s.41 Authority; and (ii) the date that is 40 days after the date on which ERA was served with a Cessation Notice under clause 18.l(c).
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 3.2 (b) - Cessation of Mining Operations	(b) Subject to clause 3.2(c), on cessation of Mining Operations ERA will vacate the Ranger Project Area, other than as required for Rehabilitation purposes.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 4.1 - Sustainability Payment	Subject to clause 4.2 below, in each Annual Period during the currency of this Agreement in which Mining Operations are conducted and for the two Annual Periods following the Cessation of Mining Operations, ERA must pay to the NLC an annual payment (a Sustainability Payment) to or for the benefit of the Traditional Aboriginal Owners of the Ranger Project Area.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 4.2(c) - Timing for Sustainability Payment	Each subsequent payment is due on the 9 January of each Annual Period (being the anniversary of the date on which the Original s.41 Authority was granted).

Instrument	Title	Section	Obligation
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 6.1 - General	In conducting the Operations on the Ranger Project Area, ERA must manage the development of resources and the protection of the Environment by complying with the Environmental Requirements and, and in doing so must: (a) consistently maintain the best practicable standards of Environmental planning and management; (b) comply with all Environmental Authorisations; (c) regularly monitor the Environmental performance of the Operations and ensure that proper management procedures are in place to meet its responsibilities; and (d) maintain certification to the current or most recent relevant Australian or international standards for Environmental management, being, at the date of this Mining Agreement, the International Organisation for Standardisation ("ISO") 14001 Environmental Management Systems (AS/NZS ISO 14001).
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 6.2 - Notification of Breach	If ERA becomes: a) aware it may not be able to comply with its obligations in clause 6.l(b) or 6.l(d), ERA will: (i) within 7 days provide a written report to the NLC and Relationship Committee Members providing details of the event and the action taken or proposed to be taken to mitigate the results of or likelihood of the· incident; and (ii) if requested by the NLC or Relationship Committee Members, immediately consult with the NLC or Relationship Committee and take all reasonable steps requested by the NLC or Relationship Committee Members to mitigate the results or likelihood of the incident, including by monitoring, remediation and reporting on the likelihood of a recurrence of such an event; and (b) aware it is in breach of its obligations under clause 6. l(b) or 6. l(d) (an Event), ERA will: (i) where such Event is capable of rectification or remedy, immediately rectify or remedy the Event; (ii) immediately provide an interim report regarding the Event to the NLC and Relationship Committee Members by phone, fax or e-mail; (iii) within 7 days provide a written report to the NLC and Relationship Committee regarding the Event, including details of the Event and the action taken or proposed to be taken to mitigate the results of the Event; and (iv) if requested by the NLC or Relationship Committee Members, immediately consult with the NLC and Relationship Committee and take all reasonable steps requested by the NLC and Relationship Committee Members to mitigate the results of the Event, including by monitoring, remediation and reporting on the likelihood of a recurrence of such an event, provided in the case of either 6.2(a)(ii) and 6.2(b)(iv)

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			that such action is not inconsistent with a request or direction from the MTC or relevant regulatory agency.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 6.5 - Disposal of Mining Property within the Ranger Project Area	(a) If ERA, or a Related Body Corporate of ERA, wishes to permanently dispose of Mining Property within the Ranger Project Area (including by burying such Mining Property), ERA will give to the Relationship Committee: (i) notice of the proposed disposal, with such notice to include basic details of the Mining Property proposed to be disposed of; (ii) particulars as to the method of disposal; (iii) particulars as to whether the disposal is contemplated in the Rehabilitation Plan; and (iv) particulars as to any environmental impacts that may arise due to the disposal.(b) ERA will consider any comments that the Relationship Committee may have on environmental management and rehabilitation issues associated with disposal. ERA will adopt a collaborative approach to dealing with such issues.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 7.2 - ERA Support for Traditional Owner Business	ERA is supportive of Traditional Owners' objective to develop business opportunities and entrepreneurial skills and capabilities, and will assist the Traditional Owners to achieve this objective by: (d) offering Traditional Owners the opportunity to purchase Local Assets in accordance with clause 7.6; and (e) offering Traditional Owners the opportunity to purchase Fixed Assets in accordance with clause 7.7.

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Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 7.3 - Business Development Strategy	(a) ERA will, in consultation with the Business Entity and the Relationship Committee, develop a business development strategy (the Business Development Strategy) which will be aimed at: (i) developing strategies and mechanisms whereby ERA can assist the Business Entity and other Traditional Owner Entities, including through supporting training and development in a range of fields; and (ii) developing a joint approach between ERA and Traditional Owners in minimising adverse impacts on Traditional Owners from cessation of Mining Operations and Final Close Out. (b) The Parties acknowledge that Traditional Owners have expressed particular interest in the following business opportunities, such opportunities to be discussed during development of the Business Development Strategy: (i) archaeology; (ii) provision of art works; (iii) cultural heritage matters; (iv) servicing in Jabiru; (v) tourism; (vi) landscaping; (vii) rehabilitation; and (viii) commercial contracts associated with the Operations including workers' camps. (c) The Parties and the Business Entity will discuss the development of the Business Development Strategy at meetings of the Relationship Committee. The Parties will aim to have the Business Development Strategy finalised within 12 months of the Commencement Date. Once the Business Development Strategy is finalised, ERA will implement the strategy in conjunction with the Relationship Committee and the Business Entity.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 7.6 - Local Asset Disposals	(a) If ERA wishes to sell to a third party (which, for the purpose of this clause, does not include a transfer or sale of assets to a Related Body Corporate of ERA or a joint venture in which ERA or its Related Bodies Corporate have an interest): (i) light vehicles; (ii) demountable accommodation facilities; or

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			(iii) another class of asset that members of the Relationship Committee agree in writing are of a type that could be used by the Business Entity for personal or community purposes and should be subject to the provisions of this clause 7.6, which are located on the Ranger Project Area or at Jabiru (Local Assets), ERA will give the NLC and Business Entity written notice of that proposed sale, with such notice to include basic details of the Local Asset proposed to be sold.
			(b) ERA will provide written notice pursuant to clause 7.6(a) at least 30 days before the Local Assets are either sold or to be transported from the site of the Operations to another location for sale (Notice Period).
			(c) If a Traditional Owner Entity is interested in purchasing the Local Asset, it can advise ERA of this before the end of the Notice Period. If the Traditional Owner Entity does advise ERA within this time that it is interested in purchasing the Local Asset, then ERA and that entity will have discussions regarding the terms of a proposed sale within the Notice Period or such longer period as may be agreed, but neither party will be under an obligation to agree to the sale or purchase of the Local Asset.
			(d) ERA will advise at the Relationship Committee meetings of any planned upcoming Local Asset sales. However, for the avoidance of doubt, a Local Asset may be sold even if it has not first been raised at a Relationship Committee meeting, provided the other provisions of this clause 7.6 are complied with by ERA.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 7.7 - Sale of Fixed Assets	(a) If ERA wishes to sell to a third party (other than a transfer or sale of assets to a Related Body Corporate of ERA or a joint venture in which ERA or its Related Body Corporate have a majority or controlling interest), or otherwise permanently dispose of a Fixed Asset, ERA will give the Business Entity written notice of that proposed sale or disposal with such notice to include basic details of the Fixed Asset proposed to be sold or disposed of.
			(b) ERA will provide the written notice pursuant to clause 7.7(a) at least 30 days before the Fixed Assets are either sold or are to be disposed of (Notice Period).
			(c) If the Business Entity is interested in purchasing the Fixed Assets and advises ERA of this before the end of the Notice Period, then ERA and the Business Entity may have discussions regarding the terms of a proposed sale, within the Notice Period or such longer period as may be agreed, but neither party will be under an obligation to agree to the sale or purchase of the Fixed Asset.
			(d) The purchase of the Fixed Asset by the Business Entity shall be subject to the terms of any subleases ERA has in relation to the Fixed Asset.

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			(e) The NLC acknowledges that unless ERA and the Business Entity otherwise agree, the Fixed Assets will be sold on an 'as is, where is' basis, and to the maximum extent permitted by law ERA gives no warranty or undertaking as to the state or fitness for purpose of any Fixed Asset.
			(f) If ERA and the Business Entity do not agree on the terms for the sale and purchase of a Fixed Asset within the Notice Period, or such longer period as is agreed, ERA may sell the Fixed Asset to a third party or otherwise dispose of the Fixed Asset.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 8.1 - Acknowledgement	The Parties acknowledge that Traditional Owners have a strong interest in the rehabilitation of the Ranger Project Area. The Parties also acknowledge that it is ERA's responsibility at law to meet any legal obligations regarding rehabilitation on the Ranger Project Area.
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 8.2 - Conduct of Rehabilitation Works	(a) ERA supports the involvement of the Traditional Owners in the undertaking of rehabilitation works for the Operations in accordance with the provisions of this clause 8.
			(b) ERA is at all times itself able and entitled to perform rehabilitation on the Ranger Project Area. Alternatively, ERA may choose to engage contractors to carry out the rehabilitation.
			(c) If ERA chooses to invite third parties to tender to undertake rehabilitation works on the Ranger Project Area, then ERA will conduct that tender and give preference to a Traditional Owner Entity in awarding such contracts in the same manner as provided under clause 7.4 for the award of other Local Jabiru Contracts.
			(d) If ERA does not decide to perform certain rehabilitation works itself, and also decides not to put the work out to third party tender, but wishes to enter into an agreement with a particular third party to undertake certain rehabilitation works, then ERA will:
			(i) advise the Relationship Committee members and the Business Entity in writing of this intention, and provide them with the basic details of the rehabilitation work to be performed (such as the nature of the rehabilitation work, and when it needs to be completed) but not the price or other commercially sensitive or confidential information that may have been provided by a third party;
			(ii) The Business Entity and other Traditional Owner Entities will have 30 days from receipt of such notice to submit a proposal (including price) for undertaking the rehabilitation work
			(iii) If a Traditional Owner Entity does submit such a proposal within the 30 day period, ERA must consider that proposal and in deciding whether to accept the Traditional Owner Entity's proposal or the third party proposal, ERA must generally

Instrument	Title	Section	Obligation
			apply the same preference principles that apply to a tender process under clause 7.4; and
			(iv) if the Traditional Owner Entity does not submit a proposal within the 30 day period, ERA may enter a contract with a third party for the performance of the work.
			(e) Clauses 7.4(a), 7.4(b) and 7.5 will apply to any tenders issued for rehabilitation related works as if the references in those clauses to "Local Jabiru Contracts" were references to "rehabilitation works contracts in relation to the Operations".
			(f) Nothing in this clause 8.2 prevents ERA contracting with a third party in relation to rehabilitation work on the Ranger Project Area if ERA enters a contract with a Traditional Owner Entity pursuant to this clause 8.2 but that contract does not cover all the rehabilitation works ERA requires to be undertaken at that time.

Instrument	Title	Section	Obligation
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 12.10 - Reports	(a) ERA will provide the NLC and Relationship Committee with a report (Project Report) at the first Quarterly meeting of the Relationship Committee after 1 July each Year. The Project Report will include sufficient information and details to enable the Relationship Committee, the Traditional Owners and other Local Aboriginal People and the NLC to understand the nature and impacts of the Operations in relation to the preceding calendar year, including particulars of: (i) the nature and scope of the Operations, means by which the Operations have been undertaken, the minerals mined and processed and the effects of the Operations upon the Environment and on the Traditional Owners and other Local Aboriginal People; (ii) total Operations costs, which need not include more detail than a person listed on the Australian Securities Exchange is required to provide in its annual report to the Australian Securities Exchange; (iii) implementation and results of implementing the Environmental Management Plan or Mine Management Plan; (iv) Environmental monitoring, such as soil analysis, erosion studies and water quality analysis; (v) any incident involving non-compliance with an Environmental Authorisation or any unauthorised event occurring on the Ranger Project Area which affected or may affect the Environment (such as the occurrence of wild fire), and where ERA considers that no such incident has occurred it will provide a certificate to that effect; (vi) action taken in compliance with requirements of Applicable Laws, Environmental Authorisations or this Mining Agreement in relation to Rehabilitation including progressive rehabilitation requirements; and (vii) outcomes pursuant to the Business Development Strategy and Local Aboriginal employment and training and business development plans and outcomes. (b) A Project Report may, and will where necessary in order to comply with the requirements of clause 12.10(a) and this clause, include maps, plans and photographs. (c) The Parties acknowledge that reports provided by ERA in compliance with the Environmental Requirements and Environmental Authorisations may form the basis of the Project Reports. (d.) ERA will, within 3 months after the Termination Date (or such longer period as the NLC in writing allows) furnish the NLC with a final Project Report for the period not already included in a previous Project Report. This clause survives termination of this Mining Agreement.

Instrument	Title	Section	Obligation
Agreement	Ranger Uranium Mining Project Mining Agreement 2013 (NLC and ERA)	Clause 15.1 - Use of Materials	(a) Subject to clause 15. l(b), ERA may discover, mine, recover treat, process or use Materials sourced from the Ranger Project Area: (i) as is necessary for the proper and efficient implementation of the Operations; and (ii) in accordance with Applicable Laws. (b) ERA will not: (i) remove any Materials, Low Grade Ore or Tailings from the Ranger Project Area; or (ii) use Low Grade Ore or Tailings from the Ranger Project Area for the purposes of construction, including building and road works, without the consent of the NLC. (c) In the event that ERA wishes to use any Materials, Low Grade Ore or Tailings in the circumstances described in clauses 15.l(b)(i) or 15.l(b)(ii), ERA will provide particulars (a Proposal) identifying: (i) locations where ERA proposes to source Materials, Low Grade Ore or Tailings to be removed from the Ranger Project Area or for the purposes of construction and the proposed destination location; (ii) the proposed use of Materials, Low Grade Ore or Tailings to be removed from the Ranger Project Area or for the purposes of construction; and (iii) any measures adopted by ERA to protect the Environment, to the Relationship Committee Members and to the NLC at least 30 days prior the proposed removal or use detailed in the Proposal. (d) Relationship Committee Members and the NLC must consider any Proposal and the NLC may: (i) consent to the Proposal; (ii) consent to the Proposal on conditions, where such conditions may include consideration of matters relating to: (A) Cultural Heritage, the Environment or Rehabilitation; and (B) payment of a royalty for Materials used, at rates negotiated in good faith between the Parties. (e) Except with the consent of the NLC, which consent will not be unreasonably withheld, where it is necessary for the proper and efficient implementation of the Operations, ERA will not take, direct or use any: (i) timber on the Ranger Project Area; or (ii) surface water outside the Operations Area and within the Ranger Project Area.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 3.1	This Agreement will continue in full force and effect until it is terminated on the earlier of:
			(a) 8 January 2026;
			(b) the date this Agreement is terminate by mutual agreement between the parties; or
			(c) the date of Final Close Out
			(Termination Date)
Agreement	Ranger 'Section 44' Agreement between the	Clause 4.1	On the Termination Date:
			(a) the Commonwealth must, within 60 days of the Termination Date, pay to the NLC all moneys then due and payable and comply with any obligation or meet any

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	Commonwealth of Australia and Northern Land Council		liability which may have arisen or accrued prior to the Termination Date and which has not
			been complied with or met at the Termination Date;
			(b) except as provided in this clause or otherwise provided in this Agreement neither party shall have any claim against the other of them in respect to any matter or thing contained in or arising out of this Agreement, but this provision shall be without prejudice to the liability of either party in respect of any antecedent breach, unlawful activity or default; and
			(c) the Commonwealth must ensure that ERA vacates the Ranger Project Area, except to the extent ERA is authorised to undertake rehabilitation or revegetation after the Termination Date.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 7.2	Subject to the provisions of the Mining Agreement, the Commonwealth and ERA shall be at liberty at any time during the currency of this Agreement and six months after its termination to remove from the Ranger Project Area all property referred to in sub-clause 7.1 which is owned by them or any of them.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 8.1	The Commonwealth will ensure that ERA complies with the New s 41 Authority, including the Environmental Requirements.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 11.1	The Commonwealth will ensure that all Rehabilitation work in the Ranger Project Area is undertaken by ERA in accordance with the New s41 Authority and the Government Agreement.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 11.2	If, for any reason, ERA fails to carry out the whole or part of the said Rehabilitation work, the Commonwealth will carry out any part of the work not carried out by ERA.
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	Clause 11.3	The Commonwealth will require a Risk Management approach to Rehabilitation, Close Out, any post-Close Out actions and any actions after the termination or revocation of the New s41 Authority, which will be implemented in consultation with the Traditional Aboriginal Owners and the Ranger Minesite Technical Committee.
Agreement	Ranger s. 44 Agreement - "Extension Agreement"	N/A	The s. 44 Agreement is extended for a further 26 years (21 years mining, 5 years' rehabilitation) and the parties are required to agree on a new s.44 agreement.

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Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 20.1	E.R.A. undertakes to rehabilitate the Ranger Project Area in accordance with the conditions and restrictions of the News 41 Authority.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 20.2	Rehabilitation of the Ranger Project Area shall not be delayed until the Date of Cessation of Mining Operations but shall be carried out progressively by E.R.A. throughout this Agreement so that, whenever a part of the Ranger Project Area which has been used for the purposes of the Venture is determined by E.R.A. to be no longer required for those purposes, rehabilitation of that part shall commence as soon as is reasonably practicable after that part ceases to be required for the purposes of the Venture.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 20.4	The cost of rehabilitation after the Date of Cessation of Mining Operations shall be met in the first instance out of funds held in the Ranger Rehabilitation Special Account and by payment by the Commonwealth either directly to a person, not being E.R.A., who is carrying out or has carried out rehabilitation work or to reimburse E.R.A. for the cost of rehabilitation borne by it from time to time.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 20.5	E.R.A. will undertake a Risk Management approach to Rehabilitation, Close Out and any post Close Out actions which will be implemented in consultation with the Traditional Aboriginal Owners, and the Ranger Minesite Technical Committee.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.1	The Plan of Rehabilitation as amended from time to time pursuant to this clause shall set out in a form suitable for costing a detailed description of the work which would be required to be done by E.R.A. to rehabilitate the Ranger Project Area if Mining Operations were to cease at the date of the preparation of the Plan of Rehabilitation as so amended and shall include a schedule of the work which would be required to be done in each of the 5 years, the first of which commences on the date of the preparation of the Plan of Rehabilitation as so amended.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.2	On the Changeover Date, immediately before the Date of Cessation of Mining Operations, and at the end of every six month period (or such other period, not being less than 6 months, as the Minister may, by writing under his hand, determine) commencing on 1 September 1980, E.R.A. shall review the Plan of Rehabilitation or the Plan of Rehabilitation as amended as the case may be and make such amendments or further amendments thereto as may be necessary.

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			Immediately on completion of the review, E.R.A. shall prepare a written report thereon.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.3	In the preparation of an amended Plan of Rehabilitation, regard shall be had, inter alia, to: (a) the conditions and restrictions of the New s41 Authority, (b) the provisions of the Renegotiated s 44 Agreement, (c) the views of the Supervising Scientist and of any Supervising Authority with which E.R.A. has consulted, and (d) the provisions of this Agreement.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.4	As soon as an amended Plan of Rehabilitation has been prepared, E.R.A. shall submit it to the Minister and send a copy of the plan to the Commonwealth.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.5	The Minister shall within 60 days after receiving an amended Plan of Rehabilitation: (a) accept the amended Plan of Rehabilitation as so submitted and notify E.R.A. of this action, or (b) refer the amended Plan of Rehabilitation to E.R.A. together with his suggestions, for further consideration.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.6	Where an amended Plan of Rehabilitation has been so referred to E.R.A., E.R.A. shall, immediately after receipt of the amended Plan of Rehabilitation, give further consideration to the amended Plan of Rehabilitation having regard to the suggestions of the Minister and, within the time fixed by the Minister not being less than 30 days after the receipt of that amended plan, or such further time as the Minister may be writing under his hand allow, again submit the amended plan, with or without alterations, to the Minister, together with E.R.A.'s comments on the suggestions of the Minister.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.7	Within 30 days of the expiration of the time fixed or of any further time allowed, as the case may be, by the Minister under clause 21.6 or of the date on which an amended Plan of Rehabilitation is again submitted to the Minister, whichever is earlier, the Minister shall accept the amended Plan of Rehabilitation as so submitted or accept the amended Plan of Rehabilitation after making such alterations as he sees fit. In either case, the Minister shall notify E.R.A. of the action taken by him.

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Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.8	E.R.A. shall ensure that the provisions of the Plan of Rehabilitation, or of the Plan of Rehabilitation as amended from time to time and accepted by the Minister pursuant to this clause, are strictly observed except to the extent that observance would be contrary to law.
Agreement	"Government Agreement" between Cth, ERA and the Atomic Energy Commission under the Atomic Energy Act 1953	Clause 21.9	When the Minister has accepted an amended Plan of Rehabilitation, E.R.A. shall forward a copy of the Plan of Rehabilitation as amended and accepted by the Minister to the Supervising Scientist.
Agreement	Complementary Agreement between the Commonwealth of Australia, Northern Land Council and ERA under the Aboriginal Land Rights (Northern Territory) Act 1976	Clause 5.1 - Consequential Amendments and Compliance	The Commonwealth and ERA agree to amend the agreement now operating between the Commonwealth and ERA dated 9 January 1979 as amended ("the Government Agreement") so that it reflects the Section 44 Agreement and is consistent with the Mining Agreement at all times.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 2.2 - Operations	Regardless of anything contained elsewhere in this Schedule, ERA shall comply with other conditions and restrictions determined pursuant to the Complementary Agreement. In the event of any inconsistency with other conditions or restrictions in this Schedule, those referred to in this condition and restriction shall prevail.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 2.3 - Operations	Subject to 2.2, in undertaking the operations, ERA shall comply with: a) this Authority including the Environmental Requirements, b) applicable laws including the Environmental Authorisations, c) the Complementary Agreement, d) the Government Agreement ande) the Mining Agreement.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 2.4 - Operations	Subject to 2.2, if it is not possible or practicable for ERA to comply with all the requirements in 2.3, the following principles shall apply to determine the order of compliance: a) the Environmental Requirements and applicable laws shall prevail over the Government Agreement and the Mining Agreement, b) if the relevant applicable law is a law of the Northern Territory, the applicable law shall prevail over the Environmental Requirements except where the Minister, in any particular case, and after taking into consideration the underlying rationale of the Environmental Requirements, and after consulting the relevant Northern Territory Minister, takes action under the Atomic Energy Act 1953; and

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			c) if the relevant applicable law is a law of the Commonwealth, the applicable law shall prevail over the Environmental Requirements.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 4.1 - Information to be kept by ERA and supplied to the Minister	ERA shall keep proper documents, records and books of account of the operations.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 5.1 - Termination of Mining Operations and the Section 41 Authority	ERA shall cease/suspend all mining operations permitted under this Authority: a) by 8/1/2021, b) immediately Section 44 Agreement is terminated/declared void/of no effect, c) no later than 6mths after: i) a court determines that this Authority is not in keeping with 25A.2, 25A.3 and 25A.5 of Section 44 Agreement, ii) the variation of this Authority is not in keeping with the Atomic Energy Act 1953/ Complementary Agreement, d) no later than 9mths after failure of Commonwealth/ERA to execute an agreement to amend the Section 44 Agreement/Mining Agreement in keeping with the Complementary Agreement, e) at any time after the Mining Agreement is executed there is no Mining Agreement in force other than because of a breach/default by the NLC, f) unless the Commonwealth and NLC agree in writing one year after notice is given by the NLC to the Commonwealth under 21.2A of Section 44 Agreement following a decrease in the determined rate payable into the Aboriginals Benefit Reserve pursuant to a determination under section 63 Aboriginal Land Rights (NT) Act 1976.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 5.2 - Termination of Mining Operations and the Section 41 Authority	Following the end of mining operations pursuant to 5.1 or action taken under the Atomic Energy Act 1953, ERA shall continue to comply with and observe its obligations under this Authority and ERA's rights under this Section 41 Authority to access, occupy or use the Ranger Project Area shall be limited to such purposes and this Authority shall, subject to 6 (Rehabilitation), continue until the earlier of: a) the date of final close out, b) 8 January 2026 or c) the date this Authority is terminated or withdrawn.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 5.3 - Termination of Mining Operations and the Section 41 Authority	If the Mining Agreement, Government Agreement or Section 44 Agreement is terminated, the Minister may terminate this Authority.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 6.1 - Rehabilitation	ERA shall promptly undertake and complete the rehabilitation of the Ranger Project Area in accordance with Appendix A (Environmental Requirements) of this Schedule.

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Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Schedule 8.1 - Variation	The Minister may, with the consent of ERA, amend or revise the conditions and restrictions contained in this Schedule to ensure that at all times this Authority is consistent with the Commonwealth's obligations under the Section 44 Agreement.
Authorisation	Ranger Authorisation under the Atomic Energy Act 1953 - Section 41 Authority	Section 41C (5)	Commencing 9 January 2000, subject to the conditions and restrictions set out or referred to in the Schedule, ERA was conferred an authority under section 41 of the Act to carry on operations in accordance with that section on the Ranger Project Area for a period of 26 years.
Authorisation	Variation of Authorisation 0108	Schedule 2 - Authorised Operations at the Ranger Mine	2.1 In addition to the obligation under the Environmental Requirements, the Operator is authorised to operate in accordance with the conditions and requirements set out in this Authorisation. In particular, the Operator is authorised to: 2.1.1 Conduct mining operations and rehabilitation activities in accordance with the latest approved Mining Management Plan, Water Management Plan and Mine Closure Plan, and all subordinate plans referenced therein, submitted in accordance with the processes set out in the Annexes.
			2.1.2 Undertake material excavation and management in accordance with the provisions of SCHEDULE 3.
			2.1.4 Operate the tailings dam and Pit #1 and Pit #3 tailing repositories and to carry out such associated activities as may be required for their operation, in accordance with SCHEDULE 5.
			2.1.6 Dispose of water by direct release from Retention Pond 1, and via the Corridor Creek Wetland Filter, in accordance with SCHEDULE 7.
			2.1.7 Dispose of water from Retention Pond 2 by irrigation within areas which are approved by the Director, in accordance with SCHEDULE 7.
			Dispose of water from pit dewatering bores by flood irrigation within areas which are approved by the Director.
			2.1.9 Pump water from Magela Creek to Retention Pond 2 subject the approval of the Director and subject to the conditions of SCHEDULE 7.
Authorisation	Variation of Authorisation 0108	Schedule 3 - Material Excavation and Management	3.2 Prior to the commencement of excavation of sand and gravel for ancillary purposes, the Operator shall ensure that:
			3.2.1 a plan of the proposed operations is submitted to a Mining Officer for approval. This plan shall depict the extent of the proposed borrow areas and the location of associated roads or other developments. It shall also include details of proposed rehabilitation; and
			3.2.2 such works are to be undertaken in accordance with the approved plan and rehabilitation works are to be carried out as soon as is reasonably practicable.

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Authorisation	Variation of Authorisation 0108	Schedule 5 - Operation of Tailings Repositories	5.1 In addition to the obligation under the Environmental Requirements, the Operator shall:
			5.1.1 to the maximum extent possible, deposit tailings in tailings repositories in such a way as to result in the maximum practicable dry density; and
			5.1.2 minimise dusting from the surface of the tailings by ensuring that exposed surfaces of tailings are maintained in a coherent near saturated condition,
			5.2 During the period of 1 May to 30 November the Operator shall not allow the water level in the tailings dam to exceed the certified crest height as approved by the Director less a 6 hour Probable Maximum Precipitation event of 1,250mm.
Authorisation	Variation of Authorisation 0108	Schedule 6 - Other Services, Operations and Requirements	6.1 In addition to the obligations under the Environmental Requirements, the Operator shall ensure that: 6.1.1 The NT Minister is notified as soon as is practicable, of any infringement of the conditions and requirements of this Authorisation.
Authorisation	Variation of Authorisation 0108	Schedule 7 - Water Management	7.1 The operator shall comply with the requirements and conditions of the Ranger Mine Water Quality Objectives in Annex C as approved by the Director in accordance with the advice of the Supervising Scientist.
			7.2 The Operator shall submit the Water Management Plan for the approval of the Director in accordance with Annex D.4.
			7.3 The Operator shall operate a water management system in accordance with the latest approved Mining Management Plan and Water Management Plan.
			7.4 The Operator shall:
			7.4.1 maintain up-to-date versions of drawings depicting the current surface runoff drainage system;
			7.4.2 instruct all appropriate personnel involved in the operation of the water management system in the details of its operation and in the implementation of contingency procedures;
			7.4.3 ensure that any discharge of waters from the Ranger mine site does not compromise the Ranger Mine Water Quality Objectives as detailed in Annex C;
			7.4.4 in relation to the disposal of treated water by irrigation, the Operator shall:
			7.4.4.1 record daily, in a log book kept specifically for this purpose:
			- the volume of water discharged by each section of the irrigation systems;
			- the times of commencement and of cessation of irrigation; and
			- any observed adverse effects of irrigation.
			7.4.4.2 undertake a daily inspection of the irrigation areas to detect any waterlogging, seepage, or other visible adverse effects during irrigation.

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			7.5 The Operator shall maintain to the satisfaction of the NT Minister and for examination by a Mining Officer, all records and data associated with the operation and monitoring of the water management system for the life of the mine up to and including rehabilitation and post closure.
Authorisation	Variation of Authorisation 0108	Schedule 8 Environmental and Radiation Monitoring and Reporting	8.1 In compliance with Environmental Requirements 13.1 and 13.2 relating to monitoring and analysis, the Operator shall:
			8.1.1. submit all plans and reports in accordance with the requirements of Annex D, as updated from time to time by t he Director;
			8.1.2 implement the environmental and radiation monitoring programs included in Annex E and Annex F as updated from time to time and approved by the Director; and
			8.1.3 conduct contingency monitoring in a manner approved by the Director in the event of the malfunction of monitoring equipment.
			8.2 The obligations on the operator of the mine imposed by SCHEDULE 8 will cease in respect of any part of the Ranger Project Area over which a close-out certificate is issued by the Minister subject to the Supervising Scientist and the NLC agreeing that the specific part of the Ranger Project Area has met the aims and objectives for rehabilitation.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 1 - Environmental Protection	1.1 The company must ensure that operation at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list; b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park; c) protect the health of Aboriginals and other members of the regional community; and d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

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			1.2 In particular, the company must ensure that operations at Ranger do not result in: a) damage to the attributes for which Kakadu National Park was inscribed on the World Heritage list; b) damage to the ecosystem health of wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park); c) an adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian Standards, codes of practice, and guidelines; d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 2 - Rehabilitation	2.1 Subject to subclauses 2.2 and 2.3, 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.
			2.2 The major objectives of rehabilitation are:a) revegetation of the disturbed sites of the Ranger project area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the Park.b) stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area; c) erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas.

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			2. 3 Where all the major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in subclauses 2.1, 2.2 and 2.3.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 3 - Water Quality	3.1 The company must not allow either surface or groundwater arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 3 - Water Quality	3.2 The company must, to the extent necessary to achieve the primary environmental objectives, take steps to minimise the volume of contaminated water that is required to be managed on site, minimise the load of contaminants within that water, and to concentrate and contain contaminants within the site.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 3 - Water Quality	Background values for key variables in water quality, including values for conductivity, pH and uranium, are determined by the Supervising Scientist from time to time and communicated to the company and other major stakeholders. Should the values for these variables measured at Gauging Station GS8210009 or other key locations show trends away from or be abruptly divergent from those background values and if, in the opinion of the Minister with the advice of the Supervising Scientist, the results may be attributable to mining operations, then the company must undertake investigations and remedial actions as required by the Supervising Authority after consultation with the Supervising Scientist and other major stakeholders.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 3 - Water Quality	3. 4 Process water must be totally contained within a closed system except for: a) losses through natural or enhanced evaporation, b) seepage of a quality and quantity that will not cause detrimental environmental impact outside the Ranger Project Area and c) subject to 3.1, 3.2 and 3.3, process water which has been treated to achieve a quality which: i) conforms to a standard practice or procedure recommended by the Supervising Scientist and ii) is not less than that of the water to which it is to be discharged.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 4 - Air Quality	4.2 Air quality must be managed in such a way that there is no physical or chemical detriment to any known site of Aboriginal culture or heritage.

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Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 5 - Radiological Protection	5.1 The company must implement a system to control the radiological exposure of people and the environment arising from its mining and milling activities. The system and the dose limits must comply, at a minimum, with relevant Australian standards, codes of practices, and guidelines. Subject to 5.3, the company must achieve the following outcomes: a) radiation doses to company employees and contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for workers, b) radiation doses to people who are not company employees or contractors must be kept as low as reasonably achievable and must always remain less than the dose limit for members of the public and c) ecosystems surrounding the Ranger Project Area must not suffer any significant deleterious radiological impacts.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 6 - Storage, Use and Disposal of Hazardous Substances and Wastes	6.1 All hazardous substances (including chemicals, reagents, fuels and oils) must be stored, used and disposed of in conformance with relevant Australian law and in accordance with any standards, practices or procedures advised by the Supervising Authority or the Minister with the advice of the Supervising Scientist to minimise the risk to human health and ecosystem health.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 6 - Storage, Use and Disposal of Hazardous Substances and Wastes	6.2 The company must ensure that wastes will not result in any detrimental environmental impact outside of the Ranger Project Area, and that the environmental impacts within the Ranger Project Area are as low as reasonably achievable.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 6 - Storage, Use and Disposal of Hazardous Substances and Wastes	6.3 From the date of the Authority the company must prepare and maintain records of the location, state and chemical characteristics of all hazardous substances and wastes contained, used and disposed of on the Ranger Project Area. The company must take all reasonable steps to include in the record details of hazardous substances contained, used or disposed of on the Ranger Project Area before the date of the Authority.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 7 - Management of Excavated Material	7.1 All excavated material must be managed such that there is no detrimental environmental impact outside of the Ranger Project Area, and that environmental impacts within the Ranger Project Area are as low as reasonably achievable.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 9 - Rehabilitation Plan	9.1 The company must prepare a rehabilitation plan which is approved by the Supervising Authority and the Minister with the advice of the Supervising Scientist, the implementation of which will achieve the major objectives of rehabilitation as set out in subclause 2.2, and provide for progressive rehabilitation.
			9.2 All progressive rehabilitation must be approved by the Supervising Authority or the Minister with the advice of the Supervising Scientist and subject to the NLC agreeing that the aim and objectives for rehabilitation as described in clause 2 are met.

Instrument	Title	Section	Obligation
			9.3 The company's obligations under clause 9 will cease in respect of any part of the Ranger project area over which a close-out certificate is issued by the Supervising Authority subject to the Supervising Scientist and the NLC agreeing that the specific part of the Ranger Project Area has met the requirements of clause 2.
			9.4 Where agreements under 9.2 or 9.3 cannot be reached the Minister will make a determination with the advice of the Supervising Scientist.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 10 - Protection of Soil, Vegetation and Fauna	10.1 All operations should be managed to minimise, to the maximum extent practicable, and to the satisfaction of the Supervising Authority or the Minister with the advice of the Supervising Scientist:a) the disturbance of soil, vegetation and fauna within the Ranger Project Area; andb) the risk to fauna as a result of drinking contaminated water.
			10.2 The company must ensure that the operations at Ranger will not result in any adverse impact on Kakadu National Park through the introduction of exotic fauna and flora.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 11 - Management of Tailings	11.1 During mining operations and prior to final placement, covering and rehabilitation of the tailings, tailings must be securely contained in a manner approved, by the Supervising Authority or the Minister with the advice of the Supervising Scientist, which prevents detrimental environmental impact.
			11.2 By the end of operations all tailings must be placed in the mined out pits.
			11.3 Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, to ensure that: i) the tailings are physically isolated from the environment for at least 10,000 years, ii) any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years and iii) iii) radiation doses to members of the public will comply with relevant Australian law and be less than limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines effective at the time of the final tailings disposal.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 12 - Best Practicable Technology	12.1 All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT.

Instrument	Title	Section	Obligation
			12.2 Where there is unanimous agreement between the major stakeholders that the primary environmental objectives can be best achieved by the adoption of a proposed action which is contradictory to the Environmental Requirements, and which has been determined in accordance with BPT, that proposed action should be adopted. Where agreement can not be reached the Minister will make a determination with the advice of the Supervising Scientist.12.2
			12.3 All environmental matters not covered by these Environmental Requirements must be dealt with by the application of BPT.
			12.4 BPT is defined as: that technology from time to time relevant to the Ranger Project which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters including: a) the environmental standards achieved by uranium operations elsewhere in the world with respect to i) level of effluent control achieved and ii) the extent to which environmental degradation is prevented, b) the level of environmental protection to be achieved by the application/adoption of the technology and the resources required to apply/adopt the technology so as to achieve the maximum environmental benefit from the available resources, c) evidence of detriment or lack of detriment to the environment, d) the physical location of the Ranger Project, e) the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation and f) social factors including the views of the regional community and possible adverse effects of introducing alternative technology.
			12.5 Proposals to amend or introduce operational approaches, procedures or mechanisms must be supported by a BPT analysis. The rigour of the BPT analysis must be equal with the potential environmental significance of the proposal. The BPT analysis must involve consultation with and have regard to the views of the major stakeholders and copies of the BPT analysis must be provided to each of the major stakeholders.
			12.6 A precautionary approach is to be exercised in the application of BPT in order to achieve outcomes consistent with the primary environmental objectives.
Authorisation	Variation of Authorisation 0108 (Annex A)	Clause 13 - Environmental Monitoring	13.1 During operations the company must carry out a comprehensive monitoring program, as required by the Supervising Authority or the Minister with the advice of the Supervising Scientist, which; a) includes monitoring stations on Magela Creek upstream and downstream of the mine at Gauging Stations GS8210028 and GS8210009 and such other sites as may be approved or required by the Supervising Authority or the Minister with the advice of the Supervising Scientist; and b) is sufficient to allow interpretive analysis of impacts from operations.

Instrument	Title	Section	Obligation
			13.2 The company must ensure proper analysis of monitoring results to the satisfaction of the Supervising Authority or the Minister with the advice of the Supervising Scientist and: a) must make data and reports available to the major stakeholders; and b) must make reports of monitoring results and analysis, other than commercial-in-confidence matters, available to members of the Advisory Committee established under the *Environment Protection (Alligator Rivers Region) Act 1978.*
			13.3 The company must carry out a monitoring program approved by the Supervising Authority or the Minister with the advice of the Supervising Scientist following cessation of operations until such time as a relevant close-out certificate is issued under clause 9.3.
Authorisation	Variation of Authorisation 0108 (Annex A)	14 - Staffing	14.1 The company must employ adequate numbers of competent, appropriately qualified and experienced staff to ensure that it can provide the required level of protection to the environment, human health and Aboriginal culture and heritage.
Authorisation	Variation of Authorisation 0108 (Annex A)	15 - Research	The company must undertake research with a view to maximising the level of environmental protection at Ranger. Plans and results of environmental research by the company will be provided to the Technical Committee established under the *Environment Protection (Alligator Rivers Region) Act 1978*to enable the committee to effectively co-ordinate environmental research in the region.
Authorisation	Variation of Authorisation 0108 (Annex A)	16 - Reporting Incidents	16.1 The company must directly and immediately notify the Supervising Authority, the Supervising Scientist, the Minister and the Northern Land Council of all breaches of any of these Environmental Requirements and any mine-related event which: a) results in significant risk to ecosystem health; b) which has the potential to cause harm to people living or working in the area; c) which is of or could cause concern to Aboriginals or the broader public.
Authorisation	Variation of Authorisation 0108 (Annex A)	18 - Environmental Management Report	18.1 The company must prepare an Environmental Management Report which is approved by the Supervising Authority and the Minister with the advice of the Supervising Scientist. Approval may be given conditionally. The company must submit the Environmental Management Report to the NLC at the same time as submitting it for approval. The Environmental Management Report must be prepared in accordance with guidelines as determined by the major stakeholders. The report must provide details of: a) the company's environmental management over the preceding 12 month period; b) the company's proposals for complying with the Environmental Requirements and all applicable environmental laws over the following 12 months.

Instrument	Title	Section	Obligation
			18.2 The report required under clause 18.1 must deal specifically with the following matters: a) water management; b) land management; c) protection of cultural sites; d) counter disaster and emergency procedures; e) environmental research; f) environmental monitoring, including any environmental monitoring required by the Supervising Authority; g) social impact monitoring; h) hazardous substances and industrial waste management; i) radiation monitoring and management; j) air quality management; k) tailings management; l) excavated material management; m) environmental planning and operating systems, including employment and training programs; and n) rehabilitation.
			18.3 The company must ensure that the Environmental Management Report is updated and submitted at such times as are required by the Supervising Authority or the Minister with the advice of the Supervising Scientist, and no less than annually.
			18.4 The company must comply with the proposals set out in each Environmental Management Report as approved and subject to any conditions set by the Supervising Authority or the Minister with the advice of the Supervising Scientist.
Authorisation	Variation of Authorisation 0108 (Annex B)	Annex B - Submission of Mine Closure Plan	B.1 This Annex sets out a process for the submission and assessment of the Mine Closure Plan as agreed in writing between the NT Minister and the Commonwealth Minister in accordance with section 34 of the *Mining Management Act*.
			B.2 The Operator must comply with the submission and content requirements set out in Annex B.3 to B.8 inclusive.
			B.4 On or before 1 October in each of the following years, the Operator must review the Mine Closure Plan and submit an updated Mine Closure Plan for approval.
			B.5 If the Operator at any other time finds it necessary to amend the Mine Closure Plan, the Operator must as soon as practicable notify the Commonwealth Minister and NT Minister of the circumstances requiring amendment and submit an amended plan for approval.

Instrument	Title	Section	Obligation
Authorisation	Variation of Authorisation 0108 (Annex B)	Annex B - Content of a Mine Closure Plan	B.6 Subject to the terms and conditions of the Authority, the Mine Closure Plan must be prepared in accordance with the mine closure guidelines accepted by the Commonwealth Minister.
			B.7 The Mine Closure Plan must demonstrate closure activities will achieve the relevant Environmental Requirements, and include, but is not limited to, the following elements … [contained within the Variation].
			B.8 In the case of an updated or amended Mine Closure Plan, the additions or amendments to the version previously approved must be clearly identified in the updated or amended Mine Closure Plan.
			B.9 Upon receipt of a Mine Closure Plan (including any updated or amended version), the NT Minister will forward a copy of the Mine Closure Plan to the Supervising Scientist, Northern Land Council (NLC), and Gundjeihmi Aboriginal Corporation (GAC) for consideration.
			B.10 The Commonwealth Minister, the NT Minister, the Supervising Scientist, NLC, and GAC may request additional information from the Operator.
			B.11 The Supervising Scientist, NLC, and GAC will each write to the Commonwealth Minister and the NT Minister setting out their advice as to whether the Commonwealth Minister and the NT Minister should approve the Mine Closure Plan, and reasons for their advice.
			B.12 The NT Minister will forward copies of the advice received to the Operator as soon as possible after receiving them. The Operator may, in turn, provide any written comment to the Commonwealth Minister and NT Minister.
Authorisation	Variation of Authorisation 0108 (Annex B)	Annex B - Approval of the Mine Closure Plan	B.13 The Commonwealth Minister and the NT Minister must assess the Mine Closure Plan and may approve, or refuse to approve, all or part of the Mine Closure Plan.
			B.14 In deciding whether to approve or refuse to approve the Mine Closure Plan, the Commonwealth Minister and the NT Minister must take into consideration the advice provided by the Supervising Scientist, NLC, and GAC and any written comment or response to that advice provided by the Operator.
			B.15 The NT Minister will decide whether to approve, or refuse to approve, all or part of the Mine Closure Plan and will write to the Commonwealth Minister to advise of his own decision, and seek the Commonwealth Minister's decision and advice.
			B.16 After receiving the written notice of the decision of the NT Minister, and taking that decision, the terms of the Authority and the advice and comments received into account, the Commonwealth Minister shall decide to approve or refuse to approve the Mine Closure Plan.

Instrument	Title	Section	Obligation
			B.17 Upon making a decision, the Commonwealth Minister will notify the Operator and the NT Minister of his/her decision in writing.
			B.18 The Mine Closure Plan will take effect from the date of the Commonwealth Minister's written notice of approval or partial approval and will continue in effect until the approval of an updated or amended Mine Closure Plan.
			B.19 If the Commonwealth Minister is not satisfied that the Mine Closure Plan , or part thereof, should be approved, the Commonwealth Minister will, by written notice, advise the Operator and the NT Minister that approval has been refused either in whole or part.
			B.20 Where the Commonwealth Minister refuses to approve the whole or part of the Mine Closure Plan, the written notice will: a) outline the specific chapter or sections of the Mine Closure Plan that the Minister refuses to approve; and b) request the Operator to submit an amended Mine Closure Plan in accordance with this Annex.
Authorisation	Variation of Authorisation 0108 (Annex C)	Annex C - Conditions for the release of process water distillate from the Ranger mine brine concentrator	C.2.1 Distillate may only be released from the process water circuit when continuously monitored electrical conductivity in the distillate stream does not exceed 20us/cm.
			C.2.2 Distillate may only be released to Corridor Creek into or upstream of GCMBL or to the RP1 catchment upstream of the RP1 weir;
			C.2.3 Distillate may only be released to Corridor Creek when total ammonia nitrogen (TAN), as measured at GCMBL, does not exceed 0.7mg/L unless another cause is identified;
			C.2.4 Distillate may only be released to the RP1 catchment when TAN, as measured at the RP1 weir, does not exceed 0.7mg/L unless another cause is identified; and
			C.2.5 Discharge of process water distillate shall not cause flow past Sleepy Cod Dam or RP1 Weir when there is no flow in Magela Creek.

Instrument	Title	Section	Obligation
		Clause C.3 - Conditions for release of pond water permeate	C.3.1 The Electrical Conductivity (EC) of the permeate streams from the plant is to be continuously monitored and not to exceed 200 uS/cm during discharge of treated water; C.3.2 Treated pond water may be discharged to land application or into, or upstream of, RP1, GCMBL or DJKRP. Release to DJKRP shall be only during periods of flow in Magela Creek; C.3.3 Discharge of treated pond water shall not exceed the guidelines for U and Ra of 40 ug/L and 100mBq/L, respectively C.3.4 The discharge of treated pond water from the treatment plant shall be discontinued when water quality at Magela Creek compliance point MG009 is above action level for any key parameter unless investigations have identified another cause; and C.3.5 Discharge of treated pond water shall not cause flow past Sleepy Cod Darn or RP1 Weir when there is no flow in Magela Creek
		Clause C.4 - Criteria for direct release of water from RP2 to Magela Creek	C.4.1 The flow rate in Magela Creek at GS8210009 shall be greater than 20 m3/s before water may be released. C.4.2 The water release rate shall also be restricted so that the total load of those constituents listed in Table 1 does not exceed the additional annual load limits specified in Table 1 in any twelve-month period commencing in September. C.4.3 Results of analyses performed for the water release monitoring program are to be forwarded weekly to the Director.
		Clause C.5 - Criteria for releases of water from RP1 and Dialkmarra Billabong	C.5.1 The water release rates shall also be restricted so that the total load of those constituents listed in Table 1 (as described in this section of the Authorisation) does not exceed the additional annual load limits specified in Table I in any twelve-month period commencing in September.
Authorisation	Variation of Authorisation 0108 (Annex D)	Annex D.10 - Rehabilitation Progress Report	D.10.1 The Operator shall provide the members of the Minesite Technical Committee a Rehabilitation Progress Report at least twice per Year, D.10.2 The Rehabilitation Progress Report must include, but is not limited to, the information shown in Table 3 (as set out in this section of the Authorisation) and any additional information that demonstrates the current status of key rehabilitation activities. D.10.3 The Rehabilitation Progress Report may take the format of a written report or a presentation to the Minesite Technical Committee.

Instrument	Title	Section	Obligation
Application	Application: Pit 3 Tailings Deposition (July 2019)	Acceptance Letter (18 July 2019)	Additional information provided on 14 June and the amended application provided on 3 July 2019 are acceptable to the department except for the tailings level change. The department is still considering the request to increase the final tailings level to -15mRL and will advise of the decision in due course. In line with the application, you are approved to: - Commence depositing dredged tailings sub-aqueously, while continuing sub-aerial deposition of mill tailings (and dredged tailings as required); and - Implement a Maximum Operating Level (MOL) of +3.5mRL for water in Pit 3. Further recommendations and comments on this application are included in Attachment A. These must be considered while undertaking any future activities.
			Appendix A - NLC & GAC - We note the need for additional work in order to assess potential impacts of mine contaminants on the offsite environment, including additional modelling integrating all potential contaminant sources, and the need for a method to verify that 95% of tailings pore water is extracted and treated. We expect this work will be completed prior to the approval of Pit 3 backfill.

Instrument	Title	Section	Obligation
			Appendix A - SSBERA has committed to a number of activities within the Application which the Supervising Scientist consider critical to the on-going stakeholder confidence in the rehabilitation of the mine site. These commitment should be tracked through the existing stakeholder forums.• In-situ tailings characterisation 2019 – to inform an update to the consolidation model• In-situ tailings characterisation 2020 – to inform the proposed postdeposition activities such as wicking requirements.• Updated tailings consolidation modelling incorporating, the new deposition methods and results from in-situ tailings characterisation.• Deposition plan to be included in the Pit 3 Operations and Maintenance Manual which will outline detailed monitoring to track progress against plan.• Monitoring to include, but not be limited to:o Regular depth measurements under the diffuser to confirm solids level rise,o Regular suspended solids measurements of the decant water,o Regular total dissolved solids measurements of the process water,o Monthly bathymetry surveys to assess maximum tailings level using,o 6 monthly geophysical surveys to assess tailings characteristics,o 12 monthly CPT testing to assess tailings characteristics.• Independent modelling of tailings consolidation for Pit 1 to be completed to provide confidence in the approach used for tailings consolidation modelling in Pit 3.• Process water to be transferred back to TSF in case of water level exceeding the MOL.• Groundwater monitoring network to be established in 2019 which collects groundwater level and chemistry data (approved in the RWMP).• Calibration-constrained uncertainty analysis on the groundwater solute egress model.

Instrument	Title	Section	Obligation
Application	Application: Pit 3 Tailings Deposition (July 2019)	Application Section 4.1 - Description of proposed method	a) Mill Tailings: Subaerial deposition of mill tailings will continue from an increased number of spigots. Tailings will be discharged from spigots on the east wall of Pit 3 to better distribute the tailings (BPT Option M2). Discharge will be through one spigot at any one time. b) Dredge Tailings: Dredge tailings from the TSF will be deposited in Pit 3 using the subaqueous deposition system currently being tested in the deposition trial (BPT Option D2). The existing subaerial discharge points will be maintained as a backup option during diffuser down time, diffuser maintenance periods and planned pontoon movement operations. •Tailings will be extracted from the TSF using two dredges, the existing Rock Crush dredge (3.9M3/annum) and a new Damen CSD500S dredge (4.7M m3/annum) to be commissioned mid-2019. The new dredge will increase the dredging capacity to meet the target date of end of December 2020 for the completion of tailings transfer. • Pumping will be via separate HDPE pipelines to Pit 3 (each pipeline sized to match flow from the dredge being served). • Floating sections of pipeline will allow discharge over all parts of Pit 3. • Each pipeline will be fitted with a novel diffuser (Figures 15 and 16, Section 2.3) to reduce the velocity of slurry at the discharge point and reduce coarse and fine tailings segregation. • Each diffuser will be designed for the slurry flow from each dredge. The second diffuser will be larger to accommodate the higher tailings transfer rate from the second dredge, but the configuration will be essentially the same for both diffusers. • Both diffusers will be supported by a single pontoon. • The diffusers will be systematically moved across Pit 3 (using diesel powered winches) following a deposition plan to ensure an even deposition across the pit. • A dredge tailings deposition monitoring program will include: o Regular depth measurements under the diffuser to ensure it does not get beached and to confirm the solids level rise is according to that estimated in the deposition plan. o Suspended solids measurements of the decant water to confirm that fine solids are not being drawn into the suction of the process water return pumps. o Monthly bathymetry to monitor the settled tailings surface and validate against predicted levels. It is estimated that the maximum height of the tailings surface at the end of consolidation will be approximately -15m RL once the transfer of mill and dredge tailings is complete.

Instrument	Title	Section	Obligation
Application	Application: Pit 3 Tailings Deposition (July 2019)	Application Section 4.2 - Tailings Deposition Schedule	The remaining tailings in the TSF will be transferred to Pit 3 by the end of 2020. Up to June 2019, approximately 311,000 m3/month will be transferred to Pit 3 by the existing dredge. The transfer rate will increase to approximately 638,000 m3/month following the commissioning of the second dredge in July 2019. The transfer rate will then be maintained at about 638,000 m3/month until December 2020, when all tailings will be removed from the TSF. Approximately 205 kt/month of ore will be processed by the mill until mill closure in December 2020. The mill tailings (approx. 262,000 m3/month) will continue to be deposited into Pit 3 until closure of the mill.
Application	Application: Pit 3 Tailings Deposition (July 2019)	Application Section 4.3 - Monitoring Program	The monitoring objectives associated with Pit 3 tailings deposition are to monitor:• The tailings solids level and distribution across Pit 3; • Water quality of process water as an indicator of the final tailings source term for groundwater contaminate transport modelling ;• Suspended solids in the return water that is being sent to the BC for treatment; and • Changes in groundwater head and solute concentrations, within each hydrogeological unit, for comparison against expected changes in the groundwater system between Pit 3 and Magela Creek, both during Pit 3 backfilling and after Pit 3 closure. To achieve these objectives, the monitoring program will include the following components Pit 3 Monitoring: Monthly (2019-2020):• Bathymetry of Pit 3;• TSS in process water return;• Process water TDS.Groundwater Monitoring 2019 to Closure:• Biannual monitoring of thirteen existing bores adjacent to Pit 3 to capture pre andpost-wet season groundwater quality.• Biannual monitoring of four new bores between Pit 3 and Magela Creek:o three new bores to be installed in 2019; ando one new bore to be installed on the north-eastern edge of the Pit 3 cap followingcompletion of backfilling at this location.

Instrument	Title	Section	Obligation
Application	Application: Pit 3 Tailings Deposition (July 2019)	Section 5 - Next Steps	A summary of each activity that has been developed to a feasibility study level will be included in the next update of the Ranger Mine Closure Plan. More detailed information regarding the closure of Pit 3 will be addressed in separate applications to the MTC and will cover the following final steps in the closure of Pit 3: • Transfer of residual tailings and contaminated material from the TSF for Pit 3 that could not be recovered by dredging; • Subaqueous installation of prefabricated vertical drains (wicks), similar to those which have been installed in Pit 1; • Subaqueous installation of a geotextile layer to provide the required geotechnical strength and allow access for backfill; • Subaqueous preloading with a layer of waste rock, to activate the wicks; • Dewatering of Pit 3 in preparation for final backfill operations; and • Bulk backfill with waste rock material. More detailed information about the final landform, surface treatment, erosion control and revegetation will be addressed in a separate application to the MTC.
Application	Application: Pit 3 Tailings Deposition (July 2019)	Acceptance Letter (29 August 2019)	Deposit tailing in Pit 3 to an average interim level of -15mRL. This level is for discharges from the fixed spigot points situated along the south and eastern pit perimeter.
Application	Application to Operate a Brine Squeezer (January 2019)	Acceptance Letter (8 April 2019)	The application and additional documents provided are acceptable to the Department. ERA is approved to operate the Brine Squeezer with the proviso that this plant complies with the water discharge requirements of the Ranger Authorisation.
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 1 - Introduction	Integrate brine squeezer technology into the existing water management system to meet the release water quality conditions and Ranger Water Management Plan objectives 3 and 4: • Minimise unnecessary additions to the pond water and process water inventories; and • Optimise pond and process water treatment and disposal mechanisms (Reid, 2017). Once the brine squeezer is commissioned and the results of the testing demonstrate that it meets release water quality, the Ranger Water Management Plan will be updated to include the additional infrastructure.
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.2 - Location	The brine squeezer plant will be located in the southern section of the site's sand blast yard, between the laterite plant and WTP2. The plant's piping feed water will be at WTP2 (brine feed) and output to WTP1 (brine squeezer permeate and residue disposal). Power will be provided by a suitably sized transformer. Limited vegetation clearing may be required for construction and this would be managed through ERA's land disturbance permit process.

Instrument	Title	Section	Obligation
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.3 - Plant Specifications	The Osmoflo brine squeezer plant will incorporate three RO trains in a two on, one standby configuration, each sized for treating 1.3 to 1.5 ML/day. Each train has its own high pressure pump, crossflow pump and 60 pressure vessels arranged in a single stage. Each vessel has four membranes installed. The brine squeezer feed is separated into two streams, permeate and reject within the membrane. Dissolved solids from the feed are concentrated in the reject, while low TDS permeate passes through as permeate. A crossflow pump recirculates the reject stream across the membranes to recover further permeate. The brine squeezer is designed to operate at recovery rates between 80 – 90%. The contract between ERA and Osmoflo includes required targets to be met including: • Permeate quality to be equal to or better than current WTP permeate. • Permeate yield to be at least 83% of the feed brine volume from the up stream water treatment plants, and cleaning waste to be no greater than 5% of the feed brine volume. • A nominal plant capacity of 3.0 ML/day. • An overall availability of 99% (factoring in 3 train installation with 2 trains operating). The brine squeezer will also have the ability to operate the third train simultaneously, if required (with reduced overall availability) to produce an instantaneous capacity equivalent to 4.5 ML per day.
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.4 - Commissioning Schedule	Commissioning of the plant is expected to be in late February 2019. Following commissioning, the brine squeezer will enter a trial phase to ensure that the plant achieves permeate water quality and stable operation. Given familiarity with most of the components of the brine squeezer (i.e. the conventional reverse osmosis stage), this trial phase is expected to be relatively short – less than thirty days. At the conclusion of the trial phase, the brine squeezer permeate discharge will be managed as per the revised criteria in Iles, (2018). Alternatively, if the revised permeate discharge conditions have not been approved, ERA will submit a separate application to the MTC for brine squeezer permeate discharge. In either case, changes will be made to the Ranger Water Management Plan to incorporate the operation of this infrastructure. Until such time that discharge conditions are approved, squeezer permeate will be managed in the same manner as water treatment plant brines – i.e. recycled to RP2 or directed to the process water inventory, based on operational requirements.
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.4 - Commissioning Schedule	Brine Squeezer contractual maximum treated water concentrations and parameters: Max Value Electrical Conductivity - 200 uS/cmMax Value Uranium - 20 ug/L

Instrument	Title	Section	Obligation
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.5 - Operating Phase	On-line, continuous measurement of permeate conductivity will be used to detect problems with plant operation. Probes for continuous measurement of conductivity will be calibrated weekly. As per the current water treatment plants, when online conductivity exceeds a threshold that is lower than the agreed contractual criteria in Table 16 for conductivity for permeate discharge, permeate from the brine squeezer will be automatically diverted to the pond water inventory. Weekly samples of permeate from the plant will be taken and analysed for major cations.
Application	Pit 1 Notification Final in-pit tailings level and Pit 1 Closure Strategy (March 2016)	Acceptance Letter (April 2017)	Pit 1 bulk backfill operations approved based on an average tailings level in the pit of 7mRL. In addition to providing its support for the final in-pit tailings level, the Supervising Scientist made a number of modelling and monitoring recommendations to inform assessment in terms of whole-of-site environmental impact and demonstration that rehabilitation can achieve the Environmental Requirements. I expect to see these recommendations addressed in the mine closure plan.
Application	Pit 1 Final in-pit tailings level and Pit 1 Closure Strategy (March 2016)	SSB Assessment Report - Ranger Pit 1 Final Tailings Deposition Level to +7mRL, February 2017.	SSB supported approval of average tailings level of 7mRL subject to: Bulk backfilling - Prior to the commencement of any further Pit 1 backfill works ERA must provide a detailed Pit 1 backfill plan for the approval of the Director with the advice of the Supervising Scientist. The plan must demonstrate how the work will reconcile assumptions made in the tailings consolidation model and should include a detailed method and schedule for fill placement, and a comprehensive monitoring program for tailings consolidation, including settlement surveys and water balance measurements. Landform design - Prior to commencing the placement of the final six million tons of backfill in Pit 1 ERA must have obtained approval for the final landform design from the Director with the advice of the Supervising Scientist. The design must specifically address issues including plant available water, the potential for plant root interactions with tailings and the formation of gullies over the top of tailings.

Instrument	Title	Section	Obligation
Application	Application to progress Pit 1 final landform (March 2019)	Section 1 - Introduction	Continue with the Pit 1 backfill strategy in April 2019 to promote accelerated consolidation settlement and recovery of process water from the decant location and in preparation for initial tree planting of the Pit 1 landform surface scheduled to commence in early 2021. The original application (March 2018) addressed approval conditions 1 and 2: Condition 1 - ERA must provide a detailed Pit 1 Backfill plan demonstrating how work will reconcile assumption made in the tailings consolidation model and a detailed method and schedule for placement; and Condition 2 - Prior to commencing the placement of the final six million tonnes of backfill in Pit 1 ERA must obtain approval for the final landform design. The design must specifically address issues including plant available water, potential for plant root interactions with tailings and formation gullies over the top of tailings.
Application	Application to progress Pit 1 final landform (March 2019)	2.2 - Pit 1 Closure Strategy	ERA has developed a closure strategy for Pit 1 that includes project-specific control measures to address the identified risks and ensure that there is minimal risk of harm to the environment, communities and individuals. Key elements of the Pit 1 closure strategy summarised below: • The removal of pit tailings flux during tailings consolidation to reduce the risk of contaminants entering groundwater or surface waters and potentially impacting RPA or offsite aquatic ecosystems. • The placement of mineralised waste rock material (2s material) below the water table to reduce the risk of contaminants impacting RPA or offsite aquatic ecosystems, and below a layer of 1s material to ensure any gamma radiation is sufficiently attenuated. • Construction of a surface layer of non-mineralised 1s material with special consideration given to the physical characteristics and thickness of the material required to support a self-sustaining native ecosystem similar to target reference ecosystems, thus reducing the risk of revegetation failure. • A final landform including drainage channels to manage erosion for the Pit 1 catchment and reduce the risk of mobilised sediments or other contaminants impacting RPA or offsite aquatic ecosystems. • Monitoring and research to continue to improve on the trials and modelling already completed. This will further reduce the risks associated with aspects of the Pit 1 closure strategy and will also inform the closure strategy for the rest of the final landform and RPA.

Instrument	Title	Section	Obligation
Application	Application to progress Pit 1 final landform (March 2019)	8 - Monitoring and Research	In order to progress the backfill, ERA has committed to implementing monitoring and research programs, as described in the Pit 1 Progressive Rehabilitation Monitoring Framework (Appendix 8). Lessons learned from the monitoring and research outcomes from Pit 1 will be incorporated into the site monitoring plan as required under an adaptive management framework. The outcomes of the monitoring and studies will be used to address relevant KKNs. The proposed Pit 1 monitoring during and after construction of the Pit 1 final landform allows an adaptive management approach to Pit 1 rehabilitation, whereby the monitoring program will provide ongoing feedback on the performance of the rehabilitation to identify any issues and inform maintenance activities.
Application	Application to progress Pit 1 final landform (March 2019)	DPIR Acceptance (1 May 2019)	Approval granted to progress placement of the final layer of the Pit 1 Landform. Please note that the Pit 1 Progressive Rehabilitation Monitoring Framework is expected to be implemented and continue to be under discussion with the planned Monitoring Evaluation and Research Review Working Group. Please refer to the Supervising Scientist Branch letter in Appendix A for further considerations. Appendix A - SSBWe recommend the priority items for the Monitoring Evaluation and Research Review Working group's consideration include: • Monitoring to inform waste rock consolidation properties, weathering and soil formation, • Monitoring to understand and validate WAVES modelling to predict Plant Available Water (PAW), and to identify opportunities for maximising PAW. • Other items identified in Table 2 of our review of the Pit 1 Progressive Rehabilitation Monitoring Framework (attached). It is expected that ERA will use the Monitoring Evaluation and Research Review Working Group to maximise the opportunity to obtain data and information throughout and after the construction of the Pit 1 Landform. Failure to acquire these data and information may impact on our ability to support the construction of the final landform.
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	Acceptance Letter (April 2019)	I have approved the application and you may now proceed to undertake the works in accordance with the plan set out in your application.
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	2 - Purpose	The progressive closure of the Ranger 3 Deeps exploration decline and portal is required to undergo approval by the MTC. The purpose of this application is to provide the MTC with information on the proposed decommissioning strategy for the decline, including the major activities and schedule.

Instrument	Title	Section	Obligation
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	3.3 - Commitments in the MTC Application to Construct the Decline	In addition to the general obligations in the ERs, the initial MTC application for construction of the decline included closure commitments, which were made prior to the construction of the decline and not assessed using Best Practicable Technology (BPT) (Jacobsen, 2011).Table 1 shows the commitments made in Jacobsen (2011) and how they have been addressed in the Decommissioning Plan. This includes: • In 2018 all hire equipment will be removed from site. If items can't be decontaminated these will be purchased by ERA. As part of the 2018 program small pumps and fans will be installed for 2019 C&M period. • Mid-2020 all surface vent bags, poly pipe, cables and concrete will be removed to one metre below the final landform (including shaft collar and portal multi-plate tunnel). All pipes, cables and vent bag to be removed from the first 100 m of decline. • In 2018 the base of the ventilation raise will be tightly backfilled with waste rock. This will allow backfilling of the shaft in 2020 from surface. In 2020 the first 300 m of decline will be tightly backfilled with waste rock.
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	4 - The Proposal	Stage 1 will involve a 2018 works program commencing with the removal of mine infrastructure in the vicinity of the ventilation shaft access at -260 mRL; backfilling the base of the ventilation shaft with waste rock; and, allowing the decline to naturally flood to -20 mRL (c. 1.3 years). A reduced level of C&M until 2021 will maintain the water level in the decline at -20 mRL (below the weathered zone). Final closure activities after January 2021 will include: • Backfilling the ventilation shaft from the surface, plugging with cemented rock fill to prevent subsidence and removal of surface concrete structures. • Tightly backfilling the top **350** metres of the decline (including portal), commencing below the weathered zone and above the controlled water level to eliminate surface subsidence. • Removal of the steel multi-plate portal down to ground level (the final landform surface).

Instrument	Title	Section	Obligation
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	4.1 - 2018 Works Program	The 2018 works program (which is detailed in Section 6), incorporates removal of infrastructure including pumping, and electrical equipment within the vicinity of the base of the ventilation shaft and subsequent backfilling of the vent shaft access. An outline of these works includes: • Install water level monitoring equipment in the vicinity of the base of ventilation shaft and monitor water level. • Decline is dewatered and pumping terminated. • Grout standpipe holes (if required), however INTERA, 2018 indicates this is not necessary. • Remove existing pumps, wait for decline to flood and install small pump at -20 mRL. • Backfilling of the -260 mRL ventilation shaft access. • Removal of refuge chambers (remove 8 and 12 person, relocate 4 person). • Removal of 1.5 Mva power system, connect to Ranger grid. • Demobilisation.
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	4.2 - Care and Maintenance	C&M activities include: • Decline is allowed to flood to around -20 mRL. • Small pump dewaters sump 1, water is discharged into the existing portal pond, which overflows into RP2. • Water level rise in decline is monitored by the decline monitor installed near base of shaft at -260 mRL and from existing surface monitoring bores. • Power supply to the decline is from the Ranger mine grid. • Forced ventilation is operated as required. A small 15-30 kW fan delivering 10 m3/sec. • Sump 1 pumps are inspected by site personal on weekly/as required basis. • The radon alpha prism traffic light monitoring system will remain in operation, (requires an annual calibration). • The leaky feeder radio system will remain in operation for the first leg of the decline.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	DPIR Acceptance Letter (April 2018)	Civil works proposed in this application is acceptable to the Department.

Instrument	Title	Section	Obligation
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.1 Proposed New Crest Level	ERA is seeking a reduction in the certified crest height to 51.0 mRL. The purpose of this application is to enable ERA to:o continue to transfer tailings from the tailings dam to Pit 3 for final storage at an optimum transfer rate;o continue to return process water from Pit 3 to the tailings dam at a rate required that will not impact on dredging; ando continue to transfer process water to both the processing plant and brine concentrator.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.2.2 Construction Materials	All notching and construction of associated access ramps will be undertaken in accordance with the construction scope appended to Saunders (2017a).
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.2.3.1 Clay core (Zone 1A)	Sampling and laboratory tests of the clay core material include: • 3 clay U-tube samples x 3 depths • 3 disturbed samples x 3 depths Laboratory tests: • Permeability by laboratory testing: 3 no. at each depth (on undisturbed samples) • 3 x hydrometer and Atterberg limits • 3 x moisture content tests • 2 x triaxial tests • 2 x consolidation tests Field tests: • 2 tests: 1 m x 1 m x1 m size pit • Soak well tests by filling with water and measuring the draw down over time • 2 x dynamic cone penetration (DCP) test if possible
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.2.3.2 Filter Zone 2B	• 3 zone 2B disturbed samples @ 3 depths Laboratory tests: • 2 x particle size distribution and Atterberg limits (no tests required if the samples are non-plastic) • 1 x hydrometer analysis if the samples are plastic • 3 x moisture content

Instrument	Title	Section	Obligation
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.2.3.3 Earthfill transition	• 3 zone 1C disturbed samples x 3 depths Laboratory tests: • 2 x particle size distribution and Atterberg limits • 1 x hydrometer analysis and Atterberg limits • 3 x moisture content tests
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.2.3.4 Rockfill	• Measurement of maximum size of the rockfill during the visit and photos with a ruler for further assessment in the office to understand the gradation of the rockfill at 3 levels.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.4 Co-commitments for Crest Height Approval	It is expected that the notching and subsequent reduction in the clay core crest height on the eastern embankment to 51.0 mRL will be completed in late Q2 2018. Inspection and sign-off by the tailings dam engineer is scheduled to coincide with practical completion of each stage. As outlined in Table 3-1, ERA will implement a sampling program of the clay core, in order to determine shear strength and permeability to validate assumptions regarding the rapid draw down and stability of the tailings dam and additionally to ascertain potential contamination issues during the deconstruction of the tailings dam. An appropriate QA/QC program will be implemented for the construction of the notch, refer Appendix D of the Coffey notch design.

Instrument	Title	Section	Obligation
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam (March 2018) (TSF Notch East)	3.6 Environmental Protection	Surface water management will be undertaken in accordance with the currently approved Ranger Water Management Plan and its successors. The clay core notching at location 1 to 51.0 mRL is a centre-line crest level and as such there is no additional impact beyond the existing toe of the tailings dam. The current surface water monitoring and management programs will continue with no change. Groundwater monitoring in the vicinity of the tailings dam will be undertaken in accordance with the annually approved Ranger Water Management Plan (RWMP). All existing piezometers and groundwater monitoring bores are located along the western and southern boundaries of the base of the tailings dam and remain unaffected by this activity, enabling continuity with previous monitoring. Contaminated Material Management and Disposal - The potentially contaminated material will be actively managed in accordance with a number of operational standards and plans. A sampling program of the in-situ clay core and upstream rock material will be undertaken to ascertain potential contamination issues during the deconstruction of the dam. Contaminated material will be stockpiled in a designated area within the disturbed mine footprint, this is a Class I (low) risk which will be actively managed.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	DPIR Acceptance Letter (January 2019)	ERA is approved to complete in entirety the planned Stage 1 notch and dredge access ramp ensuring the dam crest is not excavated below the nominated crest height of 49m RL (with a clay core of 48.5m RL). Prior to each stage of reducing the tailings dam wall crest height you must notify the Department of the activity and provide the following:- The estimated levels of process water and tailings in the tailings dam at the time of the crest height reduction. These amounts should be based on the most recent site water model forecast (accounting for model uncertainty) and actual dredge transfer rates and progress;- The estimated Maximum Operation Level (MOL) in Pit 3 once the proposed reduced crest height is implemented; and- Any additional analyses necessary to address issues with potential instability of the wall associated with rapid draw-down.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	2.3.1 Surface Water Quality	The proposed notching of the northern embankment will not materially change the surface water quality within the Gulungul Creek catchment. Runoff water from the northern wall currently flows to the west, into the RP1 catchment (release quality). Material removed from the northern wall during the notching will be placed in an adjacent, bunded area (see Section 3.2.2). The area will be shaped so any rainfall run-off is directed towards Retention Pond 6 (RP6).

Instrument	Title	Section	Obligation
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	2.3.2 Seepage	an extensive, long-term, groundwater monitoring program exists in the vicinity of the tailings dam. Site-specific Data Quality Objectives (DQOs) and Sampling, Analysis and Quality Plan (SAQPs) have been developed for bores within the vicinity of the tailings dam.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.3 Notching Location, Design and Contamination Sampling	The northern wall notching will see the compacted clay core crest height reduced to 48.5 (nominal 49.0 mRL or rockfill elevation) at the end of construction works, as per the plan view (Figure 3-5) and site plan (Figure 3-6). The earthworks will include the construction of a notch with base 49 mRL and new access ramps at the north-eastern corner and north-western corner of the notch.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.3.2 Construction Materials	Appropriately graded fill material will be used in the construction of the notch. Where suitable and practical, materials extracted during the notching excavation will be reused. For example mine waste rockfill and rip rap, extracted from Zone 3A of the notch excavation will be reused to construct the ramp embankments and for erosion protection, respectively. Similarly, material obtained from Zone 2B or 3A will be reused to cover the exposed notching base surface and placed on the running surface of the ramp embankment. Once the 500 mm thick wear course material is placed over the clay core, the notch level will be at 49 mRL. A construction report will be issued upon practical completion of the notching. The report will include design drawings, as-built drawing(s), laboratory test certificates, photographs and sketches made during construction.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.3.3 Inspection and Testing	The compacted mine waste rockfill placed in the ramp embankment will not be required for compliance testing, hence no testing programme will be implemented. However, physical testing (comprising Particle Size Distribution) should be allowed for the wearing course / cover materials. The tests shall be carried out by a qualified technician from a NATA registered laboratory or as directed by the Principal's Representative. The tests shall be carried out to such a degree as to satisfy the Principal's Representative that the criteria on material classification are met. The gradation of materials shall be tested in accordance with Test Method AS 1289 3.6.1 – 1995 Particle Size Distribution – Sieving. The minimum grading test frequency for wearing course materials shall be one test per 500 m2.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.3.4 Contamination Sampling	The same sampling program (and field and laboratory testing) that was implemented for the eastern wall notch will be used for the northern wall notching. Sample analysis will be completed by Australian Nuclear Science and Technology Organisation (ANSTO), and the subsequent results of the analysis used to inform the final disposal location and future decommissioning of the tailings dam.

Instrument	Title	Section	Obligation
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.3.4.1 Proposed field work	The sampling plan described in this memo includes the field work i.e., sample retrieval and sample analysis information. Sampling for potential contamination will be performed for the clay core zone (zone 1A) only. At each sample point, clay samples at depths of 0-10 cm will be collected by hand. Samples will be packaged in a condition suitable for laboratory analysis. Two samples will be taken between the crest of 60.5 mRL and 59 mRL. Samples to be taken at the furthest distance away from the adjacent tailings and in close proximity to each other. A total of 14 samples will be retrieved from the clay core. Twelve samples will be retrieved on three levels between 56 mRL and 48.5 mRL. The exact levels will be unplanned and will be determined by the excavation operations and safe accessibility at the level. The lowest sampling level will be as close as possible to 48.5 mRL. Four samples will be retrieved per level for metals and radionuclide analysis. The first sample will be taken as close as possible to the edge of the clay core adjacent to the tailings. The other samples will be taken in increments of approximately 30 cm from the first sample.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.7 Environmental Protection	Surface water management will be undertaken in accordance with the currently approved Ranger Water Management Plan and its successors. The notching to a nominal 49.0 mRL will not result in any additional impact beyond the existing toe of the tailings dam. The current surface water monitoring and management programs will continue with no change. Groundwater monitoring in the vicinity of the tailings dam will be undertaken in accordance with the annually approved Ranger Water Management Plan (RWMP). All existing piezometers and groundwater monitoring bores are located along the western and southern boundaries of the base of the tailings dam and remain unaffected by this activity, enabling continuity with previous monitoring.
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	3.7.3 Contaminated Material Management and Disposal	Material from these areas of the tailings dam will be contained within separate, bunded areas located between the north wall and Retention Pond 6. The potentially contaminated material will be actively managed in accordance with a number of operational standards and plans. ERA will implement the same sampling program for the northern wall notch that was completed on the eastern wall notch. Sample analysis will be completed by ANSTO, and the analysis will be used to inform the final disposal location and future decommissioning of the tailings dam.Materials from the northern notch will, be separated into stockpiles. For example, the clay core (A1) material and the upstream rock excavated from 51 mRL to 48.5 mRL will be bunded and stored separately to all other embankment materials. Contaminated material will be stockpiled in a designated area within the disturbed mine footprint, this risk which will be actively managed.

Instrument	Title	Section	Obligation
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	DPIR Acceptance Letter (May 2019)	ERA is approved to complete the proposed Stage 2 North Wall Notch, ensuring the minimum height of the clay core shall be 45.1mRL around the entire perimeter of the Tailings Dam, and that the clay core will be maintained at a minimum width of 4m and 45.1mRL. Comments on this application are included in Attachment A. These are to be considered during notching activities and for your Tailings Dam management in the future. Appendix A - DPIR Prior to each stage of reducing the tailings dam wall crest height you must notify the Department of the activity and provide the following: - The estimated levels of process water and tailings in the in the tailings dam at the time of the crest height reduction. These amounts should be based on the most recent site water model forecast (accounting for model uncertainty) and actual dredge transfer rates and progress; - The estimated Maximum Operation Level (MOL) (during both the wet and dry season) in Pit 3 once the proposed reduced crest height is implemented; and - Any additional analyses necessary to address issues with potential instability of the wall associated with rapid draw-down. In line with DIIS comments below, ERA must consider options to mitigate the risk of rapid water drawdown affecting the dam wall stability before the water level in the TSF is planned to be reduced below 40 m RL. Appendix A - NLC Reiterate concerns with the scarcity of information on contamination within the walls and below the TSF and encourage ERA to take advantage of opportunities to gather information on this contamination and share this with stakeholders. Appendix A - DIIS We do note that a risk of rapid water drawdown affecting the dam wall strength has been identified by Coffey when the water level reduces to 40mRL. We request that ERA formally consider and address this risk before the water level in the TSF is planned to be reduced below that level. Appendix A - SSB It is noted that ERA intends to undertake detailed contamination assessments in 2019 to inform a tailings dam contamination management application to be submitted early in 2020. It is requested that ERA consult with stakeholders on the scope of this contamination assessment to ensure it provides adequate information to facilitate the assessment of the tailings dam contamination management application.

Instrument	Title	Section	Obligation
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)		ERA intends to proceed with stage II of the north wall notch and seeks approval to reduce the tailings dam clay core crest height to 45.1mRL. This notch, scheduled for construction in late April 2019. In order to provide flood storage of a volume calculated in accordance with the Ranger Authorisation, the seasonal Maximum Operating Level (MOL) for this reduced crest height will be 43.8mRL during the dry season and 42.3mRL during the wet season.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.3.1 Notch Construction	The following recommendations are therefore made for the construction of north notch stage 2: • A minimum safe setback distance (for construction machinery) of 3 m from the upstream embankment edge should be maintained. • During notch construction, the crest condition should be closely observed and, in reaction to any movement or appearance of cracks in the existing embankment rockfill (however unlikely), construction machinery should immediately be moved away from the cracking toward the downstream embankment face. • Analyses for east notch excavation to 51mRL are deemed relevant to the north notch at 45.6mRL, with the 5.5 m difference in base elevation considered by Coffey unlikely to be significant to overall notch stability.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.3.3 Crane Pad	• The crane shall operate at a minimum safe setback distance of 9m from the upstream edge of the notch as shown in Figure 4-2 • Crane mats/steel plates will be required beneath the crane as indicated in section 2.7 of the scope of works attached to the north notch stage 2 design report (Appendix A) • High strength woven geotextile reinforcement (minimum ultimate strength 400kN/m) will be placed nominally 750mm to 1000mm below the crane during the construction of the crane pad.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.4 Contamination Sampling	The same sampling program (and field and laboratory testing) that was implemented for the eastern wall notch and north wall notch stage 1 will be used for the north wall notch stage 2. Sample analysis will be completed by Australian Nuclear Science and Technology Organisation (ANSTO), and the subsequent results of the analysis used to inform the final disposal location and future decommissioning of the tailings dam.
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.6 Co-commitments for Crest Height Approval	It is expected that stage 2 of the northern wall of the tailings dam will be completed in June 2019. Inspection and sign-off by the tailings dam engineer is scheduled to coincide with practical completion of each stage. Upon completion of north wall notch stage 2, the tailings dam operations and maintenance manual (Appendix C) will be updated in accordance with ERA management of change processes. An appropriate QA/QC

Instrument	Title	Section	Obligation
			program will be implemented for the construction of the notch, refer Section 2.1 of the Coffey scope of works (in Appendix A).
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.8 Environmental Protection	Surface water management will be undertaken in accordance with the currently approved Ranger Water Management Plan. The current surface water monitoring and management programs will continue with no change. Groundwater monitoring in the vicinity of the tailings dam will be undertaken in accordance with the annually approved Ranger Water Management Plan (RWMP).
Application	Application to Reduce the Certified Crest Height of the Ranger Tailings Dam North Wall Notch Stage 2 (April 2019)	4.8.3 Material Management and Disposal	Any potentially contaminated material at ERA is actively managed in accordance with a number of operational standards and plans.Material excavated during the construction of north notch stage 2 will be contained within the separate, bunded area located between the north wall and Retention Pond 6 used during the construction of north notch stage 1. ERA will implement the same sampling program for the north notch stage 2 as was completed during construction of north notch stage 1 and the eastern notch. Sample analysis will be completed by ANSTO, and the analysis will be used to inform the final disposal location and future decommissioning of the tailings dam.Contaminated Upstream face and tailings hang up (remaining from north notch stage 1) - This rock armour and tailings material (Figure 4-7) must now be removed prior to the construction of north notch 2. The tailings hang-up and rock armour will be excavated and transferred via dump truck for relocation to the north east corner of the tailings dam.Contaminated Upstream face and tailings hang up (remaining from north notch stage 2) - Similar to the north notch 1, this material will be separated from the upstream rock armour visually by the project team. As this material is identified it will managed either:• through side casting for later transport during this notching work or subsequent notching activities; or• direct transport as described above, using the same controls.

Instrument	Title	Section	Obligation
Application	Application to Change Permeate Release Conditions (December 2018)	DPIR Acceptance Letter (April 2019)	This proposal is acceptable to the Department. As per your proposal, details of operational controls to manage permeate production and release must be provided in an amendment to the Ranger Water Management Plan. The Supervising Scientist Branch (SSB) have detailed further management controls for permeate release at the proposed MG001 release point that must be addressed in your Ranger Water Management Plan. These controls have been provided in Attachment A. Attachment A - SSB We have no objections to the removal of the permeate discharge conditions from the Ranger Authorisation, provided that prior to removal, the management of permeate, including the additional controls proposed by ERA, are effectively incorporated into the whole of site release management system with the management strategies approved through the Ranger Water Management Plan (RWMP). These operational controls must clearly demonstrate that out of specification permeate cannot be released to the receiving environment and should include a description of the systems for monitoring, inspection and testing of critical components of the diversion system. Any changes to the permeate release system including adjustment of the permeate quality limits for permeate management must be submitted for approval as variations to the RWMP. Prior to discharge of permeate at MG001 the additional controls proposed by ERA to manage permeate release at MG001 must be included and approved in the RWMP. These additional controls are shown in the dot points below. • Update of the Release Plan Calculator (RPC) to incorporate MG001 permeate releases. • Cessation of permeate release at MG001 if EC at MG009 is less than 8 µS/cm. • Cessation of permeate release at MG001 if the EC at MG009 is more than 4 µS/cm less than the EC at MCUS. • Discharge at MG001 and DJKRP shall only occur during periods of flow in Magela Creek and only when predictions from the RPC indicate water quality objectives are not compromised.
Application	Application to Change Permeate Release Conditions (December 2018)	4.3 Recommendation for Condition C.3.1	Condition C.3.1 should be removed from the Authorisation. Standard operating procedures are in place to ensure the water treatment plants are operating optimally and that water out of specification is recycled.

Instrument	Title	Section	Obligation
Application	Application to Change Permeate Release Conditions (December 2018)	5.3 Recommendation for Condition C.3.2	Condition C.3..2 should be removed from the Authorisation and permeate discharges managed in accordance with the RWMP. The RWMP should be updated to allow permeate discharge to the RP1 or Corridor Creek catchments upstream of the RP1 weir and GCMBL, DJKRP and MG001. Release to DJKRP and MG001 shall be only during periods of flow in Magela Creek. Discharge to MG001 will only occur if predictions from the RPC indicate water quality objectives are not compromised and will stop if EC at MG009 drops to 8uS/cm or to 4us/cm less than EC at MCUS.
Application	Application to Change Permeate Release Conditions (December 2018)	6.3 Recommendation for Condition C.3.3	Condition C.3.3 should be removed from the Authorisation as internal system are in place to ensure optimal plant performance, and that no releases occur when the plants are operating sub-optimally.
Application	Application to Change Permeate Release Conditions (December 2018)	7.1 Recommendation for Condition C.3.4	Condition C.3.4 should be removed from the Authorisation as the condition is more stringent than that for treated process water.
Application	Application to Change Permeate Release Conditions (December 2018)	8.1 Recommendation for Condition C.3.5	Condition C.3.5 should be removed from the Authorisation as it is adequately covered by the RWMP.
Application	Application for approval to release High Density Sludge product water to the pond water treatment circuit (January 2020)	DPIR Acceptance Letter (19 Feb 2020)	ERA will implement operational controls that cease transfer of HDS product water to RP2 in the event of water quality exceeding limits stated in the application. Prior to release of treated water to GCMBL, era should demonstrate the stable operation of the refurbished HDS plant/WTP1 process, including that the quality of the treated water produced is equal to, or better than, that produced by this system previously. Include the water quality limits and controls, as well as the commitments and the Monitoring and Action Plan described in the application in future iterations of the Ranger Water Management Plan. The Ranger Water Quality Objectives will be updated to reflect the conditions for the release of process water permeate, including the proposed reduction of the TAN limit for GMCBL from 2mg/L to 0.7mg/L

Instrument	Title	Section	Obligation
Application	Application for approval to release High Density Sludge product water to the pond water treatment circuit (January 2020)	3.2 Commitments	• Incorporate release criteria and water management methods provided in the application and approval into the next version of the Ranger Water Management Plan. • Undertake all monitoring and management actions in accordance with the monitoring and action plan.• Notify the MTC when a threshold has been reached (as outlined in monitoring and action plan) and the action taken, or to be taken, in response.• Cease direct release from MG001 once the HDS plant has discharged to RP2. • Provide verification to stakeholders that permeate produced through direct feed of HDS product water to the pond water treatment plants is consistent with historical outputs. This must be provided prior to the discharge of direct feed permeate to the offsite environment.• Assess contaminant concentrations in GCMBL after twelve months of water release arising from HDS operations. The results of the assessment, including any required changes to water management, will be presented to the MTC.
Application	Application for approval to release High Density Sludge product water to the pond water treatment circuit (January 2020)	3.1 Approval sought	Direct treatment:: HDS plant product will immediately be sent to WTP1, for subsequent filtration, reverse osmosis and wetland filter polishing • Release of permeate arising from direct treatment to the wetland filter will be subject to the limits in Table 1 • Release of permeate arising from direct treatment will only occur in the dry season, as determined by the presence of stream flow downstream at GC2. • Permeate produced by WTP1 is not discharged to the offsite environment until such time as ERA is able to demonstrate the stable operation of the plant and that the chemical signature of the permeate is consistent with historical outputs • The feed of HDS plant product to WTP1 may be supplemented with pond water. Indirect treatment: HDS plant product will be sent to the pond water inventory (RP2 only), for subsequent filtration and reverse osmosis treatment by any of the pond water treatment plants on site.
Application	Application for approval to release High Density Sludge product water to the pond water treatment circuit (January 2020)	7 Monitoring and action plan	HDS product water, RP2 and WTP permeate will also subject to sampling and analysis by the ERA production laboratory on at least a daily basis, when the relevant plant is running. However these samples are not subject to the same level of quality assurance and control as the surface water monitoring samples
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	4.8.2 Earthworks material management	Undertake notch earthworks in accordance with the following environmental protection measures: - stockpile downstream rock armour with similar material removed from previous notches or within the mining 1s waste rock stockpile areas. - contain clay core material within the separate bunded area used previously for

Instrument	Title	Section	Obligation
			clay core from North Notch stage 1 & 2 - side cast upstream rock armour for storage on the upstream embankment
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	4.2.1 Phase 1 dredging and TSF clean-out	MOLs applicable to the 2020 and 2021 dry seasons and the 2020-2021 wet season: Dry season: RL36.3m Wet season: RL34.8m
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	Submit to the MTC the Stage 3 notch compliance report following the completion of notch construction
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	Update the TSF operations and maintenance manual in accordance with ERA management of change processes
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	Update the Ranger Water Management Plan where appropriate in accordance with ERA management of change processes.
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	Notify the MTC of the intention to construct a crane pad, if required, prior to the start of excavation works
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	4.6 Peer review	Undertake all relevant additional monitoring required by the Rapid Drawdown Monitoring Plan (once monitoring plan is enacted)

Instrument	Title	Section	Obligation
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	Appendix E	Prevent or mitigate environmental risks in accordance with the risk assessment provided as Appendix E in the application.
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	4.2.2.3 Maximum seasonal operating levels for Phase 2	review the process water inventory forecast at the end of each wet season to ensure TSF water levels for the upcoming dry and wet seasons are forecast to remain below the following MOLs applicable to a clay core crest level of RL37.8m: - during dry season: RL36.3m - at the start of each wet season: RL32.5m - during wet season: RL34.8m
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	4.3 notch and bund construction	submit the inventory review report to the MTC by 31 May each year providing the following information:- The water balance components for the process water inventory forecast - The rationale for the selection of the components- The sensitivity of the reforecast to the major components- The outcome of the annual review of the process water inventory forecast a) Confirmation that TSF water levels will remain below the MOLs provided above1 b) Detail on the forecast level of encroachment into one or more MOLs.- In the event of b) above; a request for approval for an increase in clay core crest height via the implementation of a clay bund. The clay bund will be constructed in accordance with the engineering and construction specification provided in the Coffey Ranger Mine Project TSF Stage 3 North Notch Design Report dated 28 February 2020.
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	If required, construct the clay bund during the dry season to ensure a minimum freeboard of 5.3 m at the beginning of the wet season and a MOL of RL34.8 m for the duration of the wet season
Application	Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility, North Notch Stage 3 (June 2020)	5. Summary and commitments	Submit the clay bund construction compliance report to the MTC following the completion of the clay bund.

Instrument	Title	Section	Obligation
Application	Application: Tailings Height for Pit 3 exceeds -20mRL	Acceptance Letter Pit 3 (7 August 2020)	Letter received by ERA from the NT Department of Primary Industry on 7th August 2020 approving deposition of tailings above -20mRL but not above -10mRL throughout the pit ensuring that the water level in Pit 3 remains below the MOL of 3.5mRLbased on: risk to offsite environment is low If ERA requires tailings above -10mRL requested to nominate a new mRL for approval that is achievable, and that the water level in Pit 3 remains below MOL of 3.5 mRL. The application for the final backfill and closure of Pit 3 should demonstrate that; objectives will be met in consideration of any changes in tailings properties, assessment of environmental risks associated with an increase in tailings above -20mRL, how these changes may effect consolidation, consideration of migrations, timeframes for pore water expression and the associated implications for water treatment, the tailings source term and containment transport.
Application	Revised Application: Ranger mine tailings storage facility - subfloor material management	DPIR Acceptance Letter (July 2020)	The purpose of the revised application to seek approval to exclude from further assessments the option to remove contaminated material from the TSF subfloor for final placement in Pit 3, and for the contaminated material to be left in situ in the TSF. - long term management of sub-floor material including any remediation requirements will be included as part of the TSF deconstruction application currently planned for mid - 2023 - further work is needed to better quantify the contaminated plume beneath the TSF and to further refine the groundwater and surface water models to complete the whole of site contaminant transport modelling and to inform the future decommissioning of the TSF including the need for groundwater remediation

Instrument	Title	Section	Obligation
Application	Revised Application: Ranger mine tailings storage facility - subfloor material management	7. Summary and commitments	This application is to leave the TSF subfloor contaminated material in situ - progression of the surface water modelling for whole of site cumulative impacts - further development of the understanding of surface water and groundwater interactions and incorporating this into surface water modelling - Progression of the groundwater solute transport model with uncertainty analysis - Undertake further analysis and assessment of the TSF subfloor drilling results to evaluate the need for in situ remediation and incorporating findings into TSF deconstruction planning - Review of potential remediation options for the TSF subfloor, following the outcomes of further assessment, and incorporate findings within the TSF deconstruction application -Completion of a BPT assessment for potential remediation options following the outcomes of further assessment - Development of a strategy for final TSF deconstruction which results in the maximum environmental benefit - Submission of an application addressing the remaining management aspects for the TSF deconstruction for regulatory approval

5 Key Knowledge Needs Supporting Studies

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GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Bioregion	An ecologically and geographically defined area that is smaller than a biogeographical realm but larger than ecoregion or an ecosystem, in the World Wildlife Fund classification scheme.
Becquerels	The Becquerel (Bq) is the SI derived unit of radioactivity. One Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.
Bininj	Aboriginal (Australian) people of Western Arnhem land in the Northern Territory.
Constituents of Potential Concern	Chemical elements identified by the Supervising Scientist Division as being of potential concern to the receiving environment
Electrical conductivity	Abbreviated to EC. Electrical conductivity is a measure of how well a material accommodates the transport of electric charge.
Gamma Radiation	Ionizing electromagnetic radiation emitted by a radionuclide during radioactive decay
Gray	The Gray (Gy) is a SI derived unit of ionizing radiation dose. One Gray is defined as the adsorption of one joule of radiation energy per kilogram of matter.
Hydrolithologic Unit	A grouping of soil or rock units or zones based on common hydraulic properties.
Georgetown Billabong	The statutory surface water monitoring point for Georgetown Billabong, which is located downstream of Corridor Creek and the Corridor Creek wetland filter.
Groundwater conceptual model	Calibrated numerical groundwater flow model encompassing all hydrogeologic elements governing groundwater flow and transport at the Ranger Mine to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions.
Land Application Area(s)	Abbreviated to LAA. An area on the RPA used as an evapotranspiration disposal method polished and unpolished pond water from the constructed wetlands filters and, more recently, permeates from the water treatment plants. However, irrigation of unpolished pond water ceased at the end of 2009. The concept of land application is to retain metals and radionuclides in the near-surface soil profile.
Land Disturbance Permit	An ERA permit required prior to undertaking any work on the RPA that may lead to surface disturbance, for example ground breaking, surface disturbance, clearing etc.
Long Lived Alpha Activity	Abbreviated to LLAA. The presence, generally in airborne dust, of any of the alpha emitting radionuclides in uranium ore, except for the short-lived alpha emitting radon decay products.
MBL Zone	A hydrolithologic zone of relatively higher permeability to the south east of Pit 1 identified through testing and pumping of bore MB_L.
Magela Creek downstream	Abbreviated to MG009. MG009 is Ranger downstream statutory or compliance surface water monitoring point. It is located on the Magela Creek,

Key term	Definition
	downstream of Ranger operations.
Magela Creek upstream	Abbreviated to MCUS. MCUS is the upstream statutory surface water monitoring point, location on the RPA.
Mirarr	Mirarr is a patrilineal descent group. Descent groups are often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Minesite Technical Committee (MTC)	A of the Working Arrangements for the Regulation of Uranium Mining in the Northern Territory dated 30 May 2005, is tasked with: Reviewing proposed and existing approvals and decisions under NT legislation Reviewing technical information in relation to Ranger Mine, including monitoring data and environmental performance Collaboratively developing standards for the protection of the environment Developing strategies to address emerging issues The MTC consists of the representatives of the Department of Industry, Tourism and Trade, the Supervising Scientist, ERA and the Northern Land Council. Representatives of the Commonwealth Department of Industry, Science, Energy and Resources may also attend MTC meetings.
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321%.
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Plant Available Water	Abbreviated to PAW. The amount of water that can be stored in a soil and be available for growing crops.
Processing	Processing is the mining term to describe all phases of the ore treatment from milling through to the final product packaging of uranium oxide.
Radon decay products or radon progeny	The short-lived radioactive decay products of radon-222. This includes the decay chain up to, but not including lead-210, namely polonium-218 (sometimes called radium A), lead-214 (radium B), bismuth-214 (radium C) an dpolonium-214 (radium C).
Ranger Project Area	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976.*
Reference level	Abbreviated to RL. Denotes a specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the TSF or depth of Pit 3.
Retention Pond	A large constructed storage facility that collects runoff and stores pond water for treatment (RP2 & RP6) or release water post-treatment (RP1).

Key term	Definition
Sievert	The Sievert is the unit of absorbed radiation dose, taking into account the differing biological effects of different types of radiation.
Tailings dam	Surface dam used to hold tailings and process water at Ranger. Commonly referred to as "tailings storage facility" or "TSF" in other ERA material. The tailings dam is one of currently three tailings storage facilities at Ranger, the others being Pit 1 and Pit 3.
U_3O_8	The most stable form of uranium oxide and the form most commonly found in nature. Uranium oxide concentrate is sometimes loosely referred to as yellowcake. It is khaki in colour and is usually represented by the empirical formula U_3O_8. Uranium is normally sold in this form.
Waste rock	The mineral waste produced in the mine but is stockpiled due to its low grade i.e. material which does not enter the processing plant. For example, 1s waste rock is typically material that has a grade of less than 0.02% U_3O_8; 2s waste rock (or low-grade ore) is typically material that has between 0.02% and 0.12% U_3O_8.
Wetland filter	A constructed biological filter system that is designed for final treatment of release water and is monitored to ensure water quality meets regulatory criteria for disposal.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
AALL	Annual Additional Load Limits
AHD	Australian Height Datum
ALARA	As Low as Reasonably Achievable
ALARP	As Low as Reasonably Practicable
ARR	Alligator Rivers Region
ARRTC	Alligator Rivers Region Technical Committee
ASS	Acid Sulfate Soils
AWBM	Australian Water Balance Model
BDL	Below Detectable Limit
BTV	Background Threshold Value
CCWLF	Corridor Creek Wetland Filter
CDF	Cumulative Distribution Function
CDU	Charles Darwin University
CEC	Cation Exchange Capacity
CM	Conceptual Model
COPC/COPCs	Constituent of Potential Concern/ Constituents of Potential Concern
CPT	Cone Penetration Test
CRE	Conceptual Reference Ecosystem
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CVs	Community Values
DEM	Digital Elevation Model
EC	Electrical Conductivity
ENSO	El Niño Southern Oscillation
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
ERM	Environmental Resource Management
ESR	Ecosystem Restoration Rehabilitation Theme
ET	Evapotranspiration
FEPs	Features, Events and Processes
GAC	Gundjeihmi Aboriginal Corporation
GCBR	Georgetown Creek Brockman Road

Abbreviation/ Acronym	Description
GCMBL	Georgetown Creek Mine Bund Leveline
GCT2	Georgetown Creek Tributary 2
GDE	Groundwater Dependent Ecosystem
GTB	Georgetown Billabong
GW	Groundwater
GWT	Groundwater Table Level
HDS	High Density Sludge
HLU	Hydrolithologic Unit
IAEA	International Atomic Energy Agency
ICRE	Initial Conceptual Reference Ecosystem
IOD	Indian Ocean Dipole
ISAM	Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities
ISWWG	Independent Surface Water Working Group
KKNs	Key Knowledge Needs
KNPS	Kakadu Native Plants Pty Ltd
LAA	Land Application Area
LAI	Leaf Area Index
LEM	Landform Elevation Model
MBO	Monosulfidic Black Ooze
MCDS	Magela Creek Downstream
MCP	Mine Closure Plan
MJO	Madden-Julian Oscillation
MTC	Minesite Technical Committee
NAQS	Northern Australia Quarantine Strategy
NESP	National Environmental Science Program
NLC	Northern Land Council
NP	National Park
NT	Northern Territory
OPSIM	Operational Simulation Model
P50, P70, P90	50th percentile, 70th percentile, 90th percentile
PASS	Potential Acid Sulfate Soils
PAW	Plant Available Water
PDF	Probability Distribution Function
PEST	Parameter Estimation Tool

Abbreviation/ Acronym	Description
PFS	Prefeasibility Study
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPA	Plant Processing Area
PSD	Particle Size Distribution
PTF	Pit Tailing Flux
Pvalue	Probability Value
R3D	Ranger 3 Deeps
Ranger GW UA	Predictive Ranger Groundwater Model with Uncertainty Analysis
RCM	Ranger Conceptual Model
REW	Relative Extractable Water Content
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
RSWM	Ranger Surface Water Model
SAQP	Sampling Analysis Quality Plan
SBES	Single Beam Echosounder
SBT	Soil Behaviour Type
SERP	Species Establishment Research Program
SPA	Soil-Plant-Atmosphere
SQG-H	Sediment Quality Guideline High Values
SQGV	Sediment Quality Guideline Values
SSB	Supervising Scientist Branch
SW	Surface Water
SWM	Surface Water Model
TAN	Total Ammoniacal Nitrogen
TARP	Trigger Action Response Plan
TLF	Trial Landform
TPM	Total Particulate Metals
TPWC Act	*Territory Parks and Wildlife Conservation Act 1978 (NT)*
TSF	Tailings Storage Facility
TSS	Total Suspended Solids
UA	Uncertainty Analysis
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency

Abbreviation/ Acronym	Description
UTL	Upper Tolerance Limits
VAF	Vulnerability Assessment Framework
WA	Western Australia
WAR	Weak Aqua Regia

5 KEY KNOWLEDGE NEEDS

This chapter provides an overview of the environmental setting of the Ranger Mine and a summary of completed and planned studies that are informing the closure strategy. The chapter provides the context to planning mine closure and a summary of a substantial knowledge base that has been accumulated by Energy Resources of Australia Ltd (ERA) and stakeholders from more than 40 years of monitoring and research investigations of the site and surrounding environment.

This section has been structured around the Key Knowledge Needs (KKNs) and associated themes:

- Landform;
- Water and Sediment;
- Health Impact of Radiation and Contaminants;
- Ecosystem Restoration; and
- Cross-theme.

The KKNs outline the relevant knowledge and tools required, primarily through research and monitoring, to ensure:

- the environment and people of the Alligator Rivers Region (ARR) are protected from the impacts of uranium mining; and
- upon reaching end-of-life, uranium mines in the ARR are rehabilitated to the standard required by the Commonwealth and the community.

The KKNs were identified via an ecological risk assessment completed by CSIRO and ERA in collaboration with the Supervising Scientist and other key stakeholders (Pollino *et al.* 2013; Bartolo *et al.* 2013).

The KKNs have been endorsed by the Alligator Rivers Region Technical Committee (ARRTC) and are revised and updated from time to time as research to answer KKNs is completed, and new knowledge needs arise. A formal amendment process, including review by ARRTC and the Ranger Minesite Technical Committee (MTC), has been developed to ensure that any changes to the KKNs are undertaken in consultation with all relevant stakeholders.

The Ranger mine has been the subject of extensive studies and monitoring programs based on the KKNs, which have been presented through various community and stakeholder consultation processes and statutory reports such as annual environment reports, mining management plans, wet season reports and groundwater reports.

A full list and description of the KKNs as published by the Supervising Scientist Branch (SSB) in November 2020 (Supervising Scientist 2020a) within their individual themes is provided in Appendix 5.1. Some KKNs are addressed by ERA, some by the SSB, and others by both. The sections below discuss the KKNs being addressed by ERA and those addressed by both ERA and SSB.

5.1 Landform theme

This section discusses the knowledge base of the physical environment and the Landform themed KKN studies.

5.1.1. Background of physical environment

Historical land use within the Alligator Rivers Region (ARR) has included indigenous occupation, buffalo hunting, missions, pastoral grazing, agriculture, mining exploration, uranium mining and tourism (Levitus, 1995). Contact between the region's Aboriginal people and other cultures increased from around the 17^{th} century and a more permanent non-indigenous presence was evident from the late 1800s (ERA, 2014b).

The Alligator Rivers Region is divided into several land tenures, and encompasses parks, mining and native title lands (Figure 5-1). The Magela catchment is located within the ARR, with the majority of its footprint within the Kakadu National Park, a World Heritage listed area and Ramsar site.

5.1.1.1 Climate

The climate of the Alligator Rivers Region and the Ranger Mine is dominated by a seasonal wet-dry monsoon cycle. The wet season extends from about October through to April in the Northern Territory (BOM, 2019). Active monsoon periods may occur at any time during this period, however the initial monsoon onset, defined by the reversal of the winds, normally occurs in late December around Darwin (BOM, 2019).

The monsoon exhibits inter-annual and intra-seasonal variability and is strongly linked to effects of the El-Niño Southern Oscillation and Madden-Julian Oscillation (Trenberth et al. 2007). Whether it is in El Niño or La Niña can have a significant impact on monsoonal variability (BOM, 2019). La Niña typically means earlier-than-normal monsoon onset, while El Niño is often associated with less than average rainfall during the monsoon season (BOM, 2019). The Madden–Julian Oscillation can be an important influence on the timing of the active and inactive monsoon phases (BOM, 2019).

The tropical cyclone season threatens northern Australia every year during the monsoonal wet season (CSIRO, n.d.). Increased cyclone activity is associated with La Niña years, whilst below normal activity has occurred during El Niño years (Kuleshov & de Hoedt, 2003, Plummer *et al.* 1999). When cyclones and tropical lows are present, the Alligator Rivers Region can experience high winds and rainfall.

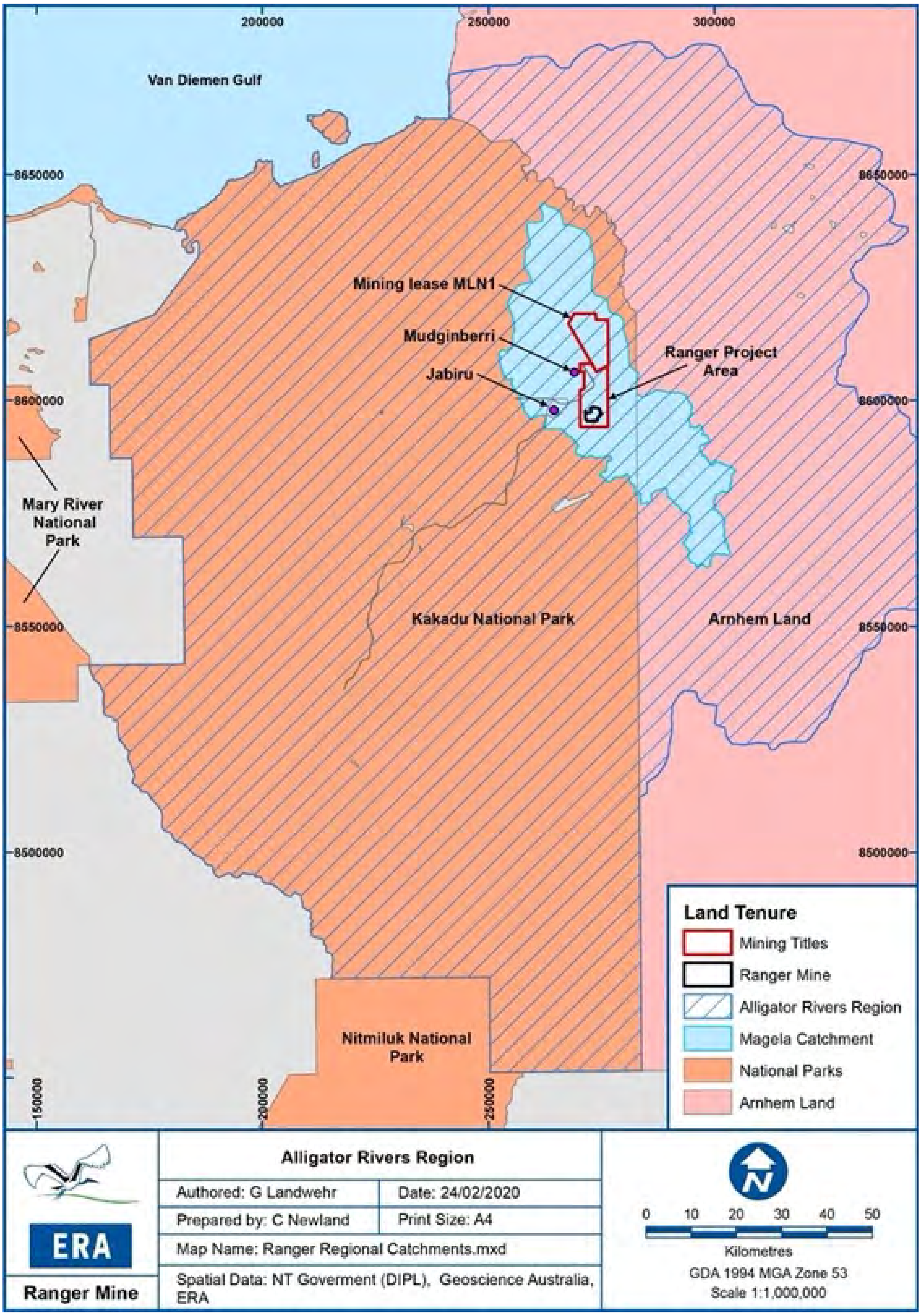


Figure 5-1: Land tenures in the Alligator Rivers Region

The wet season is typically dominated by westerly winds, whilst the dry season is dominated by easterly to south-easterly winds. Seasonal temperatures and rainfalls at Jabiru Airport station 014198 from the Bureau of Meteorology (BOM) between 1971 and 2020 displayed a temperature average of 29.7 °C for the time period 1971 to 2020 with annual rainfall of 1,553.7 mm (Figure 5-2).

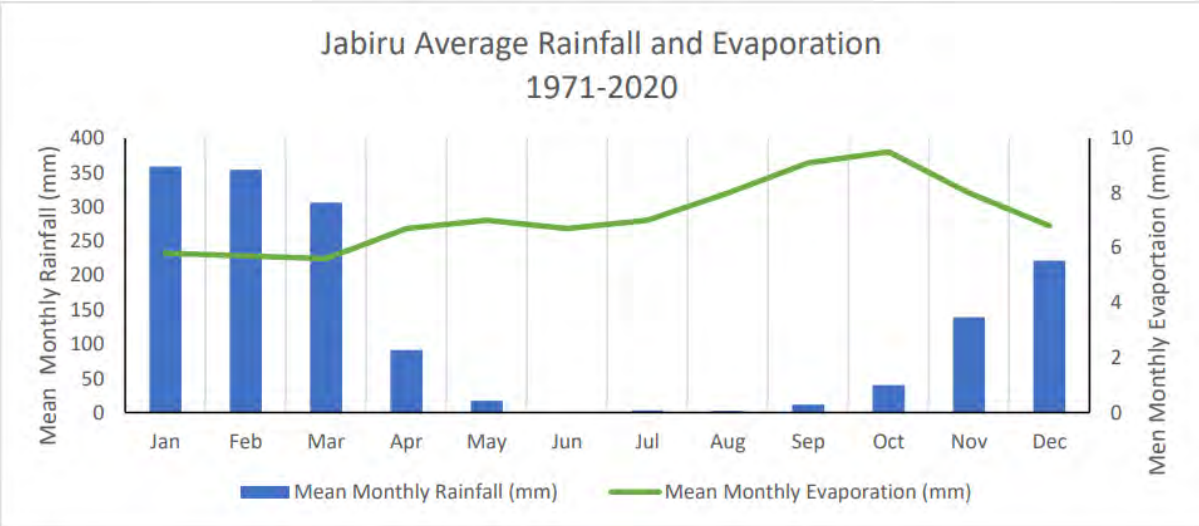


Figure 5-2: Jabiru average rainfall and evaporation 1971 to 2020 (Source: CDM Smith, 2021)

Average climatic conditions at Jabiru Airport are presented in Table 5-1.

The region has a hot climate, with average maximum temperatures typically ranging from just under 32 °C in June and July to approximately 38°C in October (BOM, 2022). Average monthly pan evaporation ranges from 295 mm in October to 160 mm in February (Chiew & Wang, 1999). Annual pan evaporation exceeds rainfall by approximately 1,000 mm. Jabiru Airport hottest annual day recorded was 41°C in October 2021 (BOM, 2022).

Table 5-1: Statistical climate data for Jabiru Airport from June 2021 to June 2022 (BOM, 2022)

Parameter	**Value**	**Month**
Mean maximum temperature	38.7ºC	October 2021
Mean minimum temperature	17.1 ºC	July 2022
Mean Maximum relative humidity	96 %	February 2022
Mean minimum relative humidity	21.9%	August 2021
Maximum average daily evaporation*	9.5 mm	October
Minimum average daily evaporation*	5.6 mm	March
Annual average daily evaporation*	7.2 mm	
Annual evaporation*	2,628 mm	
Mean annual rainfall	1,554 mm	

Parameter	Value	Month
Maximum average daily evapotranspiration	8.7 mm	September 2021
Minimum average daily evapotranspiration	0.7 mm	December 2021
Annual evapotranspiration	2354.7 mm	

Source BOM 2019b

**these values are averages from data available between 1973-1990 only*

5.1.1.2 Topography

The Ranger Mine lies on plains to the north of the Mount Brockman Massif, an outlier of the Arnhem Land Plateau. The plains are generally flat with numerous swamps rarely more than 45 m above sea level.

South and east of the Ranger Mine, the Arnhem Land Plateau escarpment rises to between 200 and 300 m above sea level (Figure 5-3). Approximately 3.5 km south of Ranger Mine is Mount Brockman, rising 170 m above the plain (Figure 5-3 and Figure 5-4).

The Ranger Mine is influenced by four land surfaces to varying degrees:

The Mount Brockman Massif – This is a quartz sandstone outlier located to the south of the mine. Its steep escarpment and skeletal soils forms part of the watershed of the Magela and Gulungul creek systems. It's resistance to erosion and low soil moisture retaining capacity readily accumulates large volumes of localised rainfall in the surface drainage networks causing rapid flood responses in creeks and drainage lines. Water infiltrates joints and fissures, contributing to groundwater recharge and the formation of springs and swamps, some of which continue to discharge well into the dry season many months after the last rainfall.

The Koolpinyah Surface - corresponding to the plains on which the Ranger Mine is located, it is characterised by level, rolling or dissected lowlands. The surface is deeply weathered bedrock partly overlain by Late Tertiary to Recent sediments derived from the erosion of Cretaceous, Middle Proterozoic and Lower Proterozoic formations. These are mantled by ferruginous soils and ferricrete crusts.

Alluvial plains - formed by the flow of numerous rivers across the Koolpinyah Surface. The Magela and Gulungul Creeks flow northerly from the Mount Brockman Massif dissecting the Ranger Project Area (RPA). Alluvial materials have been deposited by the creek systems forming the flat Magela floodplains to the northwest. Coarse, sandy Late Tertiary and Quaternary alluvial deposits cover part of the plains. These occupy channels of diverted streams and anabranches.

Coastal plains - extending north of the Koolpinyah Surface are flat, poorly drained and penetrate far inland along the broader river valleys.

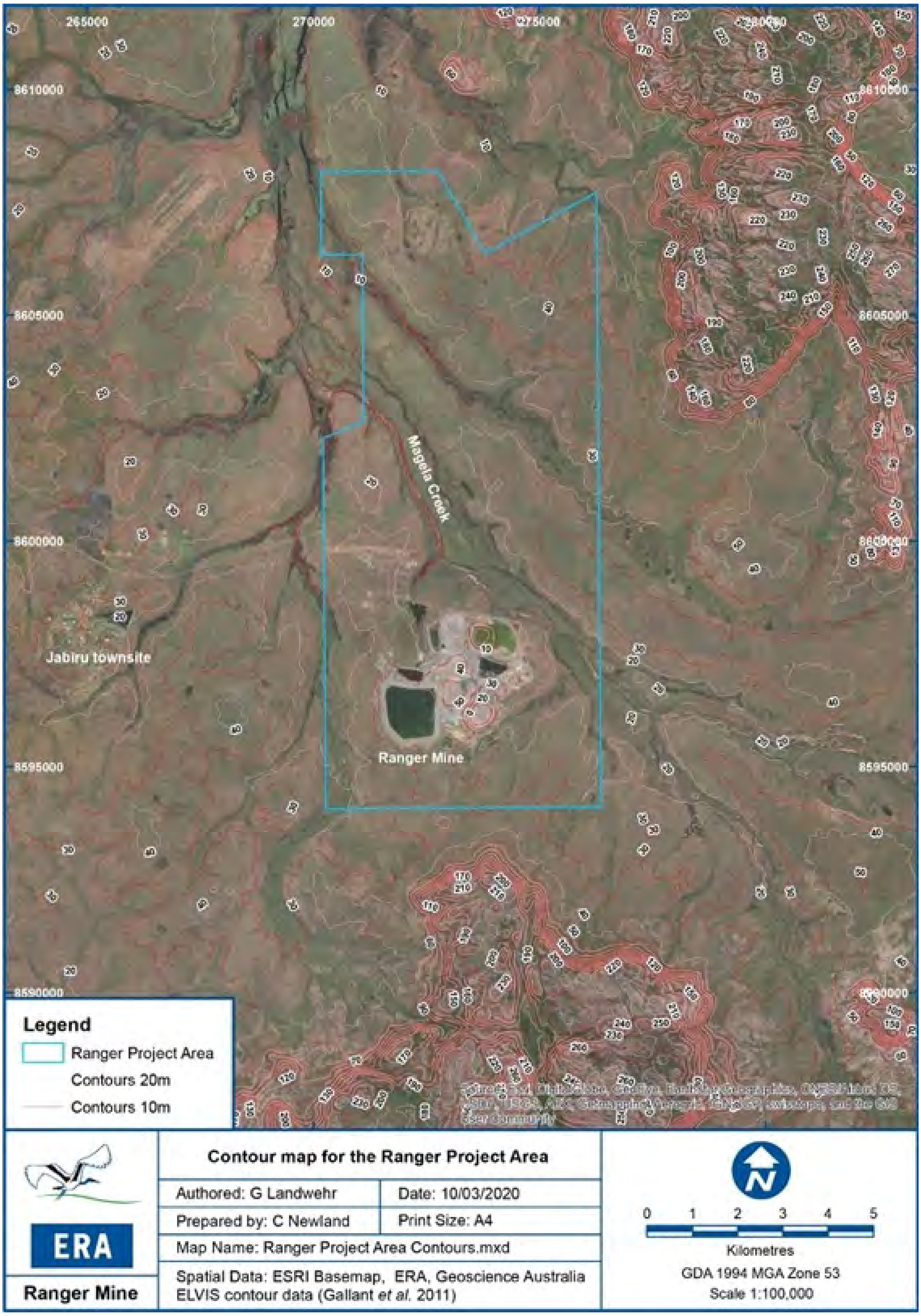


Figure 5-3: Contour map of the RPA and surrounds

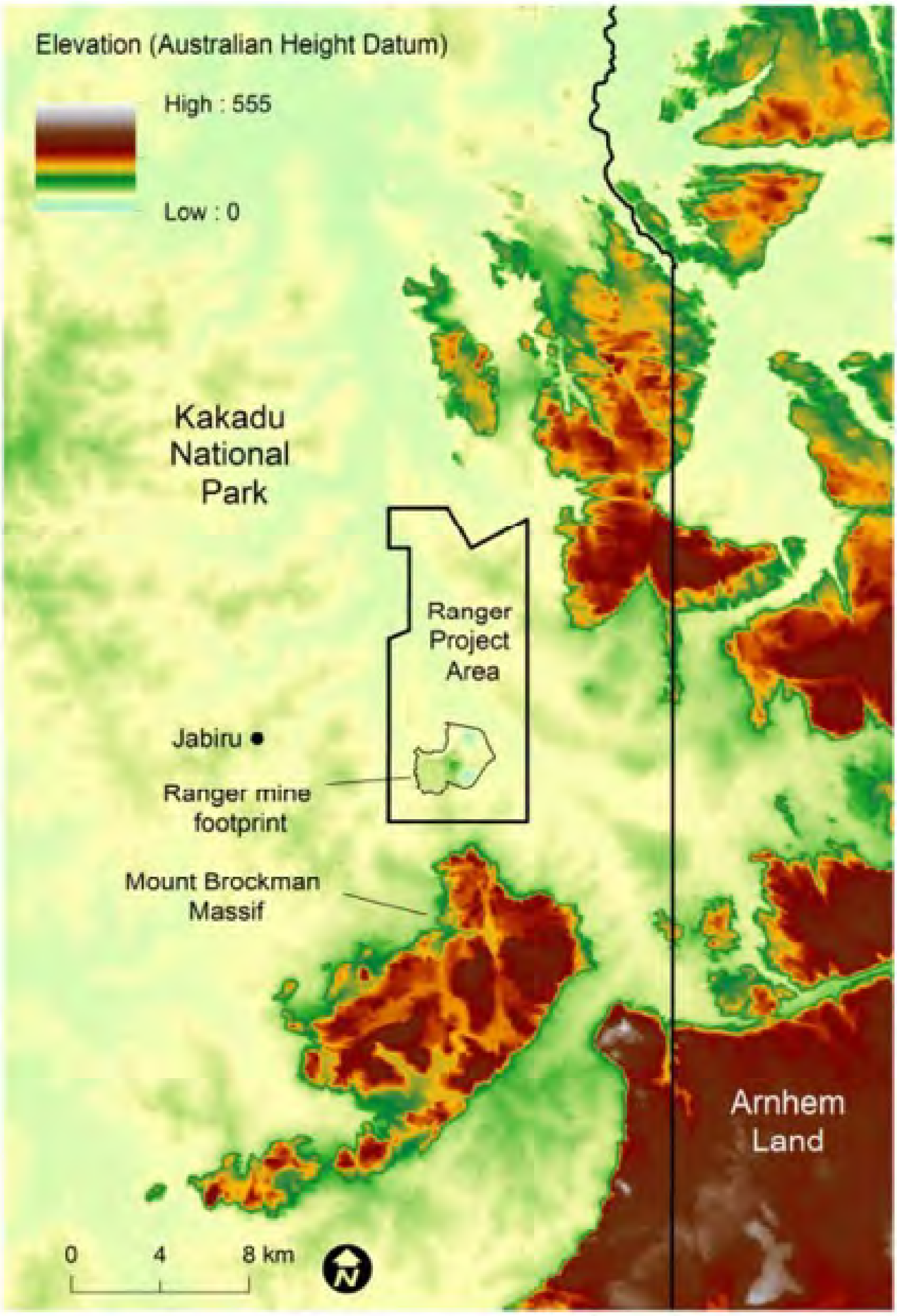


Figure 5-4: Elevation of RPA and the surrounding region

5.1.1.3 Soils

The type (class) and distribution of soils across the land surfaces of the RPA are influenced by geology, topographic position and seasonal changes to the amount of moisture in the ground (Story *et al.* 1969, Chartres *et al.* 1991 and Hollingsworth *et al.* 2005). The four main geomorphic units have associated soil types, which in turn influence vegetation assemblages.

Colour variation in the soils is primarily a product of differential drainage and the resulting mineralogy of the component iron oxyhydroxides. Stony layers within the soil profile may represent the boundary between residual and non-residual (e.g. transported) materials.

Soils are non-saline and non-sodic and can be gravelly, with clasts of quartz, ferricrete and ferruginised rock. Kaolinitic minerals are common and illite, together with minor chlorite, can be inherited from underlying Cahill Formation schists (see also 5.1.1.4). The cation exchange capacity (CEC) is generally moderate to low in the near-surface horizons and there are low levels of organic materials and nutrients. Table 5-2 provides a brief description of the soil characteristics associated with the Ranger Mine, which are also depicted in Figure 5-5.

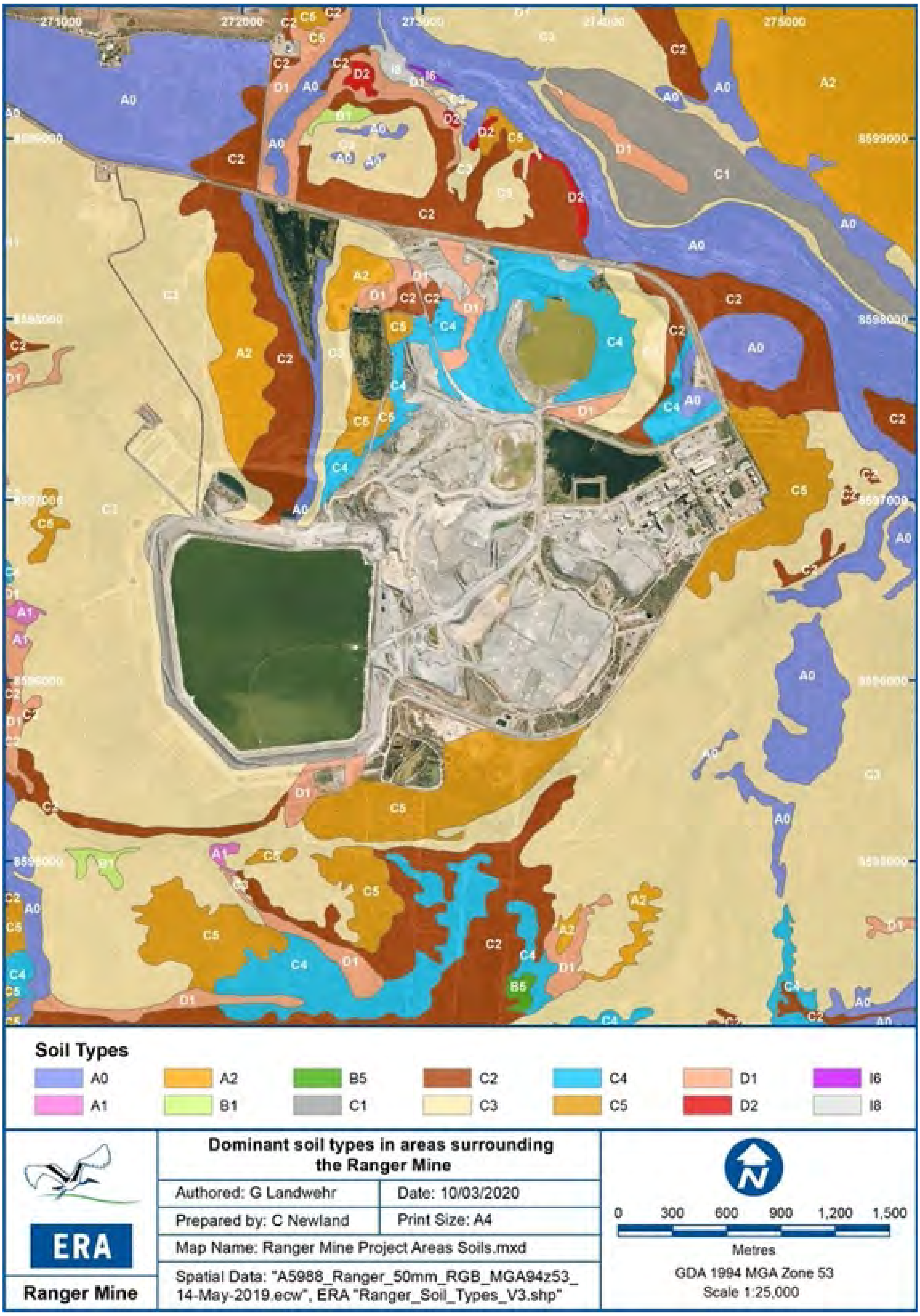


Figure 5-5: Dominant soil types in areas surrounding the Ranger Mine

Table 5-2: Key to soil characteristics locations around the Ranger Mine shown in Figure 5-5

Map unit (Hollingsworth, 1999)	Map unit description
A0	Organic horizon, sand/loamy surface.
A1	Deep pale brown, yellow and yellowish brown sands, sand/loamy sand surface and generally non-mottled single grained and sandy throughout. Variations include: light yellowish brown and dark brown; and yellow brown, yellow and faint red brown mottles.
A2	Deep yellowish brown to very pale brown; highly permeable, generally non-coherent sand, bottoming onto ferruginous and quartz gravel and stone. Profiles may vary: depths may extend from 100 cm; *in situ* gravels may occur within the lower horizons and the firm clay clod nodules may become hard; 10-15 mm, prominent, red mottles.
B1	Deep brownish yellow to yellowish brown massive gravel-free earthy sands with minor mottles common at depth. Profile variations include different degrees of mottles at depth, and on rare occasions, overlie a buried zone.
B5	Shallow, gravelly, brown to yellowish brown, massive, earthy sands. Variations may have light brownish yellow and minor light grey horizons at depth, textures may not be heavier than loamy sands.
C1	Moderately deep to deep yellowish brown to light yellowish brown, sandy earths with no gravel present. No profiles bottom onto laterite pavement and gravel pans. Profiles may be deeper, lighter in chroma and increasing in texture to sandy light clay.
C2	Moderately deep to deep sandy loams over a gravel pan.
C3	Moderately deep to deep, dark yellowish brown to yellowish brown, sandy earths with gravel throughout, bottoming onto ferruginous gravel.
C4	Shallow yellowish brown to brownish yellow sandy earths bottoming onto dense ferruginous gravel and stone. Mottles may occur. Variations include distinct, grey and prominent, red mottles in B-horizon.
C5	Shallow brown to yellowish brown gravelly sandy earths over a ferruginous and quartz gravel pan. Variations include colours to yellowish brown; depth varying to 30 cm; and gravel contents ranging between 5% and 50% within the profile.
D1	Deep light brownish grey to grey loamy earths, massive.
D2	Deep to moderately deep yellowish brown to pale brown gravel-free loamy earths over a gravel/stone hardpan. Variations include textures to coarse sandy clay at depth; colours from pale brown to grey; and mottles where sites are ponded.
I6	Deep profiles of grey to brown sands and earthy sands over a generally mottled light grey to pale brown clay and sandy clays.
I8	Profiles are very dark grey to greyish brown loamy earths and sandy earths over a brown to pale brown earthy sand, with mottles common. Considerable variation was found with all soil characteristics.

Field investigations of soil hydraulic conductivity (Table 5-3) have identified that individual soil horizons range from very permeable, due to naturally occurring piping, to impervious. The A and B horizons typically support a shallow, unconfined surface aquifer that overlays a low conductivity C horizon (Hollingsworth, 1999). This unit is underlain by an impervious unfractured bedrock D horizon. The unconfined aquifer is observed to recharge both the A and B horizons during the wet season, to the point where water expresses as baseflow in lower areas of the topography and drainage lines. During the dry season, the upper A and B soil horizons can be entirely dry down to the confining C horizon.

Hydraulic conductivities in the A and B horizons can range from 0.01 to 10 m/day (Chartres *et al.* 1991), whilst the range of hydraulic conductivities of underlying confining C and D horizons are indicative of low transmissive hydrolithologic units (HLUs) (INTERA 2016).

Table 5-3: Soil hydraulic conductivity

Horizon	Hydraulic conductivity, K
Alluvial sands and 'A' horizon	10 to 1 m/day
Bleached zone 'B' horizons	1 to 0.1 m/day
Saprolite 'B' horizon	2 to 0.01 m/day
Fractured rock 'C' horizon	0.1 to 0.001 m/day
Unfractured rock 'D' horizon	0.05 to 0.001 m/day

Depending on vegetation cover and the presence or absence of a surface rock lag, erosion is highly seasonal and is dominated by sheet erosion in the wet season. At the beginning of the wet season, understorey cover can be sparse due to preceding dry season conditions and vegetation loss due to fire. The variability of vegetation cover contributes to the impact of rain splash erosion. Where grasses and leaf litter remain, these assist in protecting the soil from early wet season rain splash erosion. However, as rainfall intensifies with the development of monsoonal troughs, other erosion processes become dominant including floods, sheet flow runoff, high winds and cyclones. Overland sheet flow, and gully erosion by streams increase and are particularly severe in areas where vegetation is disturbed. Further detail on these erosion processes are provided in Table 5-4.

Table 5-4: Typical erosion susceptibility of soils

Soil type	Erosion potential
Deep siliceous sands lacking structure	Vulnerable to rain splash and overland flow erosion but are less vulnerable if covered by vegetation
Red earths well drained with good structure	Characteristic of areas with minimal erosion
Yellow earths less well drained than the red earths	More erodible, particularly if dispersive
Duplex soils with texture contrast and massive impermeable B horizons which form aquicludes	Most erodible, very vulnerable to slope wash and gully type erosion, due to dispersive

Soil type	Erosion potential
when saturated, weakly structured topsoils	nature
Alluvial soils	Generally, recipients of other soils but prone to erosion along breaks of slope
Shallow skeletal soils	Protected by surface layer of gravel but, if this is disturbed, erosion can be rapid

5.1.1.4 Geology and mineralisation

The Ranger uranium deposits are located in the East Alligator region of the Paleoproterozoic Pine Creek Inlier. Mineralisation is contained in chlorite-altered metasediments of the Lower Cahill Formation (age approximately 1,870 million years) which overlie an older basement complex of Archaean granitoid gneisses and schists known as the Nanambu Complex (age approximately 2,470 million years). Unconformably overlying rocks of both the Lower Cahill Formation and the Nanambu Complex are sandstones and conglomerates of the Kombolgie Sandstone (age approximately 1,650 million years) which forms part of the Katherine River Group of the McArthur Basin.

Uranium mineralisation occurs within a northerly trending and gently easterly-dipping belt of Lower Cahill metasediments, directly east of the Nanambu Complex (Figure 5-6). The Lower Cahill Formation has been informally subdivided into three units. All uranium ore occurs in chlorite schists referred to as the Upper Mine Sequence schists. These overlie a sedimentary sequence dominated by carbonates and dolomites (Lower Mine Sequence) and are themselves overlain by mica schists with local horizons of amphibolite (Hanging Wall Schists), as shown in Figure 5-6.

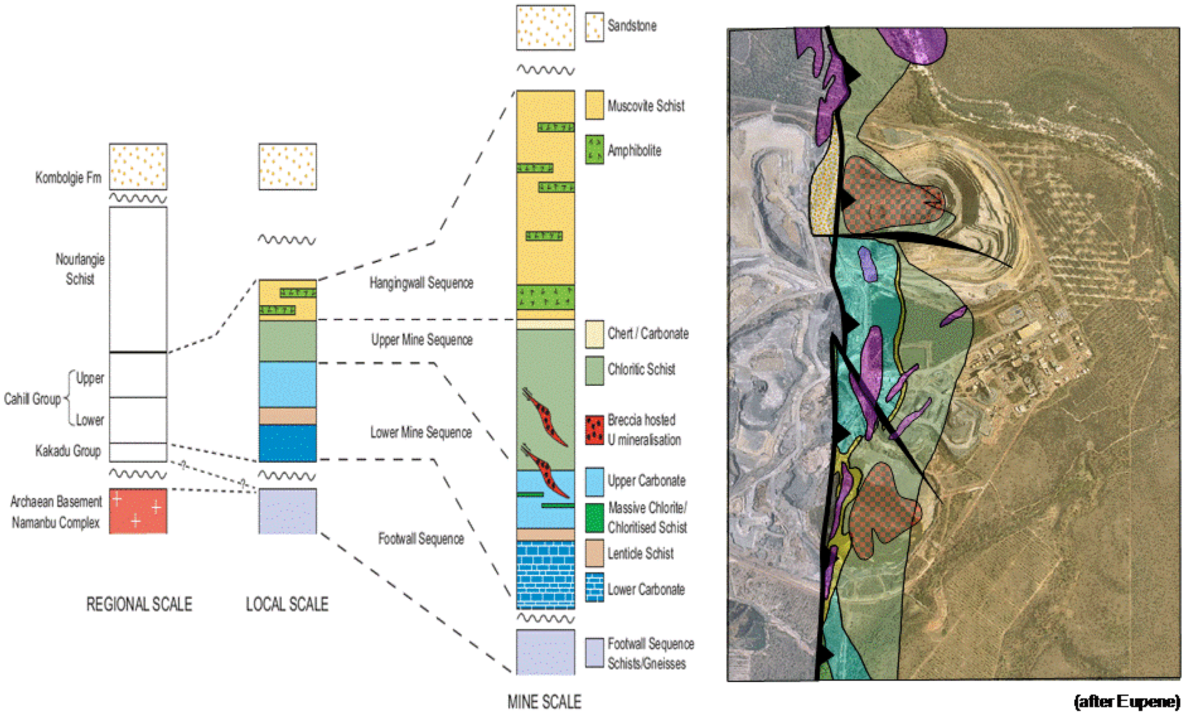


Figure 5-6: Stratigraphic sequence from regional to mine scale and corresponding geological map of the immediate area of the Ranger Mine orebodies

5.1.1.5 Geomorphology

The Magela floodplain, which lies 15 km downstream of the Ranger Mine, represents a catchment of 815 km^2 and joins with the floodplain of the East Alligator River.

The Magela floodplain is very flat with elevation changes of less than 0.7 m over more than 40 km. Although the inflow to the floodplain is well defined, waters continue to disperse across poorly or undefined channels until eventually discharging into the meandering channel of the East Alligator River. Average flow rates during a wet season, depending on channel definition, have been estimated at 0.02 – 0.05 m per second (Roos & Williams 1992). Wet season vegetative growth within the floodplain proper accelerates quickly with the onset of the wet season and has a significant effect upon flow rates. Roos & Williams (1992) demonstrated that the aquatic vegetation retained flood waters in the lead up to, and in the period immediately after, the highest wet season flow.

The pattern of sediments accumulated in the Magela floodplain has been examined using radionuclide analysis. Wasson (1992) found that 90 percent of the sediments transported by Magela Creek were deposited within the first 18 km of the floodplain. The rest of the floodplain sediments are sourced from smaller catchments that enter the floodplain further down the Magela Creek catchment. It was also found that Magela Creek has had no significant influence on sediment deposition below Jabiluka Billabong for the last 3,000 to 4,000 years.

5.1.2 LAN2 Understanding the landscape-scale processes and extreme events affecting landform stability

KKN title	Question
LAN2. Understanding the landscape-scale processes and extreme events affecting landform stability	LAN2A. *What major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, and climate)?*

5.1.2.1 Extreme natural events and the stability of tailing repositories at Ranger Uranium Mine, Northern Territory (NT)

This study identified and explored the extreme natural events which might affect the stability and longevity of the three potential tailings repositories and violate the safe storage of mill tailings. The three tailings repository sites examined were the below-grade Pit 1 and Pit 3 and the above-grade Ranger Water Dam (RWD, formerly the Tailings Storage Facility[2]).

The potential extreme natural events considered within the study included probable maximum precipitation (PMP), probable maximum floods (PMF), wind, drought, fires, erosion, sea level change, meteorite impact, seismic events, tsunami, volcanic eruptions, and mass failure. At the time of the study (1996), records of natural hazard magnitude and frequency spanned only a few decades for the Northern Territory. There was little certainty about the probabilities of extreme events and their potential consequences in the next 1,000 years or so, with estimates of the magnitude of 1:1,000 year events a matter of opinion. The probabilities of larger events, 1:10,000 to 1:20,000 years, would occur in a 1,000 year period range from 4.9 to 9.5%. The study therefore considered that Maximum Credible Events will occur in the 1,000 years under assessment and recognised that the background level of both atmospheric and geophysical extreme events fluctuate with time.

Table 5-5 summarises the existing knowledge of the likelihood of a wide range of extreme events and their potential consequences at Pit 1, Pit 3, and the RWD. Table 5-6 summarises the significant hazards and consequences for each of the three tailings repository options.

No hazards fell into the two highest concern categories, and at the next highest level the hazards of concern were all in relation to the RWD. Pit 1 and Pit 3 had identical hazards that were determined to require further consideration of risk reduction strategies.

For most extreme events there is little to choose between the potential consequences possible at the three sites. At the RWD the potential consequences of hazards such as drought, fire, tree throw, were demined to be of higher concern than at Pit 1 and Pit 3 because of the hazards potential to exacerbate erosion. The key difference between the three areas, is that the RWD is subject to a wider variety of natural hazards at a higher level of concern than at Pit 1 and Pit 3.

[2] The Tailings Storage Dam and Tailings Dam are former names of the Ranger Water Dam

Table 5-5: Extreme event likelihood and consequence summary for tailings repositories

Potential hazard	Likelihood of occurrence in 1,000 years[3]	Potential severity of consequence[4]			Confidence in estimates of occurrence and consequences[5]
		Pit 1	Pit 3	Ranger Water Dam	
PMP or near PMP events	M	L	L	L – M	M
PMF or near PMF events	M	N	M	N	M
Tree throw	E	N	N	L	L
Wind erosion	M	N	N	L	L
Cyclonic winds	M – H	N	N	M	M

[3] The scale is used for likelihood of occurrence unless better estimates are available:

N	Negligible	(<1%)
L	Low	(10%)
M	Moderate	(50%)
H	High	(90%)
E	Extreme	(>99%)

[4] The potential severity of consequences are rated N, L, M, H or E:

N	Negligible	No evident threat to tailings repository
L	Low	No evident threat to security of tailing repository though minor damage might occur
M	Moderate	Possible minor damage to containment structure
H	High	Possible damage to structure; some risk to security of tailings
E	Extreme	Likely damage to containment structure threatening security of tailings

[5] Use N, L, M, H, E scale

Potential hazard	Likelihood of	Potential severity of consequence[4]			Confidence in
Tornado winds	L	L	L	M	L
Drought	H – E	N	N	L – M	M
Tsunami	L	N	L	N	N
Volcanic eruption	L – M	N	N	N	H
Mass failure	L – M	N	N	N	H – E
Fires	M -H	N	N	L	L
Erosion – severe soil and gully erosion	M	L – M	L – M	H – E	M
Sea level change >1 m	M	N	L	N	M
Storm surge	L	N	L	N	L
Meteorite impact	N – L	L	L	L – M	M
Earthquake – near field ground shaking	L – M	L	L	L – M	M
Liquefaction	L – M	H	H	H – E	L
Long-term settlement	H	L – M	L – M	M – H	M
Earthquake – far field ground shaking	L	N – L	N – L	N – L	M

Table 5-6: Summary of significant hazards and consequences

Level of concern	Pit 1	Pit 3	Ranger Water Dam
Level 1 (lowest)	Erosion Cyclonic winds Drought Tree throw	Erosion Cyclonic winds Drought Tree throw	Probable Maximum Precipitation Earthquake (near field) Fires
Level 2	Liquefaction Long term settlement	Liquefaction Long term settlement	Cyclonic winds Tree throw
Level 3	N/A	N/A	Liquefaction Long term settlement Erosion Drought
Level 4	N/A	N/A	N/A
Level 5 (highest)	N/A	N/A	N/A

5.1.2.2 Evaluation of features, events and processes and safety functions for the Ranger Uranium Mine

The Environmental Requirements (ERs) for Ranger Mine include maintaining the world heritage attributes of Kakadu National Park and the ecosystem health of the Ramsar wetlands, protecting the health of people living in the region, and the biological diversity and ecological processes of the Alligator Rivers Region. Many of these attributes may be directly or indirectly affected by the behaviour and performance of the placement of all mine tailings in Ranger's Pit 1 and Pit 3 tailings repository system.

ERA have completed a number of studies and risk assessments over various years including a systems assessment undertaken by INTERA in 2012. Systems assessment evaluates the ability of an environmental system to meet regulatory performance objectives over very long periods of time, in this case 10,000 years. The ideas and approaches used in systems assessments consider the entire system and all potential influences on the ability of the system to protect human health and the environment.

Two systems assessment methodologies were applied to the tailings repository systems; features, events, and processes (FEPs) and safety functions. The FEPs methodology identified all conditions that may affect the ability of a disposal system to meet its performance objectives over long time periods, as well as identifying alternative scenarios for the future evolution of the system, or alternative conceptual models for the behaviour of the system under the scenarios. The safety function methodology focused on system elements which contribute to the ability of the system to meet performance objectives.

INTERA and ERA developed a set of basic assumptions and requirements to evaluate FEPs and safety functions for the site tailing repositories. For Ranger, this is the ability of the tailings disposal system to meet the ERs for tailings containment for at least 10,000 years.

The FEPs analysis was conducted in two steps. First, an initial screening of the FEPs using the available literature was undertaken to develop a draft set of scenarios for consideration and discussion by a broader audience, including Ranger staff and stakeholders. A FEPs workshop was held in December 2012. The second step identified and evaluated a fully comprehensive list of FEPs for the environmental assessment and the associated safety function analysis.

The FEPs list derived from the Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM) list, Appendix C of International Atomic Energy Agency (IAEA) (2004). The FEPs evaluation included review of available literature, conceptual and numerical modelling of surface water and groundwater systems, and geomorphic stability modelling of the final landform.

The FEPs evaluation for the Ranger mine included all items in the ISAM list, with each FEP considered and screened for relevance. The safety function analysis identified one potentially deleterious FEP associated with the depth of tailings burial, an engineered barrier system, and four potentially deleterious FEPs associated with groundwater flow in the saturated zone and/or water flow in Magela Creek, which are natural barrier systems. The identified potentially deleterious FEPs and alternative scenarios for the future evaluation of the Ranger mine fall into two categories: those related to climate or erosion/sedimentation related FEPs.

The former has the potential to alter the hydrological behaviour of the system. The latter has the potential to change the path length of groundwater flow to Magela Creek and the tailings burial depth. Climate change and erosion are linked, such that changes in climate may affect erosion and sedimentation of Magela Creek and the final landform. Therefore, climate change is indirectly linked to changes in landform only as it is linked to erosion. Further discussion on climate change and associated FEPs in provided in Section 5.6.

The safety strategy for Ranger tailings lies primarily in several features of the site and tailings characteristics. In relation to landform, the depth of gullies projected to form on the final landform as a result of erosion are less than the tailings burial depths indicating the tailings will remain buried and, therefore, not be exposed at ground surface.

5.1.2.3 Managing for extremes: potential impacts of large geophysical events on Ranger Uranium Mine, NT

The Ranger Mine is located in the seasonally wet tropics with a potential to be exposed to extreme geophysical events that may impact on landform stability such as large rain events, longer time frames for variation in wet or dry years, increased number of flood events or cyclone number and intensity.

High intensity storm events are a main contributor to soil erosion in the Alligator Rivers Region, with Erskine and Saynor (2000) approximating 69% of total soil erosion during individual storms occurs during multiyear measurements.

Extreme rainfall and intense storms can significantly impact landform stability of a rehabilitated mine. Intense storms and large floods caused by tropical cyclones may also exhibit high wind speeds. Tropical cyclones can cause tree throw, further increasing soil erosion rates across landforms.

Erskine *et al*. (2012) noted further research on catastrophic floods and tropical cyclones was required to better define the risk to the mine site. ERA have completed a number of studies and risk assessments over various years in relation to future climatic events, discussed in Chapter 5.6.

5.1.3 LAN3 Predicting erosion of the rehabilitated landform

KKN title	Question
LAN3. Predicting erosion of the rehabilitated landform	LAN 3A. *What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?*
	LAN3B. *Where, when and how much consolidation will occur on the landform*
	LAN 3C. *How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?*
	LAN3D. *What are the erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of mitigations)?*
	LAN3E. *How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?*

5.1.3.1 Landform evolution modelling

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 SSB on the trial landform (TLF), have informed the overall design and predicted performance of the current final landform design.

The final landform aims to simulate the hill slope 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. These values relate to restoring safe access to the site to allow cultural uses that occurred before mining.

The design of the final landform has been determined using a digital terrain model of natural analogue areas with the aim of producing a landform with similar indices of erosion and runoff distribution to the natural landscape (Hollingsworth & Lowry 2005). The shape of the current final landform is largely determined by the requirement to maintain pre-mining drainage and catchment areas and to ensure stability in either the current climate/rainfall regime or the predicted regime that may result from climate change. The Ranger Water Dam (RWD, formerly the Tailings Storage Facility) walls and western edges of the southern and western stockpiles sit atop high ridgelines of the pre-mining landscape. These ridges will form prominent features of the final landform and combined with a reinstated ridgeline over Pit 1, restore catchment areas similar to pre-mining. Topography of the final landform is similar to the pre-mining landform with the maximum elevation after consolidation increasing from 38 m pre-mining to a final landform maximum of 40 m Australian height datum (AHD).

Initial landform development was based on landform design criteria (Hollingsworth & Lowry 2005, Hollingsworth & Meek 2003, Hollingsworth *et al.* 2003a, Hollingsworth *et al.* 2003b) and described in the ERA 2005-06 Closure Model, which was subsequently issued to stakeholders (McGovern 2006). This was final landform version 1 (FLV1) with multiple versions being developed over the years. The current version is final landform version 6.2 (FLV6.2). ERA is in the process of designing FLV 7 incorporating stakeholder comments, kicked off in February 2022. FLV 7 design involves the utilisation of civil design software and assessment using CAESAR-Lisflood.

A preliminary slope analysis performed on final landform version 6.2 (FLv6.2) shows very gentle slopes across the landform with maximum slopes, measured from the ridgelines to the edge of the disturbed area, ranging in grade from approximately 2 percent to 4 percent (Figure 5-7). A slope analysis was also completed as part of the erosion and sediment control design work showing slopes varying from about 1 in 30 (3 %) to 1 in 200 (0.5 %), with larger catchments tending to have lower slopes, although this is not always the case. This has not changed significantly in the working progress of FLV 7 design versions, which continues to meet the original design intent with concave slope concept included.

In addition to the slope analysis, each version of the landform has been subjected to landform evolution modelling to assess the geomorphic stability of the final RPA landform over timeframes ranging from decades to millennia and the performance of the landform against closure criteria. The landform evolution modelling to date has been undertaken by SSB (Lowry & Saynor 2015; Supervising Scientist 2016b; Supervising Scientist 2019a; Supervising Scientist, 2020b). The outcomes of the modelling have been used to update the final landform design, with each version getting closer to meeting the closure criteria.

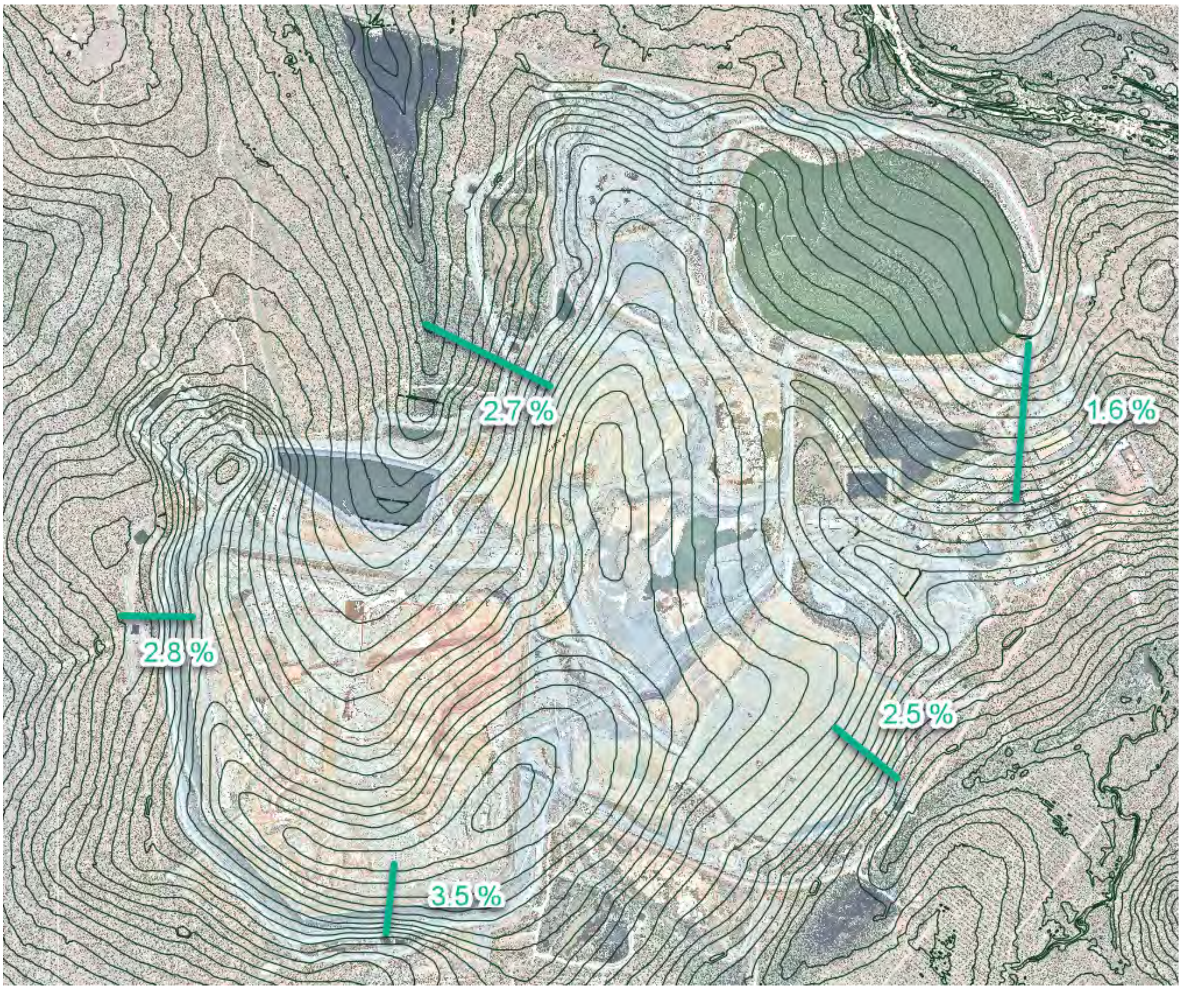


Figure 5-7: Preliminary slope analysis looking at the steepest slopes in FLV 6.2

The modelling applied a modified version of the CAESAR-Lisflood landform evaluation model (Coulthard *et al.* 2002, Coulthard *et al.* 2013). The CAESAR-Lisflood is an enhanced version of the CAESAR landform evaluation model. The key data inputs used by the CAESAR-Lisflood landform evaluation model were a digital elevation model (DEM), rainfall and surface particle size. The catchment areas used for assessing the Ranger Mine conceptual landform are shown in Figure 5-8.

A study on the calibration of parameters in CAESAR-Lisflood using the geomorphic monitoring data in Ranger Mine TLF and sensitivity analysis was completed by SSB (Lowry et al. 2020). Several parameters have been calibrated to provide a more accurate modelling prediction of erosion features on TLF. Information about the TLF parameters and monitoring that formed part of the calibration are discussed under KKN ESR7. It has been noted that further works are required to extrapolate the results to a larger spatial and temporal scales appropriately.

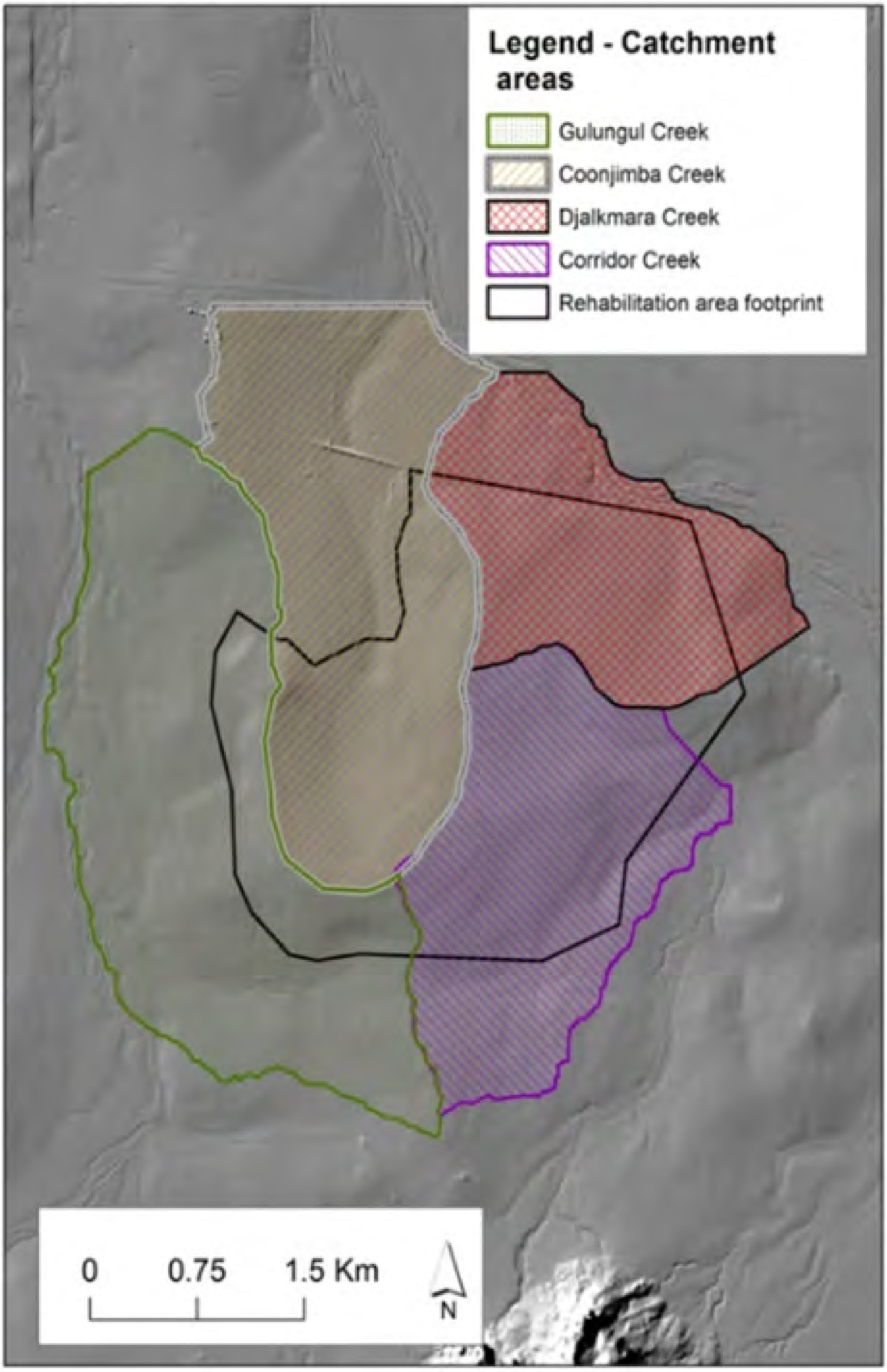


Figure 5-8: Catchment areas – Ranger Mine conceptual landform (Lowry & Saynor 2015)

The model has, to date, been conservative in nature, currently excluding any orthodox storm water and erosion control structures to reduce bedload yields and until recently no vegetation on the surface for the entire 10,000-year period. The SSB incorporated a grass cover layer in their assessment of the Corridor Creek Catchment (Supervising Scientist, 2020b).

The most recent assessment by SSB on FLv6.2 has been reported in a memorandum to ERA dated 21 February 2019, additional advice in Technical Advice #010 on 13 September 2019 and an overall assessment update in Technical Advice #22 on October 2020 (Supervising Scientist, 2020b). The predicated denudation rates and gullying depth for each catchment on are provided in Table 5-7 and the predicted erosion for simulated periods of up to 10,000 years in the Corridor Creek and Djalkmarra catchments are shown in Figure 5-9 to Figure 5-12.

The results show most of the deposition occurs in the first 100 years with erosion ongoing throughout the model. Denudation rates decrease over time and are found to approach the published background denudation rate for the region. A revised background denudation rate of 0.07 +/- 0.04 m per year for the landscape surrounding the Ranger mine has been recently published by Wasson *et al*. (2020).

The results also show the potential formation of gullies up to 9 m deep in Pit 1 and 7 m deep in Pit 3, which confirm that the locations and depths are unlikely to expose tailings based on approved final depth of tailing[6]. The identified locations have been used to inform the design of drainage channels and other erosion mitigations to minimise the potential impact on landform stability and support revegetation success (refer Section 9).

As noted above the modelling is a worst case assessment but provides a good indication of the stability of the current final landform and where additional engineering and design is required. The key things noted by the SSB as a result of the modelling were:

- Landform evolution assessment using CAESAR-Lisflood and SIBERIA have similar gully formation area across the landform, which includes Pit 1, Pit 3, and the former TSF while the gullies depth are unlikely to expose the tailings according to the approved tailing storage level in pits (Figure 5-9 to Figure 5-12).

- The final landform is unlikely to achieve the background denudation rate under extreme worst case scenario model setting over 10,000 years with the absence of vegetation surface cover while the denudation trajectory over does approach an equilibrium over time. However, Corridor Creek catchment under the dry rainfall scenario with the simulation of vegetation cover in CAESAR-Lisflood achieve the background denudation rate over 10,000 years (Table 5-7).

[6] The SSB has advised ERA that landform erosion modelling results are indicative only and should not be used to identify precise locations or depths of potential gully erosion. As such this information is used to guide the development of the final landform.

- Gulungul and Coonjimba catchments were assessed using CAESAR-Lisflood based on worst case scenario model configuration indicating the denudation rate will not approach the denudation background rate over a simulation period of 3,000 years.

Table 5-7: Predicted denudation rates and gullying depth for each catchment on FLv6.2.

Catchment	**Denudation rate (mm yr^{-1})**			**Gullying (maximum predicted depth, m)[1]**		
	CAESAR-Lisflood		SIBERIA	CAESAR-Lisflood		SIBERIA
	Dry rainfall scenario	Wet rainfall scenario		Dry rainfall scenario	Wet rainfall scenario	
3,000 years						
Djalkmara	0.19	0.27	–	4.5	5	–
Coonjimba	0.51	1.01	0.07	4	7	9.6
Gulungul	0.15	0.24	0.11	4	4.5	12.2
10,000 years						
Corridor	0.15 (*0.04*)	0.21 (*0.09*)	0.06	7	9	11.7
Djalkmara	0.21	0.24	0.11	6.5	7	10.4

*Bracketed numbers indicate denudation rate with grass cover present (Supervising Scientist, 2020)

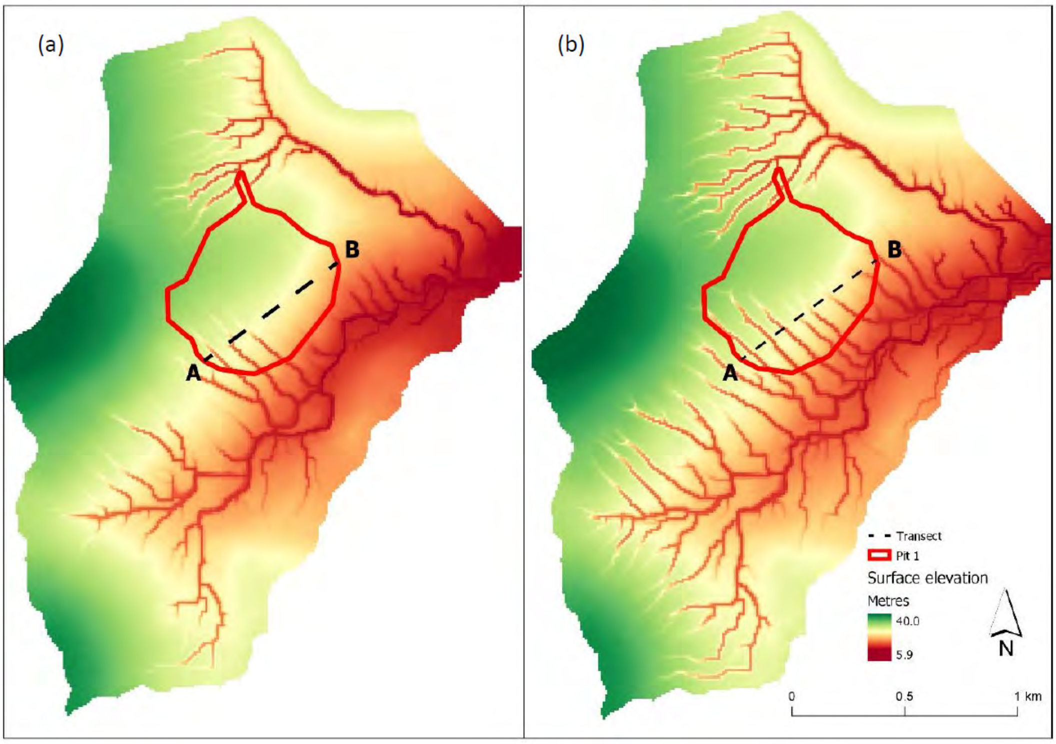


Figure 5-9: Surface of Corridor Creek catchment after a simulated period of 10,000 years under (a) dry and (b) wet rainfall scenarios.

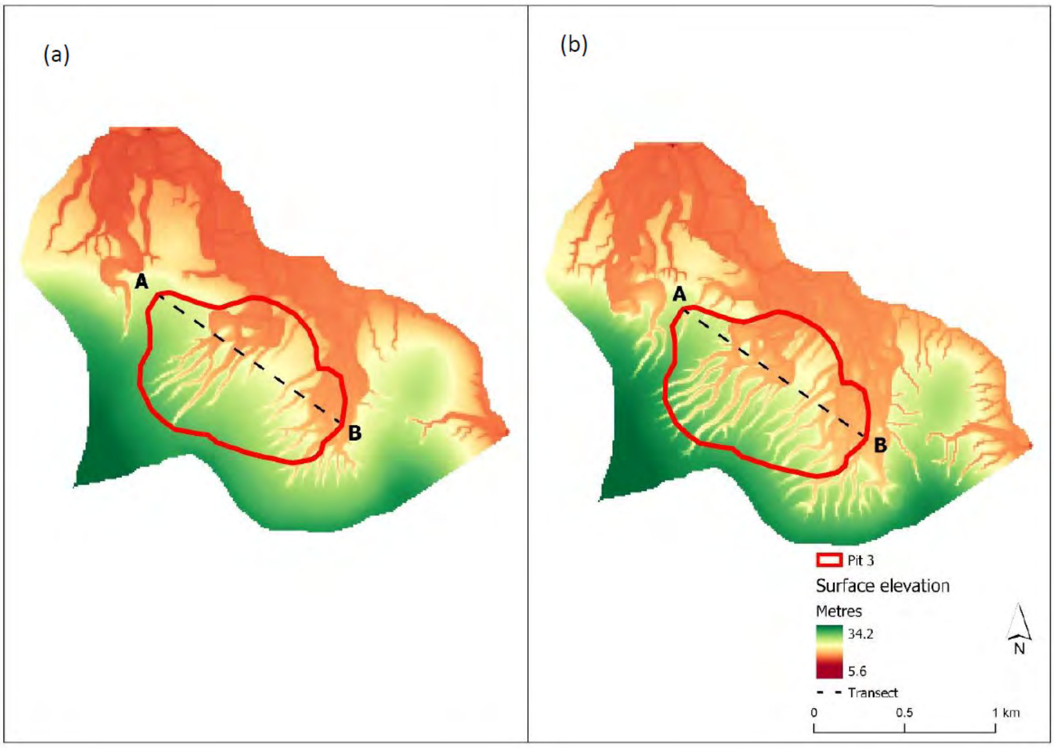


Figure 5-10: Predicted distribution of gullies in Djalkmarra catchment after 10,000 years under (a) dry and (b) wet rainfall scenarios.

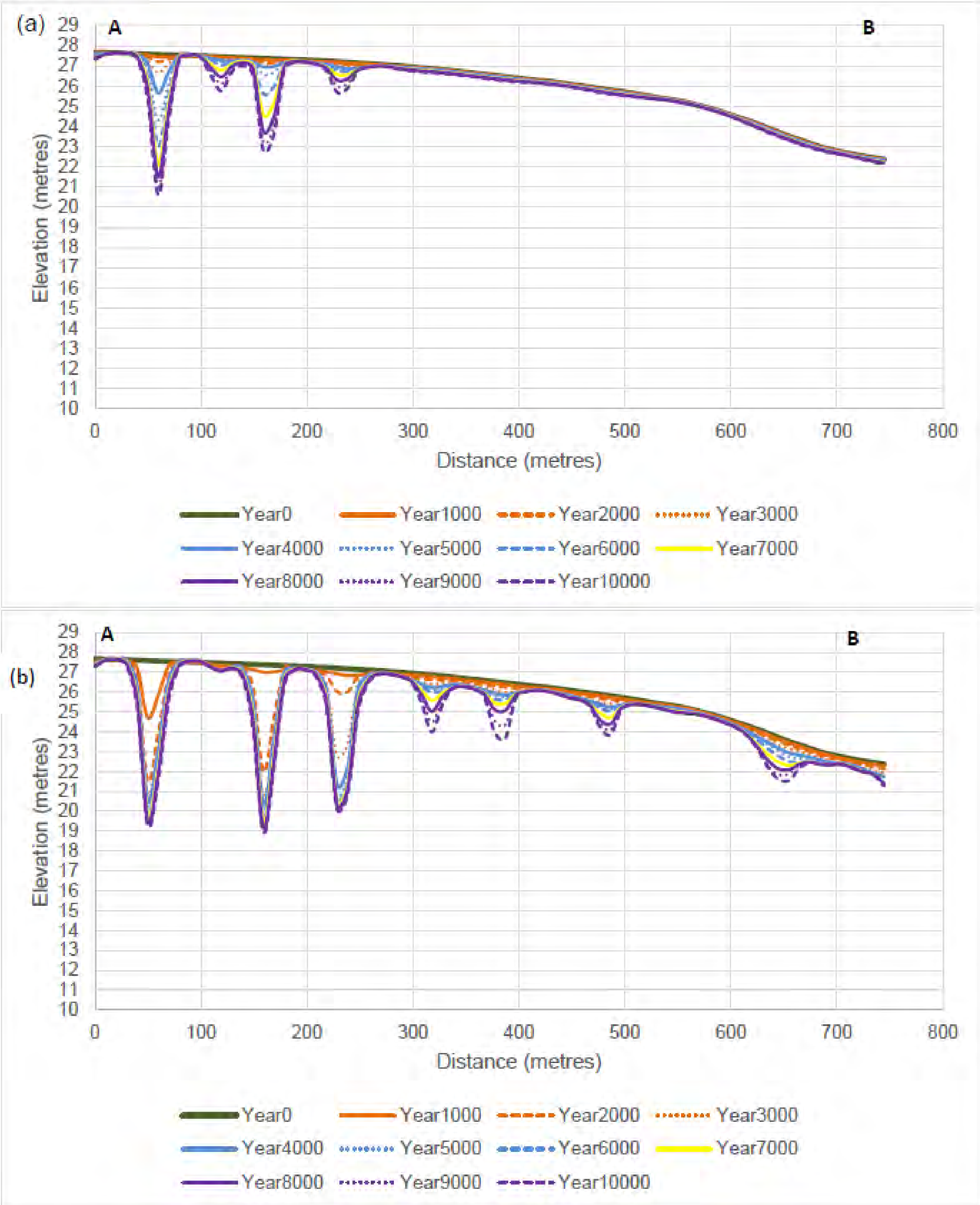


Figure 5-11: Cross sectional profile of transect A-B across Pit 1 under (a) dry and (b) wet rainfall scenarios.

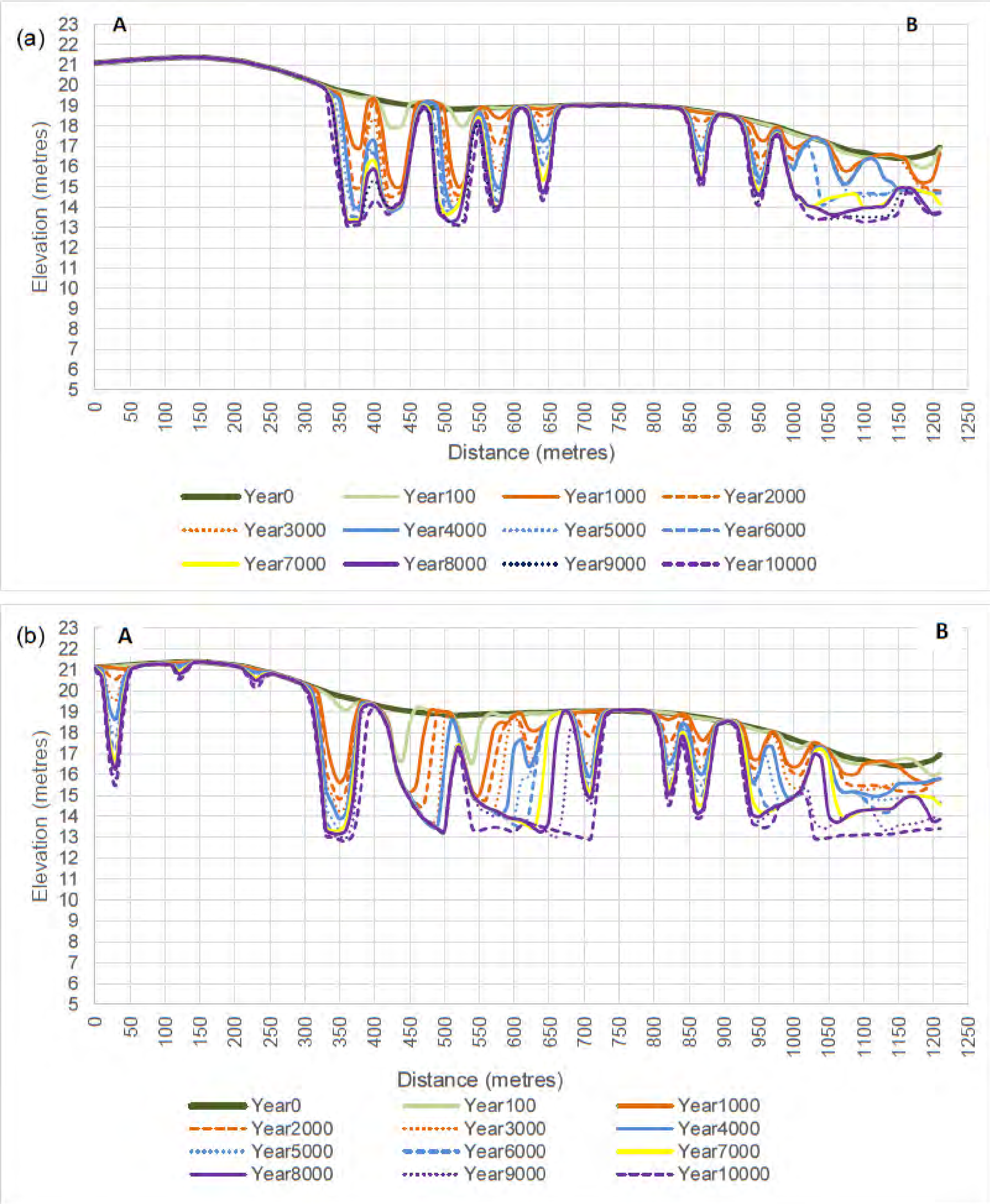


Figure 5-12: Cross sectional profile of transect A-B across Pit 3 under (a) dry and (b) wet rainfall scenarios.

ERA is expecting SSB to provide modelling results for Coonjimba and Gulungul catchments for periods up to 10,000 years utilising extreme wet-rainfall and extreme dry-rainfall scenarios data sets to complete the full suits assessment on FLV 6.2. SSB also noted that further assessments may be required for the FLv6.2 landform outside of the Corridor Creek catchment, thereby identifying locations on the final landform which may require additional mitigation such as surface armouring to eliminate any significant gullying. Results of these simulations will be presented in subsequent versions of the Mine Closure Plan (MCP), once completed.

Through late 2019 to early 2021, ERA engaged a hydrologist to build internal technical capacity to utilise CAESAR-Lisflood landform evolution modelling software. In addition to the SSB modelling, ERA has commenced studies into evaluating closure landforms and undertaking sensitivity testing of some key model parameters including climate sequences, rainfall losses, particle size distribution and vegetation cover. This project will enable faster evaluation of landforms, provide a better understanding of the modelling process and implications for erosion outcomes dependent upon both landform design and parameter choice. The other objective of building internal LEM capacity is to optimize modelling parameters to simulate a more realistic and yet conservative landform evolution processes. Initial parameter optimisation recommendation including optimised vegetation parameters to represent a surface roughness in a full vegetation cover scenario post rehabilitation, as well as hydrological parameters reflecting the local catchment behaviors in Ranger (ERA, 2021a).

Final Landform Design Optimisation

In February 2022, an ERA internal landform design group was formed which comprised of a bulk material movement modeller, a 12D civil software expert and a landform evolution modeller. The initial purpose of the landform design optimisaton is to incorporate the concave slope and first-order drainage recommendations from stakeholders into the design of a Final Landform version that achieves the background denudation rate (Wasson *et al*., 2020) in LEM 10,000-year worst-case scenarios. Future opportunistic engineering controls will be designed to ensure final landform stability performance is in the trajectory of achieving background denudation rate and the closure criterion.

Landform design is an iterative process. A workflow of literature review, concept design, design implementation and landform modelling assessment were developed in the landform design group. The landform assessment results then in turn informed the second iteration of landform design. Each landform version, once it is completed, is imported to CAESAR-Lisflood for modelling to assess its stability performance (i.e., denudation rate and vertical incision over the landform) in wet scenario using calibrated parameters from Trial Landform (Lowry et al., 2020) and vegetation cover parameters derived from an analogue site (Coulthard, 2019). This process, so far, demonstrates its reliability and robustness to generate results informing subsequent direction on landform optimisation from desktop study aspects. Where possible, the landform constructability is captured in the design to ensure it is practical to construct.

The landform optimisation project started from the Coonjimba catchment as a result of the closure sequence. A literature study was undertaken, including the historical landform studies in Ranger Mine and the ones capturing analogue sites, which demonstrated the benefits of concave design to landform stability (East et al., 1995; Hancock, 2004; Şensoy and Kara, 2014). The design criteria in Table 5-8 are adopted for the Final Landform design based on the statistical analysis on Georgetown analogue area (Hollingsworth, 2010). Channel geometry also has an impact on channel erosion: a low value of radius of channel curvature would accelerate the erosion rate due to a higher flow velocity (i.e., higher flow kinetic energy) directed towards the lateral channel cut (Janes *et al*., 2017). By contrast, the channel with higher radius of curvature in relief area can function as a buffer zone where flow velocity slows down and allow coarser sediment to drop out.

Table 5-8: Analogue landform terrain properties adopted as FLV 7 design criteria (Hollingsworth, 2010)

Variable	Units	Range
slope (%)	%	0 – 6.5
relief (m)	m	25
profile curvature	radius (m)	-5000 (concave) to 5000 (convex)
plan curvature	radius (m)	-100 (vale) to 100 (ridge)

In addition, appropriate software was utilised to analyse the slope curvatures aiming to extract the landform curvature design criteria in parallel to literature review, thus third polynomial equations were derived showing the relationship of landform cross section profile in main drainage lines form in surrounding analogue sites. Also, it was observed that the drainage line joins with the next higher order drainage line usually presented an almost perpendicular intersection. This leads to one of the reasons that location of drainage lines was introduced in FLV 7.00 (Figure 5-13a). The other factor determining the introduced channel locations are based on the slope analysis of Coonjimba Catchment in FLV 6.2 and the feasibility of introduced drainage lines to introduce concavity.

The key design features introduced and/or changed features of each subsequent version of FLV 7.00 (Figure 5-13) are summarised as follows with landform evolution modelling results provided as justification:

- FLV 7.00 used the introduced straight five drainage line locations and a sinuous main drainage before flowing out to undisturbed area as a design base. The concave profile curvature in Table 5-8 from Hollingsworth was adopted for drainage profile design.
- The third order polynomial equation was utilised to replace the -5000 concave profile curvature design criterion in FLV 7.01. The others design features stay the same as FLV 7.00
- The total sediment yield over 1000 years in FLV7.00 deceases by 4.01% compared to FLV 6.2, whereas FLV 7.01 produce about 24% more sediment compared to FLV 6.2. This led to the adoption of design criteria in Hollingsworth (2010) again in FLV 7.02. Two new elements were trialled in Channel 2 and Channel 3.1 compared to the drainage layout in FLV7.00, respectively wider and constant width in Channel 2 and a V-shape Channel 3.1 (Figure 5-13).
- The modelled erosion rate at the V-shape channel and the wider channel in FLV 7.03 were investigated. The wider (i.e., 60 m channel width) overall has a lower denudation

rate in the channel compared to the 30 m wide channel in FLV 7.00. The gradual increasing channel width exhibits a natural landform feature, therefore was adopted as the channel shape in FLV 7.03 while the modelling result favours a constant channel width.

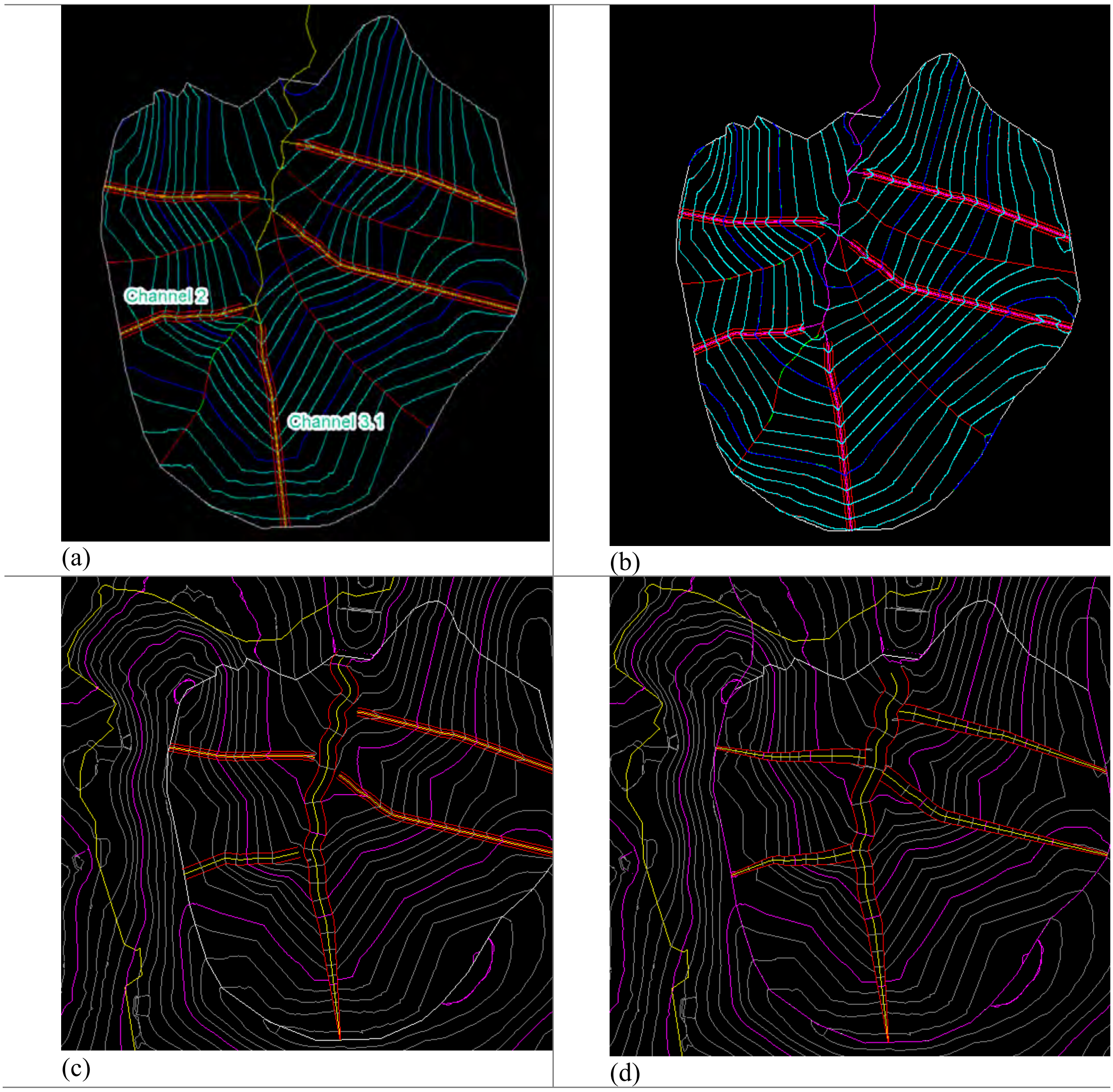


Figure 5-13: Drainages in each Final Landform 7 deisgn iteration versions, respectively FLV 7.00 (a), FLV 7.01 (b), FLV 7.02 (c) and FLV 7.03 (d) of Coonjimba working area (southern Coonjimba Catchment)

Table 5-9: CAESAR-Lisflood simulation results of FLV 7 iterations in Coonjimba catchment compared to FLvV6.2 base case

	verage denudation rate (mm/year) over 1000 years	tal sediment yield (m3)	ediment Yield reduction compared to FLV 6.2
FLV6.2	0.2979	1131991	n.a.
FLV7.00	0.2860	1086631	4.01%
FLV7.01	0.2865	1403033	-23.94%
FLV7.02	0.2897	1100985	2.74%
FLV7.03	0.2944	1118728	1.17%

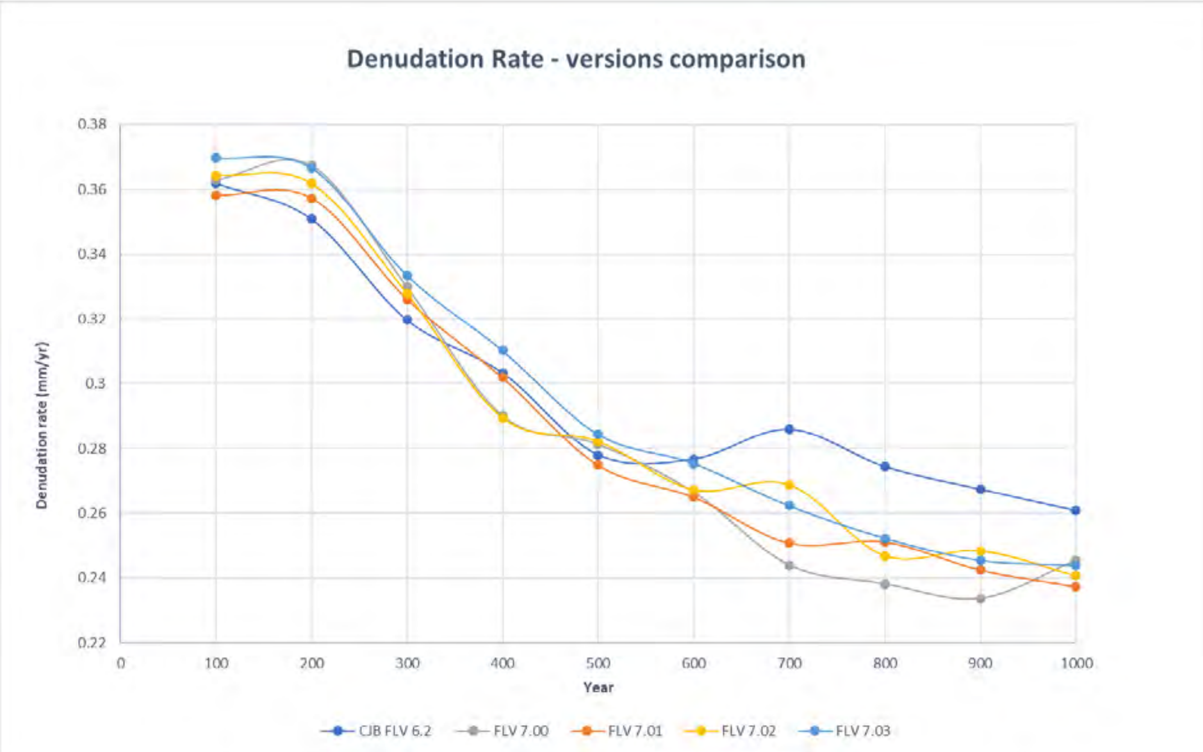


Figure 5-14: 1000-year average denudation rates of different landform versions in wet-scenario model running

Table 5-9 summarises the sediment yield of four Coonjimba catchment landform iterations over a 1000-year simulation period. It demonstrates, together with the denudation trajectories shown in Figure 5-14, FLV 7.00 has the best stability performance amongst the design versions solely according to the modelling results. Ongoing literature search and stakeholder recommendations suggest introducing low relief first-order drainages will create flow confluence, and in turn provide confidence on future infrastructure design requirements (e.g., location and design magnitude) to for a better long-term erosion control. FLV 7.04 in Coonjimba including multiple upper-stream order drainages with gradual increase widths and a wider central drainage channel is being developed during this mine closure plan update.

The landform design features tested effective in erosion reduction in the landform design iteration version of Coonjimba are kept and is being applied to the conceptual landform design in Djalkmarra catchment, and it will be applied to landform optimisation in Corridor Creek and Gulungul catchments.

Landform optimisation (FLV 7 design) including drainage channels design and other erosion mitigations is ongoing to minimise the potential impact on landform stability and revegetation success. The results of the simulations to date provide a guide for future enhancements both to the landform design and the landform evaluation model software. As a consequence, in parallel to the landform design optimisation in which LEM using calibrated parameters based on landform studies carried out in TLF, ERA will continue to work collaboratively with SSB in selecting and reaching agreement for optimised parameters for input into the landform evolution model (LEM) maximising the accuracy of the model predictions as the mine rehabilitation knowledge is further progressed. The rehabilitation knowledge includes the ecosystem re-establishment (e.g. canopy cover increase providing erosion protection) and evolution behaviour on the freshly constructed landform.

5.1.3.2 Infiltration, runoff, and erosion

Four erosion plots (approximately 30 m × 30 m) were constructed on the TLF during the 2009 dry season (Saynor *et al.*2009) (Figure 5-15). The TLF surface was ripped on the contour prior to construction of the erosion plots. The plots represent two types of potential final land cover layers; a waste rock only and waste rock – laterite mix with planting methods of both direct seeding and tube stock. The plots were physically isolated from runoff from the rest of the landform by raised borders.

Sensors installed in each plot included a tipping bucket rain gauge, primary shaft encoder with a secondary pressure transducer to measure stage height, a turbidity probe to measure suspended sediment concentration, electrical conductivity (EC) probes located at the inlet to the stilling basin and the entry to the flume to provide a measure of the concentration of dissolved salts in the runoff, an automatic pump sampler to collect event based water samples, a data logger with mobile phone telemetry connection and a rectangular broad-crested flume to accurately determine discharge from the plots (Saynor *et al.* 2014) (Figure 5-16).

Monitoring results including generation and transport of solutes, hydrology and bedload yields, have been reported (Saynor *et al.* 2009, Saynor *et al.* 2011, Saynor *et al.* 2012b, Saynor *et al.* 2014, Saynor *et al.* 2015). These studies also inform KKN ESR7.

Infiltration

In his PhD study into surface hydrological modelling for rehabilitated landforms, Shao (2015) developed a modified runoff model (RunCA) applying it to the TLF as a case study. Good agreement was achieved between the simulated and observed discharge volumes, runoff curves and flow distributions for the rainfall events monitored during four wet seasons from 2009 to 2013. The study utilised the existing SSB erosion plots on the TLF (e.g. Saynor *et al.*

2012b) undertaking additional field infiltration measurements (September 2013) to determine the hydraulic properties of the TLF and the infiltration parameters for the RunCA model.

The following is an excerpt from Shao (2015) and details the field methods used to obtain infiltration measurements on the TLF in September 2013:

> *Due to the large width of the rip lines, four measurements were conducted on the rip lines at randomly selected areas on the waste rock cover, using a ring infiltrometer with a large diameter of 1 m. Another four measurement were also conducted randomly on the non-ripped areas between the rip lines, using a smaller ring infiltrometer with a diameter of 0.4 m. The falling head method was employed in all these measurements. Each measurement lasted until a stable infiltration state was reached, and then the final steady infiltration rate* i_f *was calculated by averaging the last three measured infiltration rates. Core samples were also taken in the areas immediately adjacent to the infiltration measurements for the laboratory determination of various properties. Specifically, the total porosity TP was assumed to be equal to the saturated water content, which was reached by leaving the core samples in a tray filled with shallow water for 2-4 days, and field capacity* θ_{FC} *was achieved by leaving the saturated core samples on a suction plate with 33 kPa (0.33 bar) suction pressure for 7 days. Initial soil moisture* θ_0*, TP and* θ_{FC} *were then determined by weighing the core samples before and after oven-drying at 105°C for 24 hours in the laboratory.*

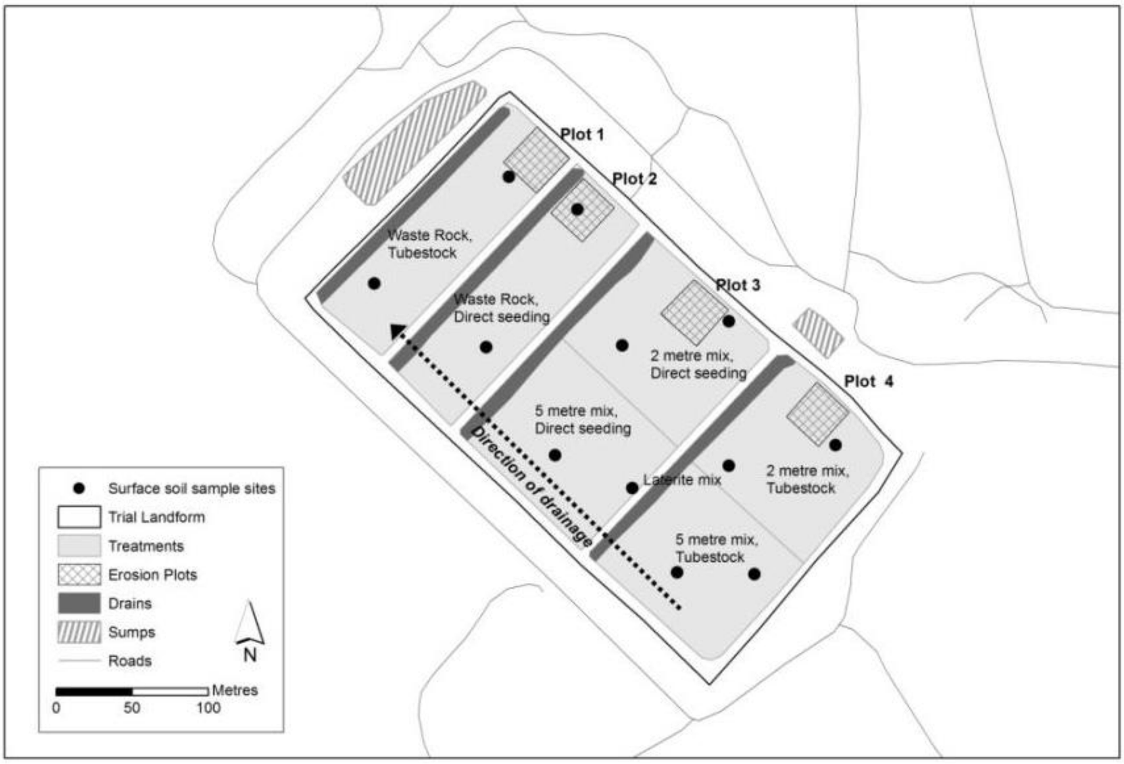


Figure 5-15: Layout of the erosion plots on the trial landform (Boyden et al., 2016, Saynor et al., 2016)

Figure 5-16: Runoff through the flume on the trial landform erosion plot 3 during a storm event (Saynor et al., 2014)

Discharge volumes, runoff curves and flow distributions for the rainfall events monitored during four wet seasons from 2009 to 2013 were used to determine the hydraulic properties of the TLF (Shao 2015) (Table 5-10 and Table 5-11). Shao's direct measurements from the TLF were used to calibrate the WAVES model (ESR7).

Table 5-10: Statistical values for the observed rainfall events in the four wet seasons (water years) from 2009 to 2013

Water year [a]	Annual rainfall (mm)	Annual runoff (mm)	Number of events	Event duration (min)		Runoff coefficient (%)	
				Range	Mean	Range	Mean
Plot 1							
2009-10	1528.1	77.7	68	15-534	113.1±104.2	0.7-14.2	5.6±2.5
2010-11	2205.4	300.2	96	15-631	139.0±140.3	2.6-88.2	6.0±9.1
2011-12	1481.0	101.2	78	16-713	87.5±127.6	2.2-40.3	5.4±4.4
2012-13	1283.0	121.8	62	8-2135	88.1±275.8	1.2-29.9	4.6±4.3
Plot 2							
2009-10	1531.5	132.0	68	26-543	156.2±114.3	1.1-22.3	8.0±4.0
2010-11	2293.6	328.5	96	31-760	177.5±148.5	3.7-78.2	8.7±7.9
2011-12	1531.4	166.3	78	26-1017	130.2±154.0	2.5-30.9	8.9±5.0
2012-13	1274.2	196.4	62	13-2154	127.8±270.8	2.2-57.9	11.7±9.7

[a] A water year is defined as the period from 1 September to 31 August of the following year

Table 5-11: Summary of field infiltration parameters for the TLF

Measurement No.	Infiltration parameters [a]						RMSE (mm h^{-1})	R^2
	i_f (mm h^{-1})	θ_{FC} (m^3 m^{-3})	θ_0 (m^3 m^{-3})	*TP* (m^3 m^{-3})	*a* [b] (mm)	*D* [b] (mm)		
Rip lines								
1	25.20	0.09	0.07	0.30	0.60	180	7.37	0.84
2	24.00	0.12	0.09	0.26	0.50	90	5.09	0.84
3	18.00	0.11	0.07	0.30	1.30	100	6.79	0.82
4	30.00	0.09	0.08	0.26	2.50	120	7.76	0.95
Mean	24.30	0.10	0.08	0.28	1.23	122.50	6.75	0.86
SD	4.94	0.02	0.01	0.02	0.92	40.31	3.35	0.03
Non-ripped areas								
5	7.50	0.08	0.06	0.23	0.75	100	9.38	0.83
6	19.20	0.08	0.07	0.23	1.50	150	6.23	0.96
7	12.00	0.06	0.06	0.21	1.50	50	5.00	0.96
8	14.00	0.11	0.07	0.25	1.00	80	7.73	0.85
Mean	13.18	0.08	0.07	0.23	1.19	95.00	7.08	0.90
SD	4.85	0.02	0.01	0.01	0.38	42.03	1.90	0.07

[a] i_f: final steady infiltration rate (mm h^{-1}); θ_0: initial soil moisture (m^3 m^{-3}); θ_{FC}: field capacity (m^3 m^{-3}); *TP*: soil porosity (m^3 m^{-3}); *a*: a constant (mm$^{-0.4}$ h^{-1}) in modified Holtan model; *D*: depth of control zone which affects the infiltration process (mm).

[b] unmeasurable parameters determined by curve-fitting with observed infiltration rates.

Runoff

Annual runoff from the TLF was greatest in the wettest year, and there is a close relationship between event rainfall and event runoff over the full range of rainfall for all monitored years.

There is an apparent exponential relationship between event rainfall and event runoff over the full range of rainfall for five years monitoring of plot 1 (Figure 5-17), however due to technical issues with large events this has not yet been tested statistically (Saynor *et al.* 2015). Saynor *et al.* (2015) hypothesised that event rainfall greater than 30 mm generates proportionally greater runoff as smaller events do not totally infill the rip lines with water. Event rainfall greater than 30 mm can totally infill the surface storage, generating runoff from the whole plot surface.

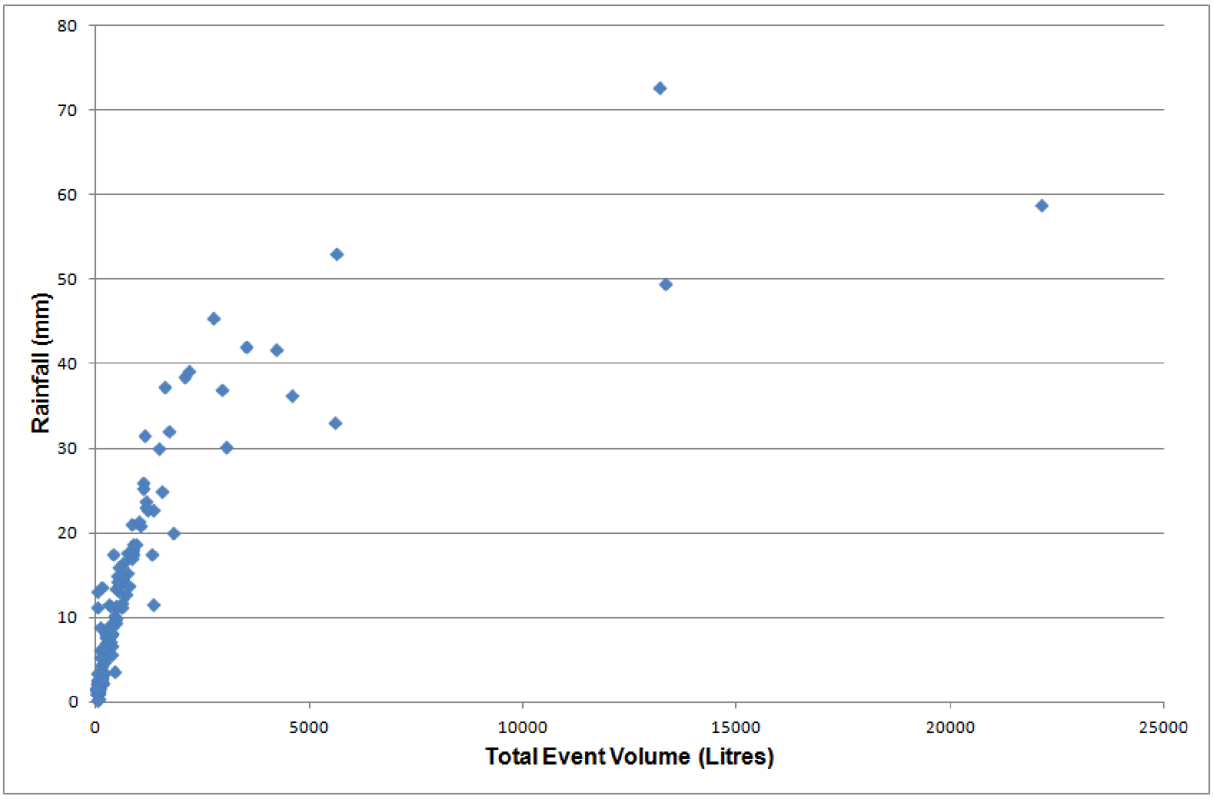


Figure 5-17: Relationship between total event rainfall and runoff for erosion plot 1 for 156 runoff events in the 2013–14 wet season (Saynor *et al.* 2015)

Erosion

Run-off and erosion rates measured on the TLF have been used to assess the long- term geomorphic stability of the TLF and have been applied by extension to the final landform (comparing measured export rates with those modelled from the landform evolution model).

Bedload samples were collected at weekly to monthly intervals during each wet season, depending on the magnitude of runoff events and staff availability. In general, sediment yields for major land disturbances, such as construction or landslides, are characterised by an initial pulse followed by a rapid decline (Duggan 1994 cited in Saynor *et al.* 2015). This is true for the TLF annual bedload yield, which is characterised by an exponential decline since construction (Figure 5-18). Saynor *et al.* (2015) also noted that since construction, eroded material has been washed into the rip lines, but there is still a large amount of potential sediment storage before the rip lines are diminished. Fine materials and fines earth accumulated in the rip lines and other depressions are important for the soil formation on the final waste rock landform and sustainability of the revegetation. The formation of soils is further discussed under KKN ESR7.

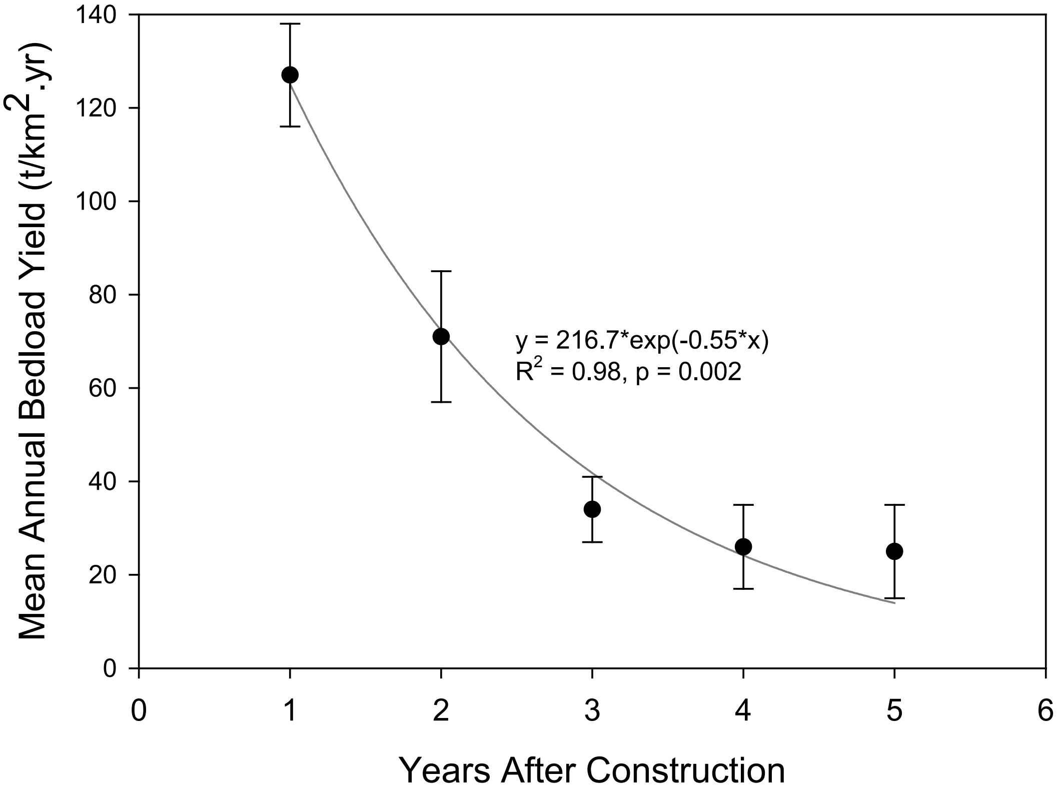


Figure 5-18: Exponential decrease in mean annual bedload yield with time since construction for the four plots on the trial landform. Data represent annual mean and standard error of estimate for all plots (Lowry & Saynor, 2015)

5.1.3.3 Landform material properties and Landform Evolution Modelling improvement

Studies on the particle size distribution of waste rock have been completed by both ERA and SSB. Table 5-12 shows the indicative particle size distribution for the 1s waste rock material taken from the TLF (Saynor & Houghton 2011). SSB has also undertaken particle size distribution analysis over ten years using sieve analysis in 2009 and the grid by numbers method in in 2012, 2014 and 2018 (Hancock et al., 2020).

Pit 1 top 6 m material (1s grade material) was undertaken as per commitments made in the Ranger Application to Progress Pit 1 Final Landform and associated *Pit 1 Progressive Rehabilitation Monitoring Framework*. The sampling plan was developed from this framework and aligns with the research objectives of project 1230-04 under KKN LAN3. Samples were taken on a 100 m designed grid following the completion of waste rock placement in Pit 1

(Figure 5-19), between October 2019 and September 2020. The sampling and analysis regime was executed by Douglas Partners and followed the Northern Territory Government Standard Test Method *NTTM 217.1* for oversized materials and *AS 1289.3.6.1* for determining the PSD by sieving analysis.

Table 5-12: Particle size distribution in percentage for the waste rock dump materials and Koolpinyah surface materials, adapted from Hancock et. al (2020)

Phi	Size (mm)	Waste Rock in Pit 1 (%)	Waste Rock in current LEM (%)	Koopinyah (%)
-7	128	18	8	0
-6	64	22	9	0
-4	16	11	33	0
-2	8	11	22	1
0	1	9	14	12
1	0.5	9	4	14
2.47	0.18	10	6	42
3.47	0.09	3	3	15
4	0.063	7	1	16

Figure 5-19: PSD sampling locations in Pit 1

A visual approximation of the results showing the fines (mass fraction < 2.36 mm in fraction size) in upper (U; 1.5 m) and lower layer (L; 1.5 m to 6 m) are shown in Figure 5-20 and Figure 5-21.

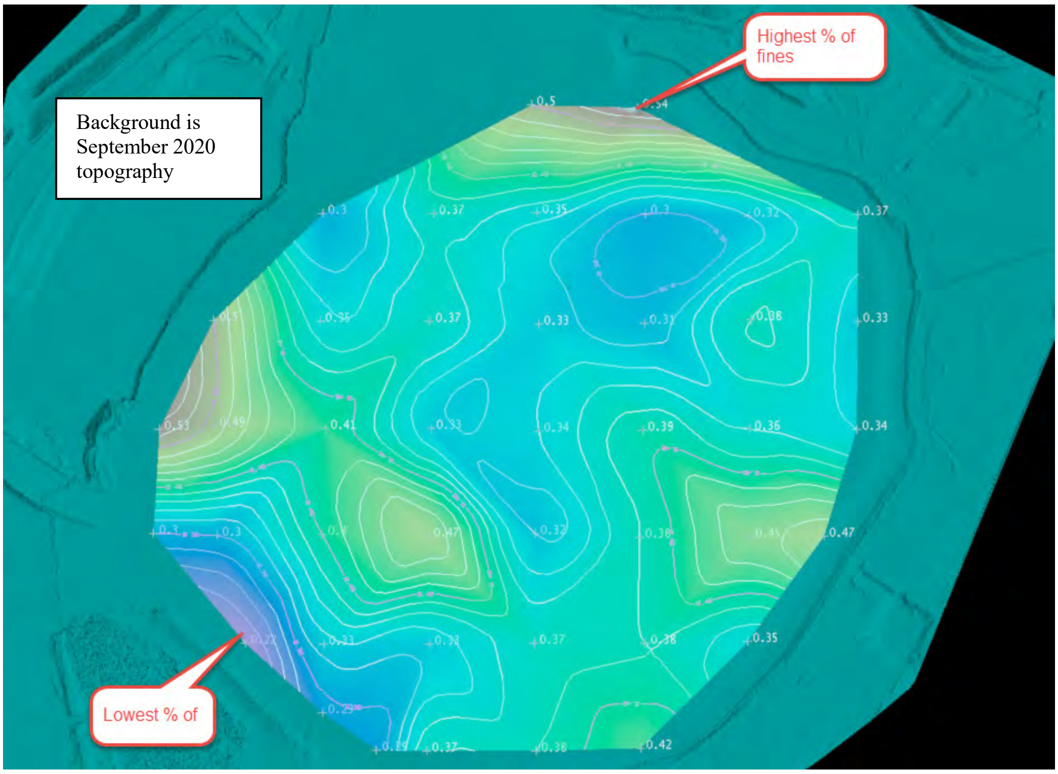


Figure 5-20: Upper layer with the mass fraction less than 2.36mm

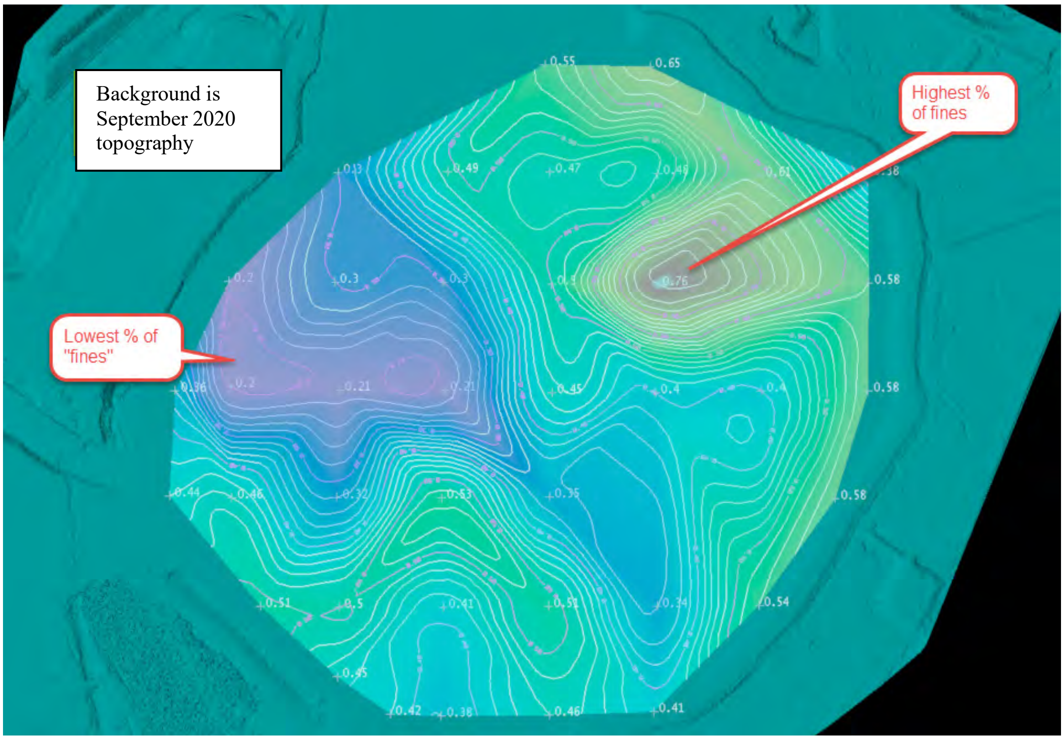


Figure 5-21: Lower layer with the mass fraction less than 2.36mm

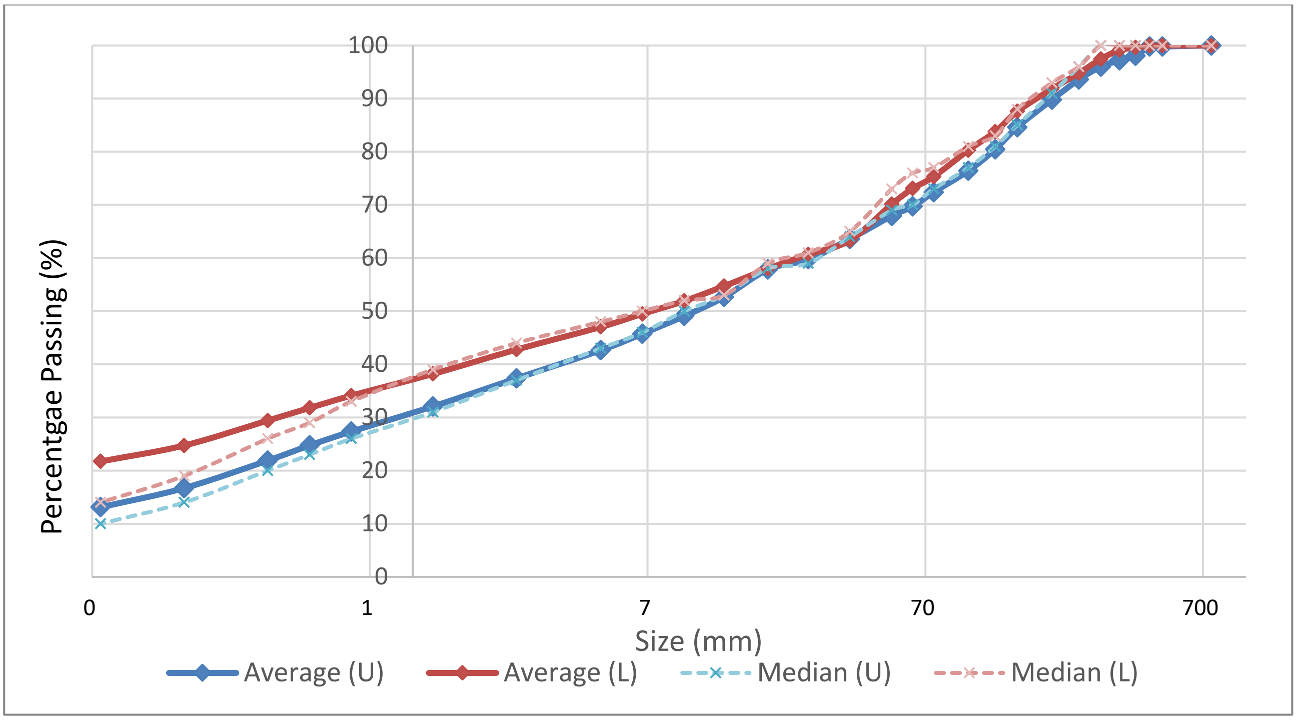


Figure 5-22: PSD result average and median for upper and lower layer

Figure 5-22 shows the average and median PSD results of the upper layer and lower layer materials sampled. There is an approximate ten percent difference between the average and median value of the fine fraction for the lower layer, indicating material characteristics of the lower layer potentially present a more heterogeneous form in the fine size fractions compared to that in the upper layer materials.

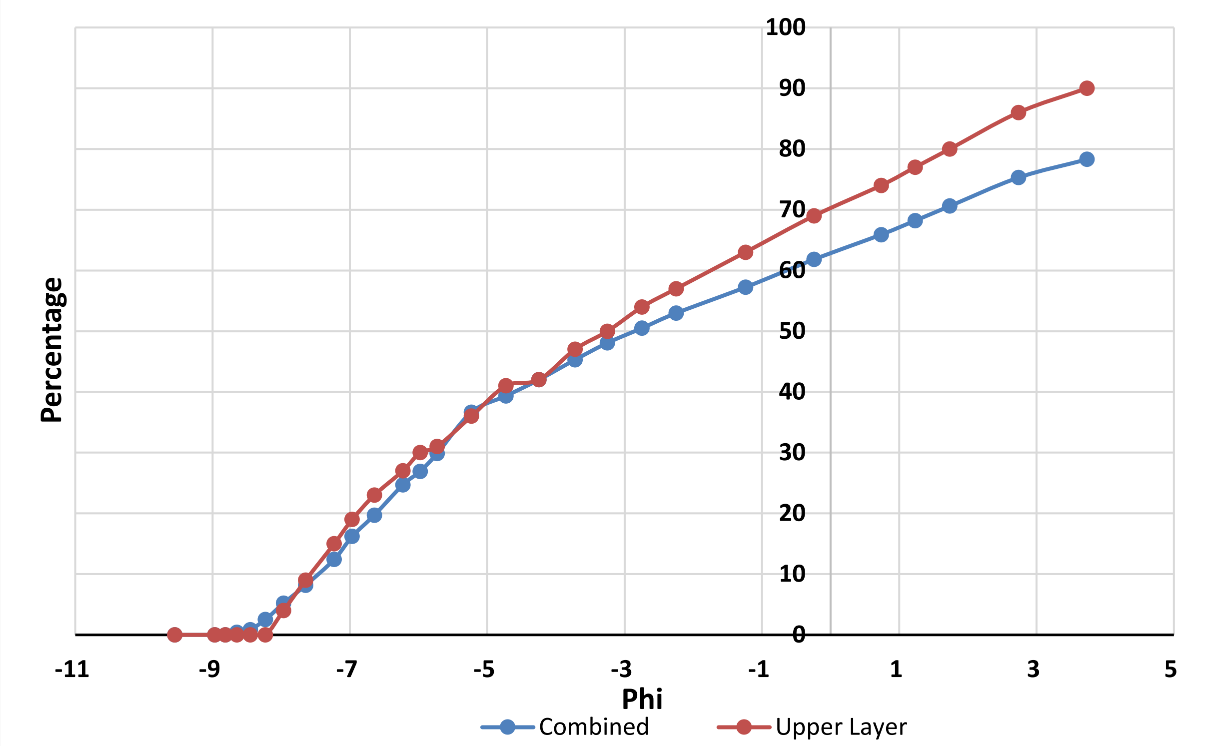


Figure 5-23: Upper layer PSD curve and combined PSD curve.

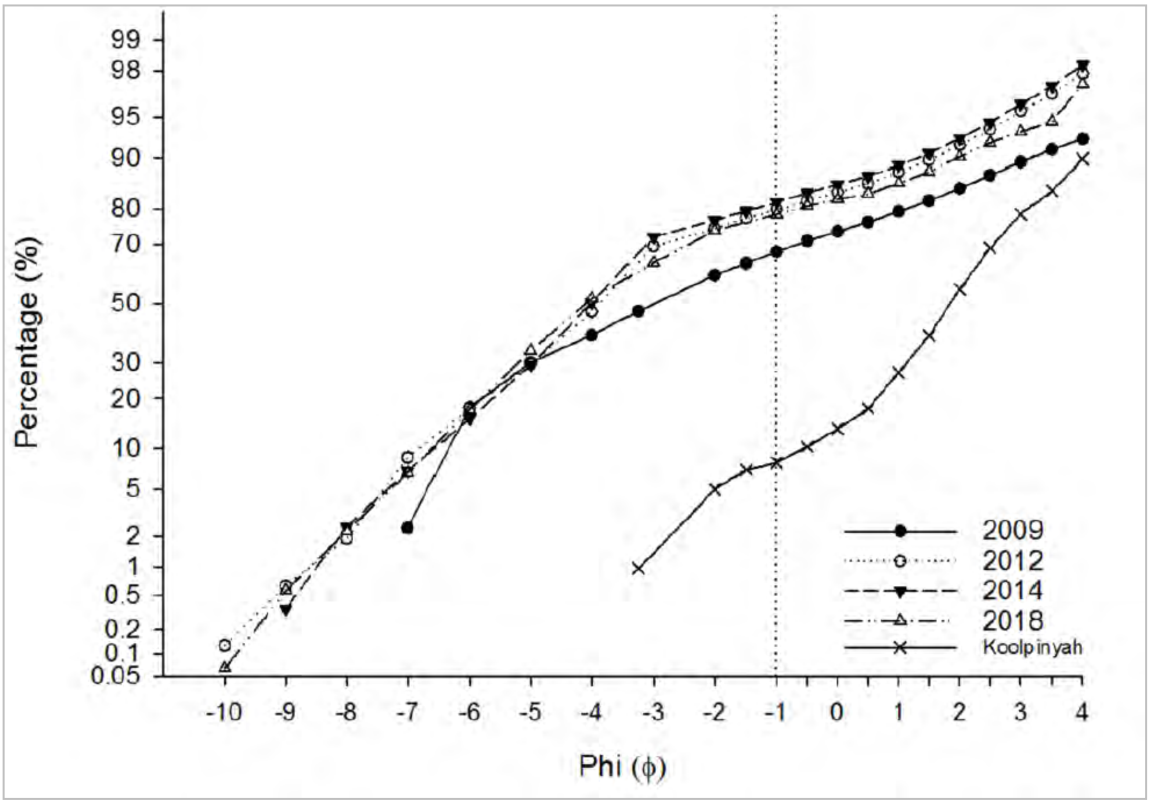


Figure 5-24: Particle size distribution from the Ranger trial landform in 2009, 2012,2014 and 2018 (Hancock et al., 2020).

Figure 5-23 indicates the Pit 1 upper layer material has a coarser distribution compared to the combined material (i.e., top 6-m material). This figure can also be used to compare the Pit 1 PSD results with that previously plotted for the Particle size distribution from the Ranger trial landform (TLF) in 2009, 2012, 2014 and 2018, and Koolpinyah sediment in Figure 5-24. The comparison suggests the Pit 1 materials are generally in line with the TLF surface material PSD results determined using sieve and hydrometer methods.

The PSD results can then further be used to update the waste rock PSD applied in CAESAR-Lisflood for landform evolution model. CAESAR-Lisflood only allows a maximum of nine PSD size fractions to be modelled. To enable use of the most recent dataset collected on Pit 1, a single PSD curve using the average of upper layer and lower layer materials for each size group was generated and plotted in Phi scale (Figure 5-25). This enabled a single PSD compatible dataset to be used in CAESAR-Lisflood. A realistic, conservative approach was undertaken for compressing the data into a single PSD dataset, suitable for landform evolution modelling.

The default setting currently used in CAESAR-Lisflood has a set of predetermined PSD intervals, ranging from -7 Phi to 4 Phi, or 128 mm to 0.063 mm. When calculating the single PSD dataset, the fraction size intervals remained the same, and were treated as the median of each interval (i.e. 128mm, 64mm etc). This allowed for the interval boundary values in the Phi scale to be extrapolated using Figure 5-25. In doing this, fraction sizes for a single PSD dataset could also be easily aligned to existing waste rock and Koolpinyah PSD datasets which are currently used in the LEM. Table 5-12 summaries the particle size group derived from Pit 1 PSD result (refer to the third column) compatible for CAESAR-Lisflood in comparison to the waste rock PSD datasets used prior to obtaining Pit 1 PSD data and the natural Koolpinyah PSD datasets surrounding the mine footprint areas.

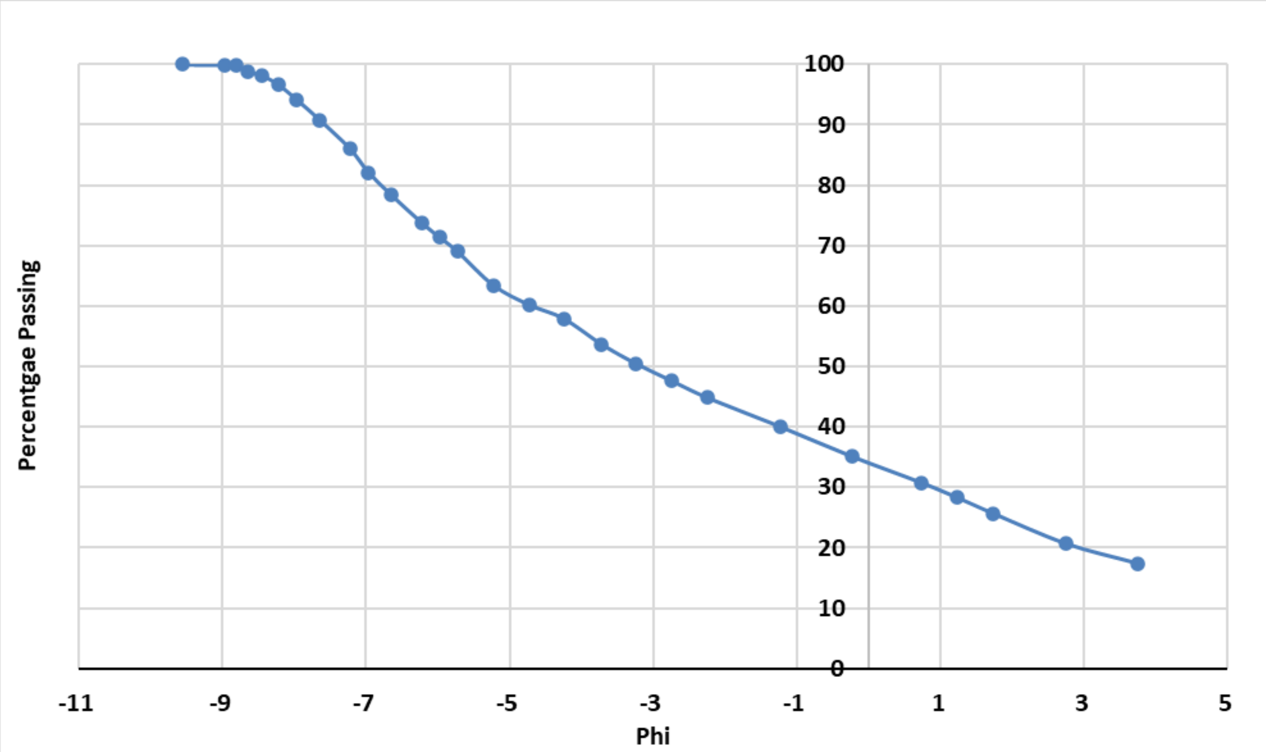


Figure 5-25: Pit 1 waste rock PSD curve in Phi scale

The progressive understanding of the material properties on newly constructed landforms forms part of the closure knowledge needs and will continue to evolve as new data becomes available.

5.1.3.4 Tailings consolidation model

KKN LAN3B asks question around consolidation, in particular the degree of subsidence within the rehabilitated landform (e.g. over Pits 1 and 3 associated with tailings consolidation) may influence erosional processes. Determining these rates will require some knowledge of predicted location and extent of consolidation over the pits.

As part of Pit 1 closure planning, ERA commissioned a series of Pit 1 tailings consolidation models (Australian Tailings Consultants, 2003, 2007, 2009, 2012, 2014, Fitton 2015, 2017). These models allow the prediction of final tailings elevation within Pit 1 and the forecast volume of process water to be expressed during consolidation. The model was then later adapted for use in Pit 3. This section describes the model. Subsequent sections detail the specific models of both Pit 1 and Pit 3.

The consolidation models have been supported (verified) by a number of tailings characterisation studies by geotechnical investigations and geophysical surveys. These studies are summarised later in this section.

The consolidation modelling software was established in the late 1980s and is based on a formulation developed by Somogyi (1980). The initial purpose of the program was to provide inputs into a sophisticated water balance developed by the author for the Golden Cross Gold Mine in New Zealand (Murphy & Williams 1990).

The program solves the various partial differential equations describing self-weight consolidation using an implicit finite difference method. The author extended the original Somogyi model to include:

- a technique to allow for variable basin geometry and/or changing solids deposition rate with time;
- underdrainage to atmospheric pressure; and
- the application of surcharges.

The program models tailings deposition at user defined time steps and quiescent consolidation with or without a surcharge.

The program was presented as a minor thesis (Murphy 1994) as part of a Master of Engineering Science at Monash University in 1994. The examiner was David Williams (now Professor) of the University of Queensland.

Method of addressing variable basin geometry

Variable geometry is addressed by considering the tailings impoundment as a series of five annular areas, as described in Appendix 5.2. As the tailings level rises, the effective discharge rate reduces as the area increases at each stage. At each stage, the mass of solids discharged into each annuls is modified to compensate for the greater consolidation settlement in deeper columns. The relative mass of solids deposited is greatest in the deepest column and reduces towards the edge of the TSF. This technique ensures that the model compensates for the greater settlement in deeper parts of the deposit. For example, in a deep pit, such as Pit 1 at the Ranger Mine, a dished surface does not exist until after deposition ceases. At this time, tailings no longer progressively fill the area above the deeper parts of the pit where consolidation is greatest, and a ‘dish’ subsequently develops.

The technique, developed in 1987, is effectively a pseudo 3-dimensional consolidation model and is believed to pre-date other such models. Figure 5-26 compares the actual Pit 3 at the Ranger Mine with the "as-modelled" pit. The "annular" boundaries are shown on the figure.

Typical density profiles for an earlier Pit 3 consolidation analysis are shown in Figure 5-27. The figure shows density profiles at the end of deposition. The impact of the effective discharge rate is seen as the degree of consolidation being greater for tailings of lesser depth at the end of deposition.

Underdrainage

Underdrainage is introduced into the model by allowing for seepage forces and negative excess pore pressure. The various pore pressures for an under-drained deposit are presented in Appendix 5.3.

It should be noted that at equilibrium, provided a water pond is maintained at the surface and the underdrain remains operational, there will be constant flow from the surface to the base. At this time consolidation is complete and the flow is constant seepage. This concept is illustrated in Lambe & Whitman (1997: page 258, Figure 17.11).

Outputs

Program outputs include:

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

With respect to flows, the integrated flow out of the base of each "column", effectively determines the flow out of the base and sides of the pit.

Validation

The computer program was initially validated against a number of published examples (Townsend 1990). The Townsend paper presented the results of a number of scenarios whereby practitioners were invited to present solutions to the scenarios. All of the modelled scenarios resulted in excellent agreement.

The underdrain case was validated against a large-scale experiment carried out by Glenister & Cooling (1986). Again, the model showed excellent agreement and the author has been able to validate the model against many real applications including:

- Golden Cross Gold Mine New Zealand (Murphy 1997)
- Century Zinc Mine, Queensland (Murphy 2006)
- The Granites Gold Mine, Northern Territory (Murphy 2007)
- A coal mine in the Hunter Valley (Seddon & Pemberton 2015)

In these examples the model was able to predict:

- tailings elevation with time
- density profiles
- pore pressure profiles.

It should be noted that closure of Bullakitchie Pit (Murphy, 2007) at The Granites Gold Mine is featured as a case study in *Tailings Management: Leading Practice Sustainable Development Program for the Mining Industry* published by the Australian Government (2016). The original paper for this example was presented by the author at a conference in 2007.

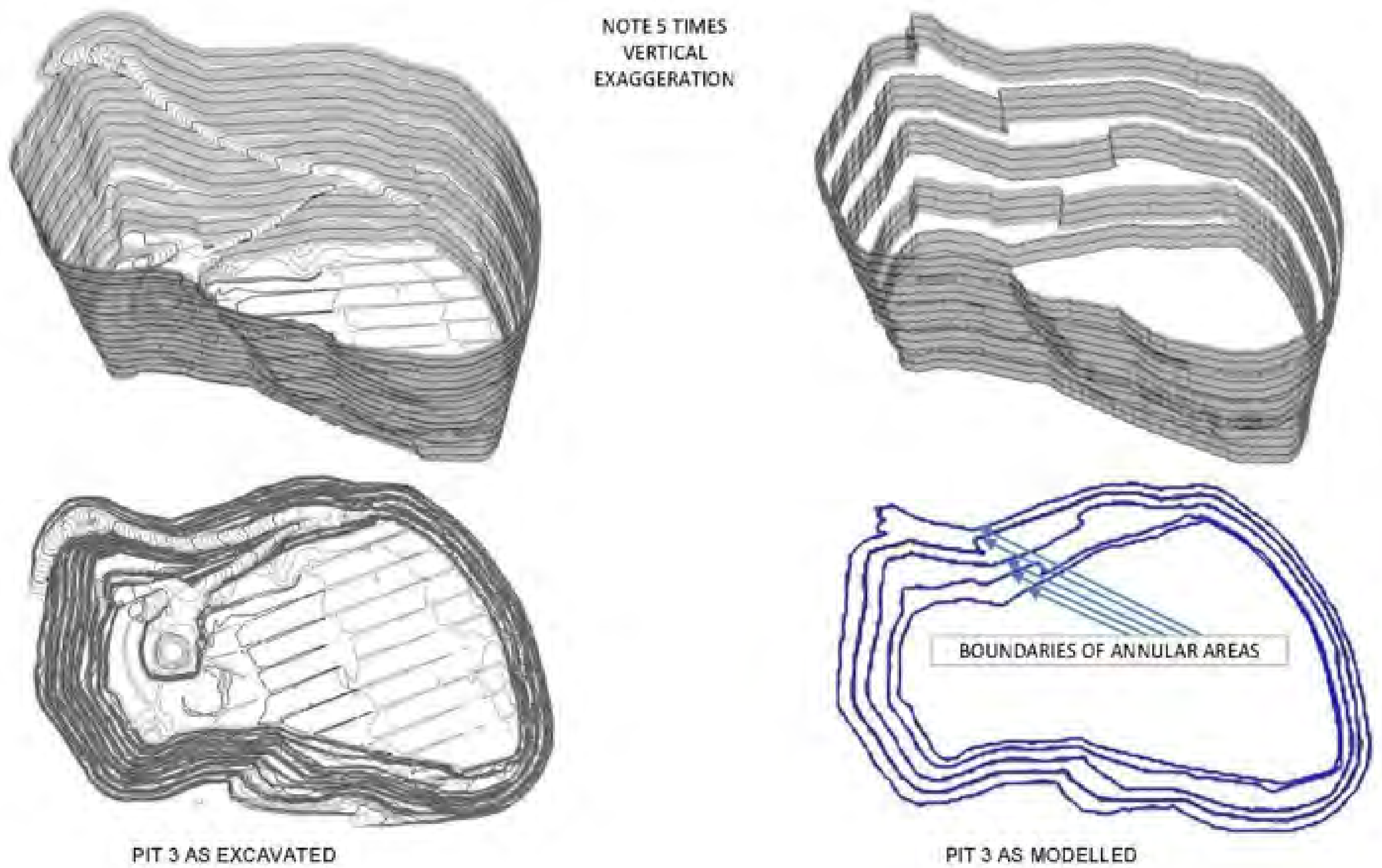


Figure 5-26: Pit 3 as excavated and as modelled

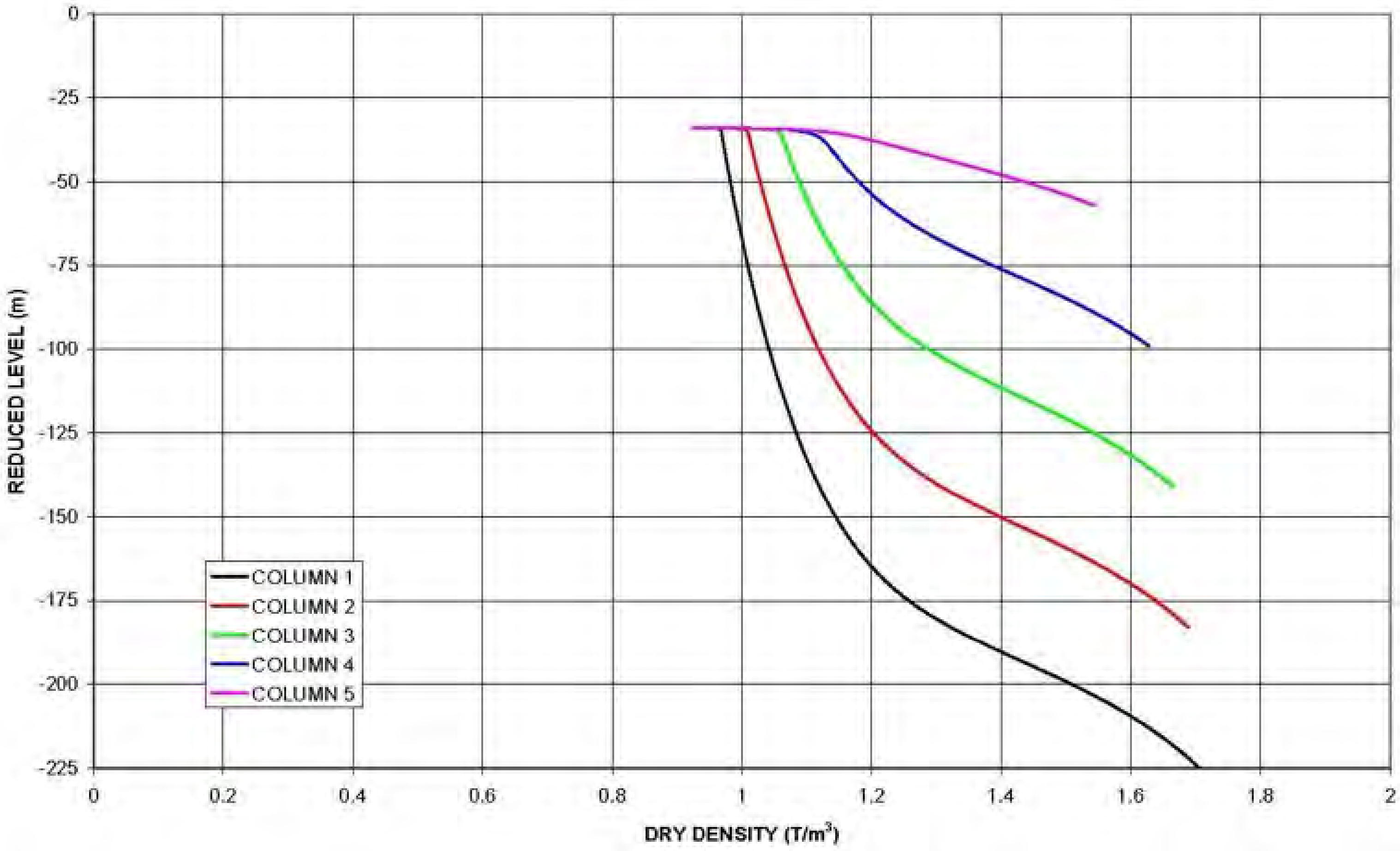


Figure 5-27: Pit 3 density profile - end of filling

5.1.3.5 Pit 1 tailings consolidation

Tailings consolidation modelling in Pit 1 has been ongoing since 2003. The Australian Tailings Consultants (2012) model predicted that the average final tailings level in Pit 1 would be 7.72 mRL with a minimum level of 0.5 mRL in the centre and approximately 12 mRL near the edges. This surface is presented as a contoured digital elevation model (DEM) in Figure 5-28.

In 2015 the Australian Tailings Consultants model was updated by Fitton Tailings Consultants (Fitton). The 2015 model assumed that the 2012 model was essentially correct but provided updates to some of the assumptions in the model (Fitton 2015a). The model also estimated the volume of expressed process water over time (Figure 5-29) and indicated that most process water (greater than 99 %) will be removed via the decant structures by January 2026.

Validation of the consolidation model is enabled by surveying 28 standpipes, attached to settlement monitoring plates, installed across the tailings surface prior to the placement of the initial capping. Validations were initially completed in 2017 and 2020, and then on a regular basis, following the completion of backfilling activities.

Consolidation in Pit 1 is determined by the standpipe survey measurements and presented in terms of average vertical settlement. Average vertical settlement is calculated through dividing the settlement volume by the tailings area (Fitton 2020). Figure 5-30 plots the corrected average vertical settlement from 2008 to April 2021 and compares it with the predicted settlement from the 2012 and 2015 consolidation models (Fitton 2020). This figure shows that measured settlement has generally followed the trajectory of the 2015 consolidation model, but the final settlement will be closer to the 2012 prediction than the 2015 prediction.

Changes in the rate of consolidation were driven largely by the timing of capping and backfill placement (Fitton 2020). This is shown in Figure 5-31, which compares cumulative backfill volume, with the progressive consolidation volume. Initially, tailings were consolidating under their own weight (quiescent consolidation) (Fitton 2020). This had largely plateaued by August 2013 when initial capping commenced (Fitton 2020). Initial capping was carried out until early January 2016 when about 2.8 m depth of fill, including 1 m depth of laterite, had been placed. At this time the rate of consolidation was tapering off. Placement of bulk fill commenced at a rapid rate on 10 May 2017 and the rate of consolidation increased. The rate of fill placement slowed between March 2018 and April 2019 and the rate of consolidation again plateaued. The rate of bulk fill placement increased again in May 2019 and the rate of consolidation increased again.

Following the completion of backfill activities in August 2020, Fitton made a prediction of the ultimate settlement value using methodology developed by Asaoka. The method uses the results from settlement monitoring to predict long term settlement and involves plotting, for a constant time interval, the previous settlement value against the current value (Fitton 2021a). The ultimate settlement is taken to be the point at which the plot intersects a 45- degree line passing through the origin (Fitton 2020). Figure 5-32 shows the settlement data plotted in accordance with the Asaoka method, predicting an ultimate settlement of approximately 4.52m.

Consolidation of tailings, in Pit 1, has proceeded in accordance with predictions (Fitton 2021b). Using the data from the settlement standpipes, and the surveyed tailings surface prior to backfilling, a DTM of the current tailings surface has been produced (Figure 5-33). The average tailings level, as of June 2021, was +7.75 mRL (Steven Murphy, personal communication, 12 January 2022). Based on the predicted ultimate settlement of 4.52 m the degree of consolidation at the time of the last survey is approximately 98 to 99% complete (Fitton 2021b & Steven Murphy, personal communication 5 July 2021).

With consolidation virtually complete, in July 2021 the standpipes were cut to just below the level of the landform, capped and buried. This process was completed to allow other rehabilitation activities to commence unimpeded. The location and height of the pipes was surveyed, so the monitoring system can be reinstated should the need arise.

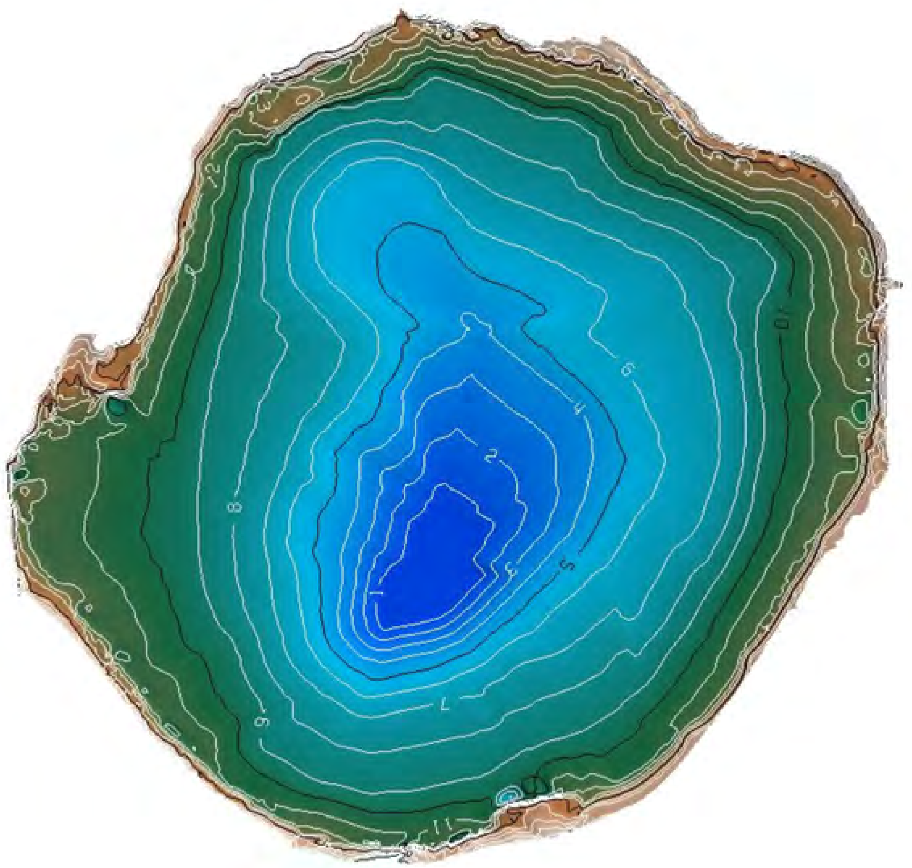


Figure 5-28: Predicted final tailings level (m) across Pit 1

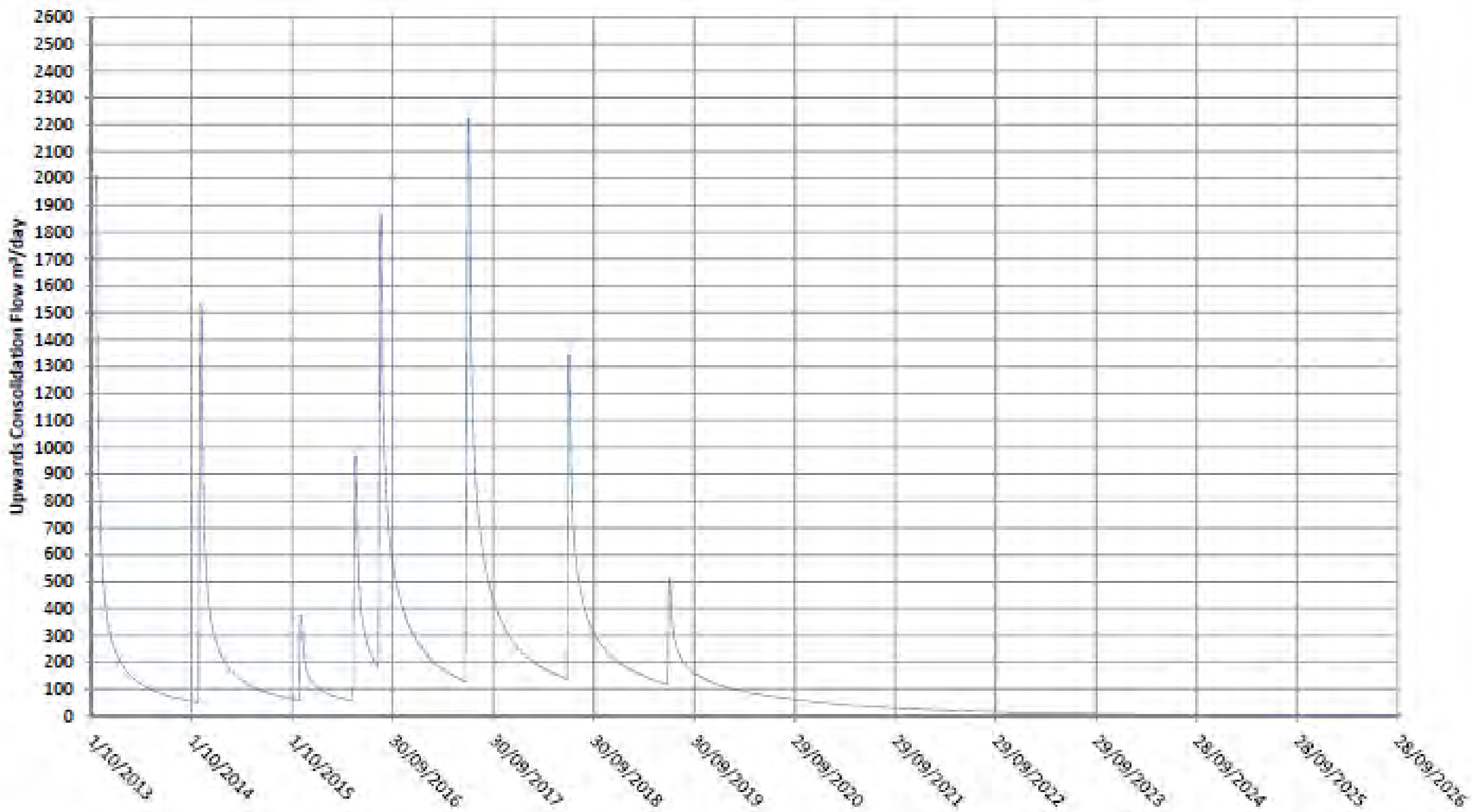


Figure 5-29: Predicted flow of process water from Pit 1 during consolidation (Fitton 2015, 2017; Figure 5)

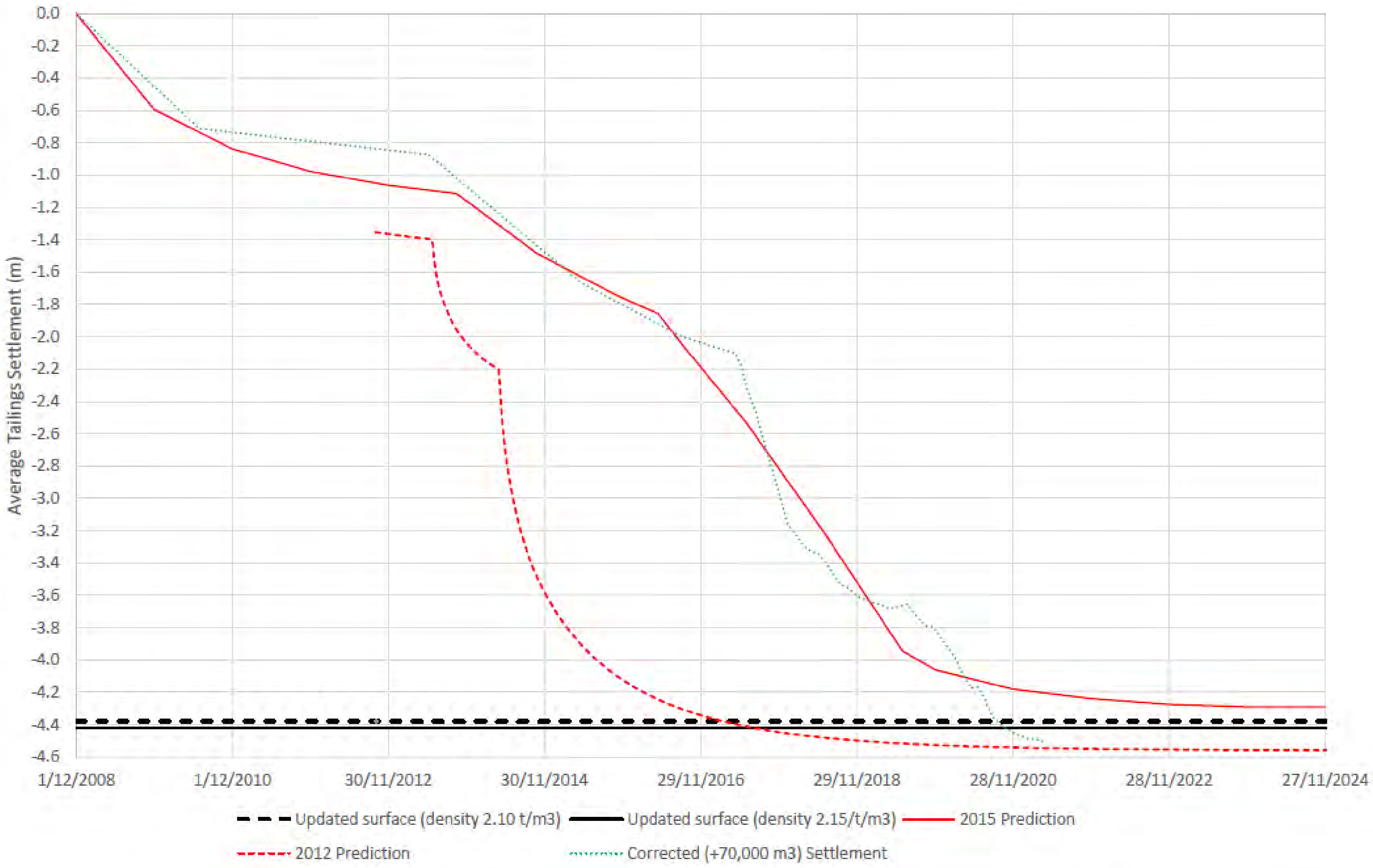


Figure 5-30: Predicted versus measured average tailings settlements in Pit 1

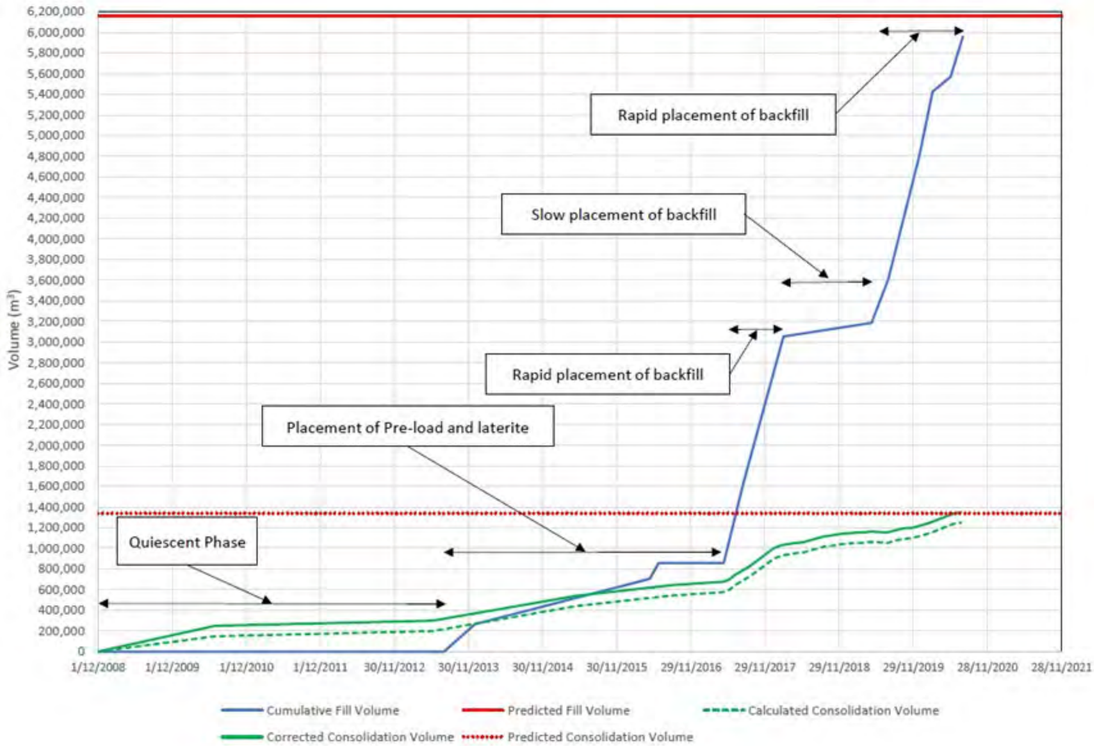


Figure 5-31: Cumulative backfill volume compared with the progressive consolidation volume (Fitton 2020)

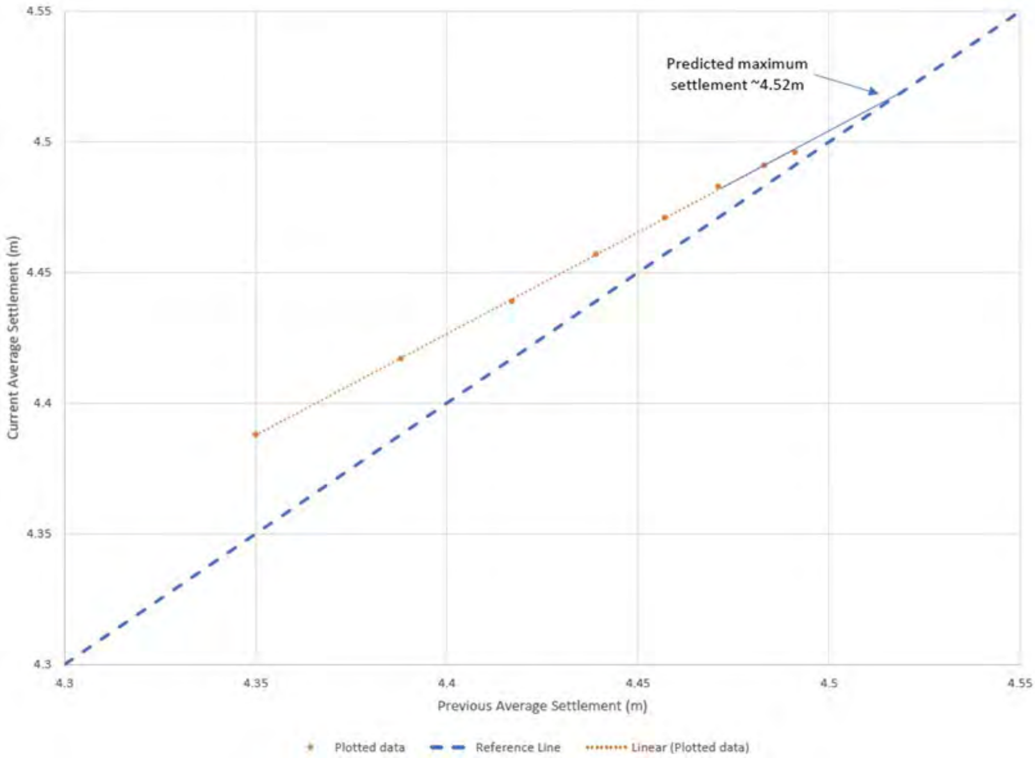


Figure 5-32: Settlement data plotted in accordance with the Asaoka method, predicting an ultimate settlement of approximately 4.52m (Fitton 2021a)

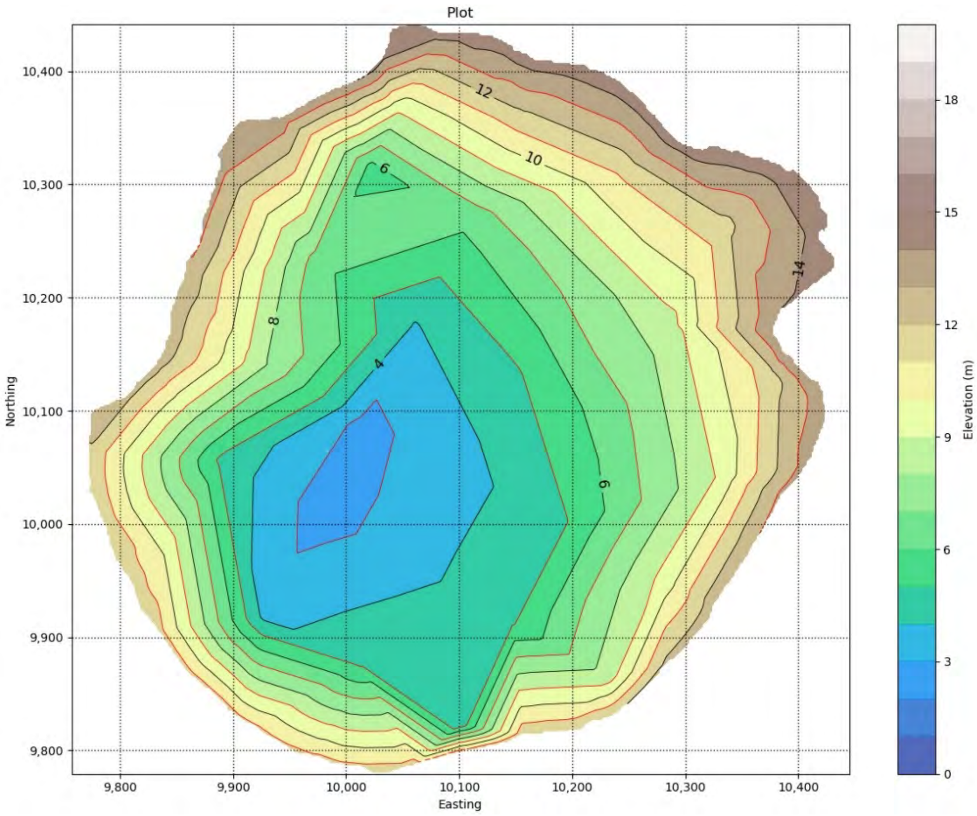


Figure 5-33: Calculated tailings surface as of May 2021 (Steven Murphy, personal communication, 1 June 2021)

5.1.3.6 Pit 3 tailings consolidation

ERA made a submission to the MTC in August 2014, describing the assessment of potential environments impacts from the interim final tailings level in Pit 3 (ERA 2014a). Included in this submission were the results of the predicted tailings consolidation; excerpts of which are provided below, along with the most recent updates of the tailings consolidation model.

Australian Tailings Consultants (2014) outlined the various field and laboratory studies they have conducted to confirm the tailings geotechnical properties and provide up-to-date parameters for the in-pit tailings consolidation modelling.

Testing indicated that the geotechnical properties of the Ranger Mine tailings have and will continue to vary with time, likely due to the inherent variability of the ore type and historical changes to the process. To account for this and provide a sensitivity analysis, three sets of consolidation parameters were considered in the modelling as follows:

- conservative (i.e. relatively slow consolidation) model - based on a Rowe Cell test of the reconstituted sample of pre-1996 TSF tailings and recent mill tailings
- best estimate model - based upon 'best fit' curves from Rowe Cell test results
- non-conservative (i.e. relatively fast consolidation) model - based on the consolidation process in Pit 1.

Consolidation modelling was conducted for all three parameters. Results demonstrated that consolidation could be achieved by 2026 for all cases. The consolidation model was updated to reflect the "as constructed" situation in early 2016 and was completed for the best estimate case only. The model was again updated in 2018, 2019 and 2020 to understand the impact of tailings segregation, tailings deposition, tonnes transferred and estimate the tailings surface over the deposition and post deposition phases. Results of the consolidation models are summarised in Table 5-13. It can be noted that, over time, the predicted end of deposition dry density has reduced from 1.42 t/m^3 to 1.30 t/m^3. This is due to a number of factors:

- The 2014 model was based on thickening the tailings after the first year; for all other cases the thickener was deleted from the closure plan;
- In the earlier homogenous model, the finer particles are trapped in the interstices of the coarser tailings leading to a lower overall volume;
- Segregation results in coarser tailings that are less compressible and finer tailings that are more compressible, but when fully consolidated, the combined overall dry density is lower;
- In the most recent case, due to a slower than expected dredging rate, the rate of deposition must accelerate with time to meet the closure date. The more rapid rate of deposition towards the end of deposition results in a lower final dry density; and
- In the most recent case, the mass of tailings is approximately 1.4 and 0.83 Mt more than the previous segregated models prepared in 2018 and 2019, respectively.

The latest (2020) model update considered two cases of wicking:

- Case 1 – The wicks fail after about six months due to kinking and clogging; and
- Case 2 – The wicks continue to operate though the closure period and beyond

The modelling indicates that consolidation will be practically complete by January 2027 and July 2025 for Cases 1 and 2 respectively. It should be noted that practical completion in this case means that 95 % consolidation has been achieved. It has since been identified in the water pathways risk assessment that a higher consolidation targe may need to be set (e.g. 97%), this is currently under evaluation and will be subject to stakeholder consultation and review during the Pit 3 backfill application and approval process. Figure 5-34 shows the flow of process water in Pit 3 estimated from the most recent model.

The Pit 3 consolidation model was used in the design of the Pit 3 tailings deposition plan implemented during operations phase and currently being used in the Pit 3 backfill and capping design. Additional details of these have been provided in Section 9.

The tailings consolidation model has also been used as input into the groundwater solute transport modelling undertaken by INTERA. A detailed assessment of the post-closure Mg loading to Magela Creek from Pit 3 tailings was undertaken to support the Pit 3 tailings deposition application, this study specifically considered the heterogeneous nature of the deposited tailings following consolidation.

Table 5-13: Summary of Consolidation model results

	Feb-14	May-16	Sep-18	Nov-19		Sep-20	
				Case 1	Case2	Case 1	Case 2
Average base level (RL m)	-100	-99.7	-99.7	-99.7	-99.7	-99.7	-99.7
Underfill/drain volume (m^3)	15,298,380	15,658,180	15,658,180	15,658,180	15,658,180	15,658,180	15,658,180
Tonnes	41,781,246	40,345,324	40,345,324	40,882,759	40,882,759	41,709,136	41,709,136
Deposition duration (yrs)	5.75	5.92	6	5.92	5.92	6	6
Thickening?	After year 1	No	No	No	No	No	No
Dry density - end of deposition (t/m^3)	1.42	1.39	1.35	1.38	1.31	1.30	1.30
Dry density - end of consolidation (t/m^3)	1.68	1.66	1.63	1.63	1.63	1.62	1.62
Average level -end of deposition (m)	-21.3	-21.53	-20	-19.8	-17.8	-16.2	-16.2
Average level - end of consolidation (m)	-31	-31.3	-30.3	-29.9	-29.9	-29.5	-29.5
Average cover depth (m)	48.64	48.94	50.93	50.3	50.3	50.2	50.2
Cover volume (m^3) **	25,292,800	25,448,800	26,534,530	26,204,815	26,204,815	26,523,188	26,523,188
Water expressed - during deposition (m^3)	14,707,410	21,938,520	16,860,080	?	?	13,647,631	13,647,631
Water expressed - post deposition (m^3) ***	4,370,360	4,721,000	5,163,690	4,454,068	6,126,766	6,395,879	6,395,879
Wick area (m^2)	238,235	416,216	145,000	?	?	145,000	145,000
Water expressed by wicks (m^3)	2,334,780	2,125,840	430,439	?	?	1,132,775	1,132,775
Consolidation complete	May-27	May-27	May-28	?	?	Dec-35	Dec-29
Consolidation practically complete****	Feb-25	Dec-24	Jun-25	?	?	Mar-27	Apr-25

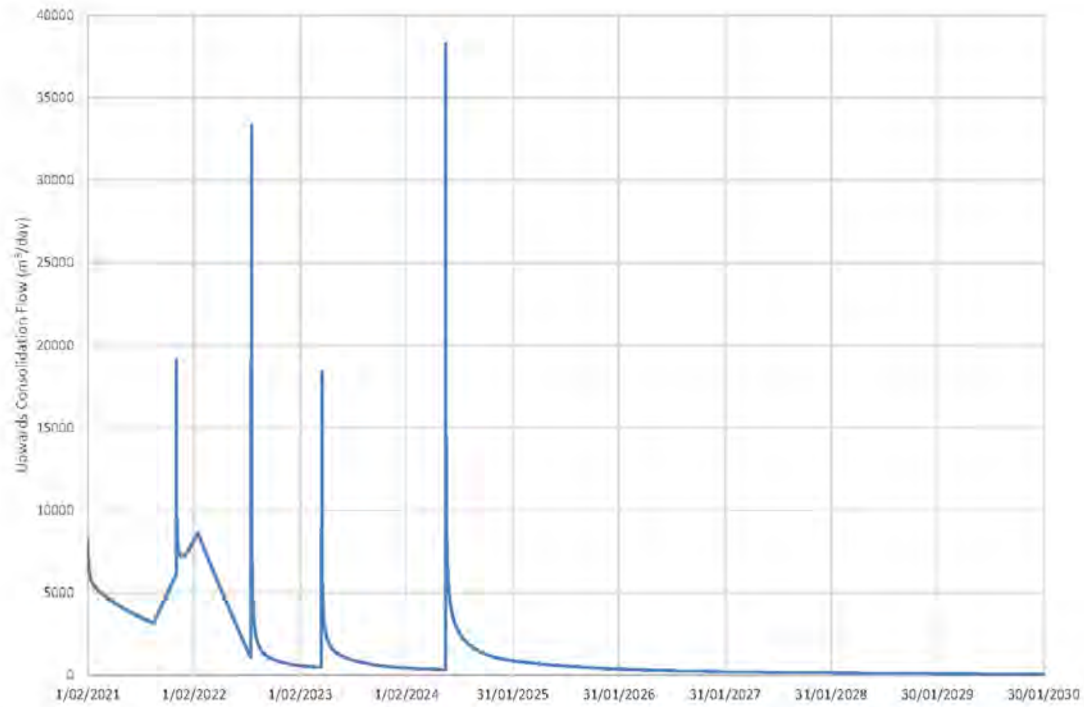
The number of decimal places presented in this table does not imply a level of accuracy. The numbers are presented to identify, sometimes, small differences in results.

**In previous reports volumes were based on an adopted pit edge. The volumes in this table for Feb 14 and May 16 are less than previously presented as they have been based on final tailings area in accordance with this report.

***Includes wick volume.

****Based on removal of 95% of mobile pore water.

? Not calculated for this analysis.



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ENERGY RESOURCES OF AUSTRALIA LTD

RANGER URANIUM MINE

Pit 3 Consolidation Update

Case 1 Post Deposition Upwards Consolidation Flow

Date:	1/09/2020	Job No:	1504.20	FIGURE 32

Figure 5-34: Typical predicted flow of process water from Pit 3 during consolidation

5.1.3.7 Tailings properties

Around 43 Mt of dry tailings from the mill and the TSF will be transferred to Pit 3 by November 2021. It was calculated that tailings would be deposited to a thickness of approximately 80 m and a volume of about 33.1 Mm^3. Section 9 provides details of tailings transfer activities.

Tailings transfer from the TSF 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:

- TSF geophysical surveys (Fugro 2012 and 2018)
- TSF magnetometer survey (Fugro 2012)
- Magnetic survey (Surrich 2019)
- TSF characterisation and cone penetration test (CPT) program (Shackleton 2013; in2Dredging 2020).

5.1.3.8 TSF Bathymetric surveys and geotechnical investigation

Prior to commencement of dredging and every quarter during the dredging operation a bathymetric survey was completed. The initial bathometric survey determined that there were 23.1 Mm^3 of tailings contained within the TSF. At the completion of bulk dredging in February 2021, 20.4 Mm^3 of tailings had been dredged to Pit 3. Typical survey results are presented in Figure 5-35.

Magnetometer surveys were conducted prior to and during dredging. These surveys provide magnetic intensity data from a towed magnetometer. The data from the 2019 magnetometer survey compared to that from 2012 is shown in Figure 5-36 The primary objective of the survey was to locate any potential buried iron objects which could impact proposed dredging operations.

As expected, 'magnetic' objects were identified close to the TSF embankments, whilst the central area was relatively free of anomalies. The magnetometer detected a very strong anomaly on the south-eastern side of the dam, believed to be the sunken remains of the old survey barge/pontoon. No other features of similar magnitude were found. Many anomalies, either localised or diffused, are likely to be caused by magnetic material in the tailings, accentuated by variations in the water depth that changes the range between source and detector. Small, localised anomalies, particularly around the TSF perimeter, probably represent iron debris.

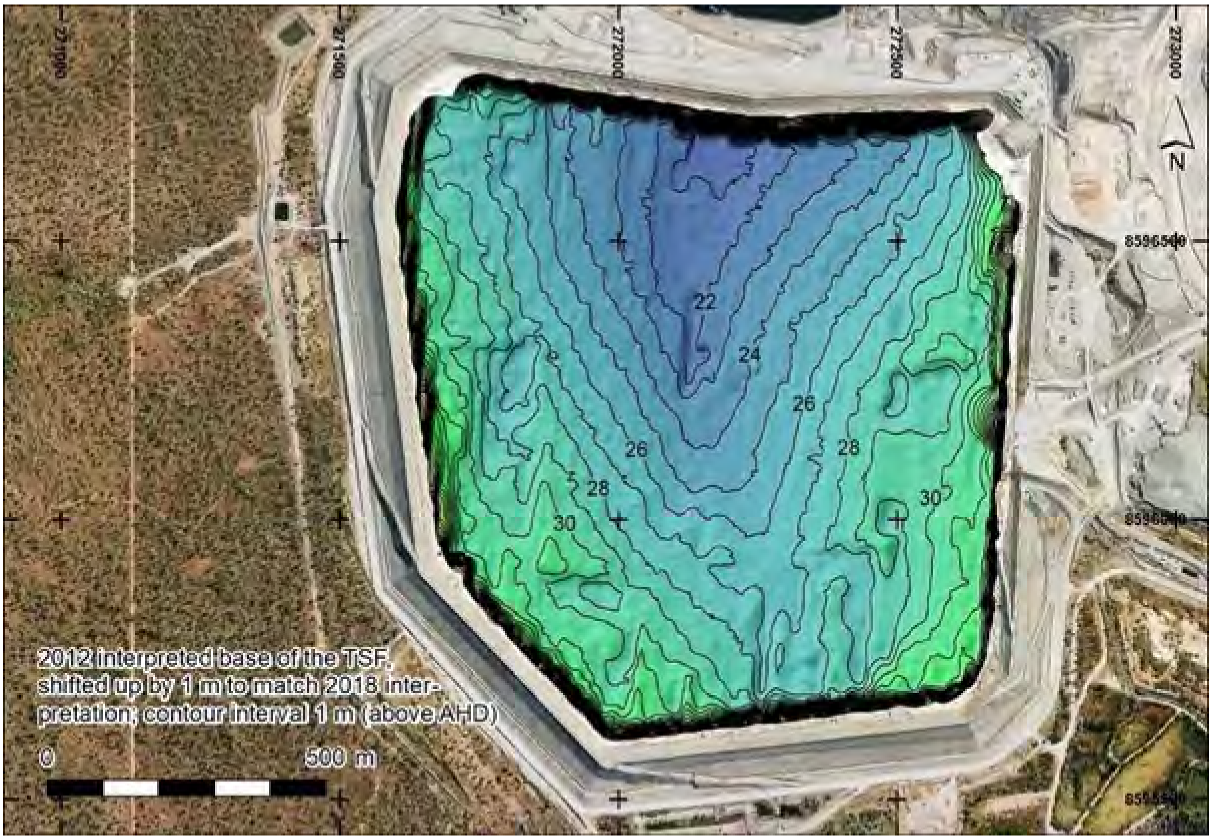


Figure 5-35: TSF topography (blue: low elevation; green: high elevation) (Fugro 2018)

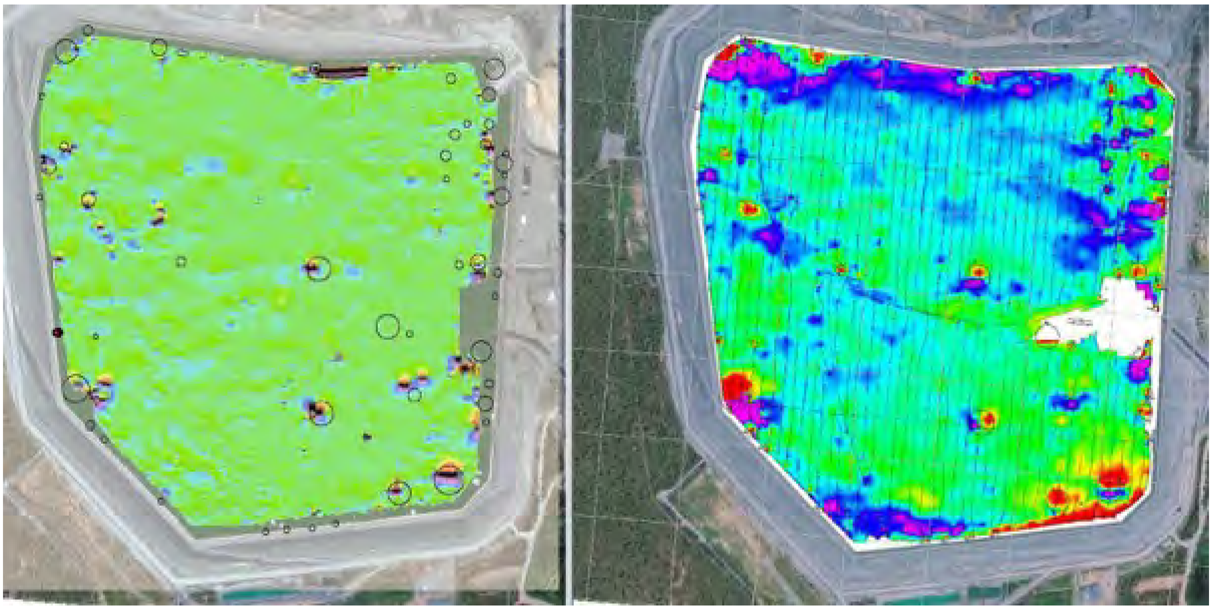


Figure 5-36: April 2019 Magnetic Anomaly Map (left frame) comparison with the 2012 Magnetic Anomaly Map (right frame)

Between 27 August and 25 November 2012, ATC Williams was assigned to undertake an investigation into the in situ condition of the tailings in the TSF (Shackleton 2013) to facilitate the selection of an appropriate dredge and pumping equipment, along with the design of a feasible work method. This work entailed cone penetrometer tests and tailings sampling (Figure 5-37).

The data analysis from the CPTs, laboratory results and onsite observations indicated two separate zones within the TSF:

- an outer zone comprising of sands and silty sands, overlying a sandy layer, followed by the foundation on the perimeter of the TSF in shallower water.
- an inner zone of under consolidated fines of very low strength, overlying a sandy layer, followed by the foundation, located within the deeper sections of the TSF (Shackleton 2013; p 11).

The outcome of the TSF geophysical and magnetometer surveys validated the expected tailings volumes and provided valuable knowledge on the segregation and characterisation of tailings in the TSF. These studies together with the CPTs assisted the overall design of the TSF dredge and subsequent dredging method. Additional geotechnical investigation was carried out in the TSF by in2Dredging (May 2020) to augment the previous investigation conducted by Australian Tailings Consultants (2012). It involved CPT, vane share test (VST), and tailings sampling. The study determined the undrained shear strength of the tailings and the approximate floor of the TSF to optimise the use of the two dredges, Brolga and Jabiru (In2Dredging 2020).

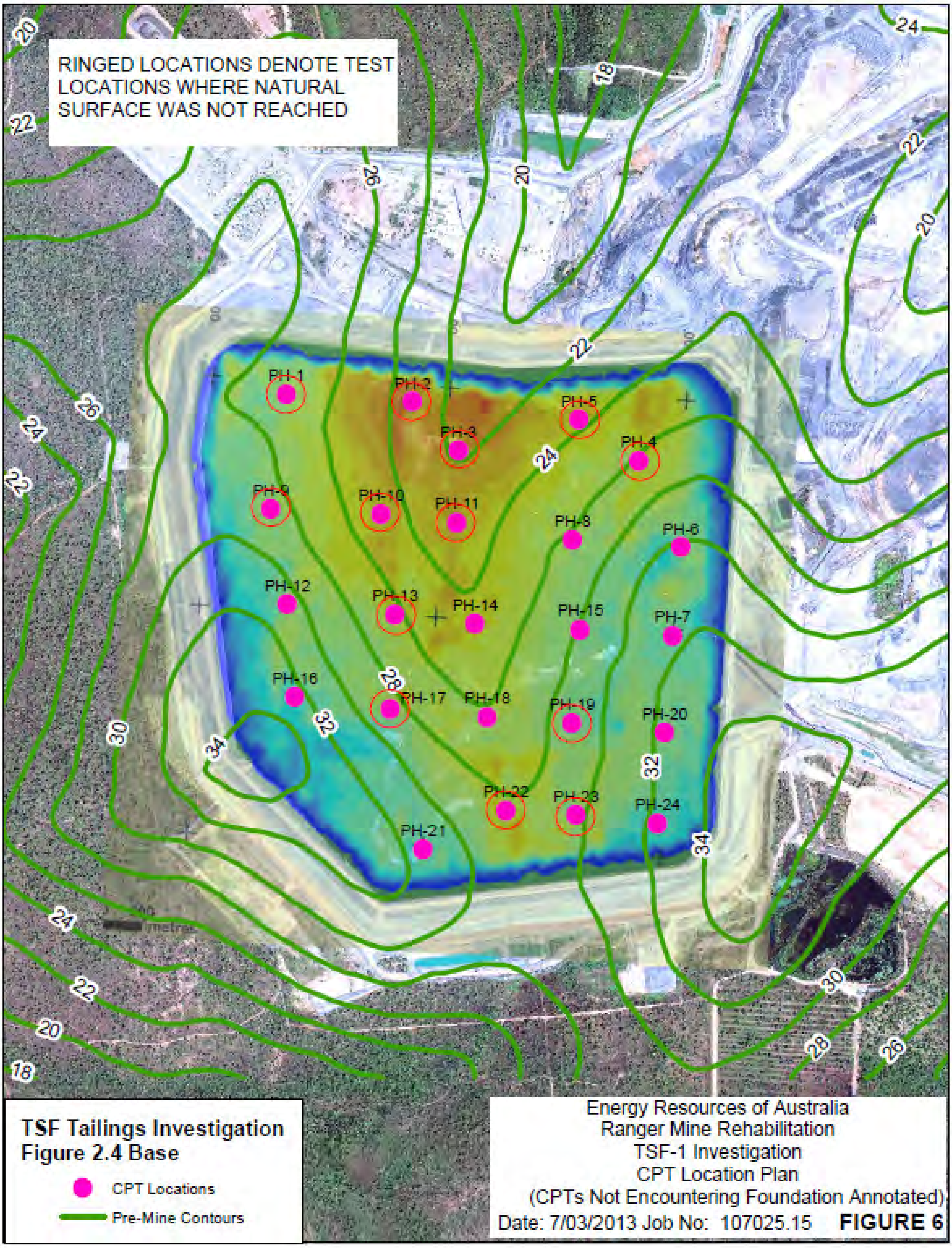


Figure 5-37: Cone penetration locations (Shackleton 2013)

5.1.3.9 Pit 3 geotechnical investigation

Geotechnical investigations were conducted in Pit 3 in 2018 (Fitton 2019), 2019 (Fitton 2020b) and 2020 (Fitton 2021) to verify the consolidation model. The 2020 investigation involved CPT, pore pressure dissipation test, tailings sampling, and VST at locations shown in Figure 5-38. A few test locations from 2018 and 2019 investigations were re-tested to understand how the fine tailings consolidation was occurring. Details of the 2020 CPT is summarised in Table 5-14.

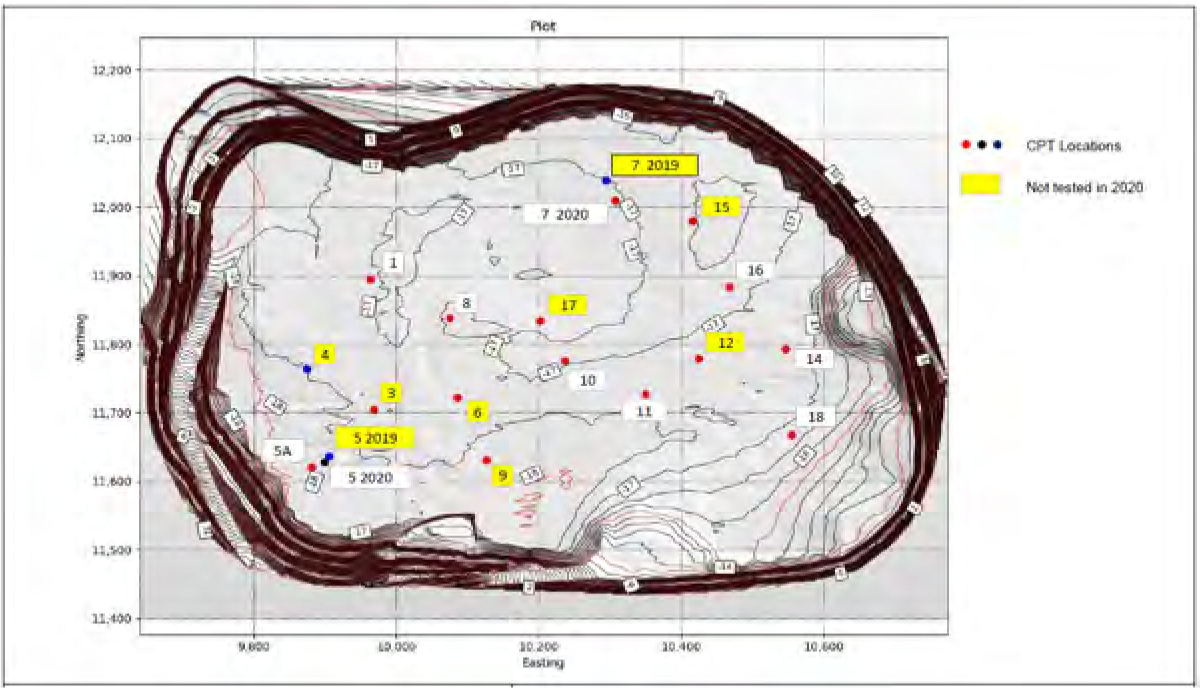


Figure 5-38: CPT Locations

Table 5-14: Details of 2019 CPT

Location	Date	Water RL (m)	Water Depth (m)	Top of Tailings (m)	CPT Depth (m)	Base RL (m)	RL Reached (m)	Operator	Location E	Location N
1	16/10/2020	-18.17	0.90	-19.07	79.86	-97.88	-98.03	David Chapman	273711	8597984
5	21/11/2020	-16.33	2.25	-18.58	59.86	-75.33	-76.19	David Chapman	273625	8597713
5A	14/02/2021	-9.93	7.80	-17.73	51.38	-63.06	-61.31	Russell Vincenzi	273606	8597707
7	14/12/2020	-14.71	3.75	-18.46	64.30	-97.49	-79.01	David Chapman	274065	8598055
8	21/10/2020	-18.09	1.28	-19.37	80.58	-100.03	-98.67	David Chapman	273823	8597904
10	28/11/2020	-15.75	2.30	-18.05	60.45	-99.51	-76.20	Russell Vincenzi	273975	8597828
11	5/12/2020	-15.08	2.90	-17.98	55.96	-99.01	-71.04	Russell Vincenzi	274077	8597773
14	8/12/2020	-14.92	2.98	-17.90	43.10	-98.23	-58.02	Mitch Ebrington	274274	8597817
16	16/11/2020	-16.88	1.00	-17.88	41.40	-98.20	-58.28	David Chapman	274208	8597919
18	12/12/2020	-14.81	1.90	-16.71	42.96	-98.25	-57.77	David Chapman	274281	8597695

It is noted that only 2 out of 10 probes reached the base of the pit – the target depth. This is due to the very challenging conditions within Pit 3. Typically, there is a considerable depth of very soft under consolidated tailings overlying consolidated tailings. The soft tailings provide no lateral support to the rods resulting in potential, and actual, buckling of the slender rods used to advance the CPT cone. Buckling can occur when consolidated tailings are encountered at depth. This can be overcome, to a certain extent, by driving casing when lateral deflection is observed to commence. Unfortunately, this did not always alleviate the issue as tailings within the casing caused binding of the rods and buckling still occurred.

The CPT data was analysed with software package (CPet-IT), provided by Geologismiki. The software can draw on the results of laboratory testing to enhance the estimation of soil behaviour type (SBT), which is different from soil classification usually based on index testing including particle size distribution and Atterberg Limits and is often referred to as textural based classification. The CPT software classifies a soil based on correlations of soil behaviour type, not textural classification. For example, a soil may classify as silt, but its SBT may be more like sand. The SBT of the tailings encountered are grouped into two:

- Group 1 (Probes 1, 5, 5A, and 8, on the west of the Pit): It consists predominantly of finer tailings over the full depth of the probes. The tailings are initially classified as fine-grained sensitive due to zero or near zero friction sleeve reading. At depth, the friction sleeve reading increases and the tailings behave as clay and silty clay.
- Group 2 (Probes 10, 11, 14, 16 and 18, on the east of the Pit): In this group, the finer tailings behave in a similar way to the fines in group 1 until coarser tailings are encountered. The tailings below the fines behave as sandy silt and silty sand with thin bands of clean sand.

Typical SBT profile for Group 1 and 2 are presented in Figure 5-39 and Figure 5-40, respectively. The SBTs are one piece of evidence that confirms the tailings deposition model adopted for the consolidation analysis.

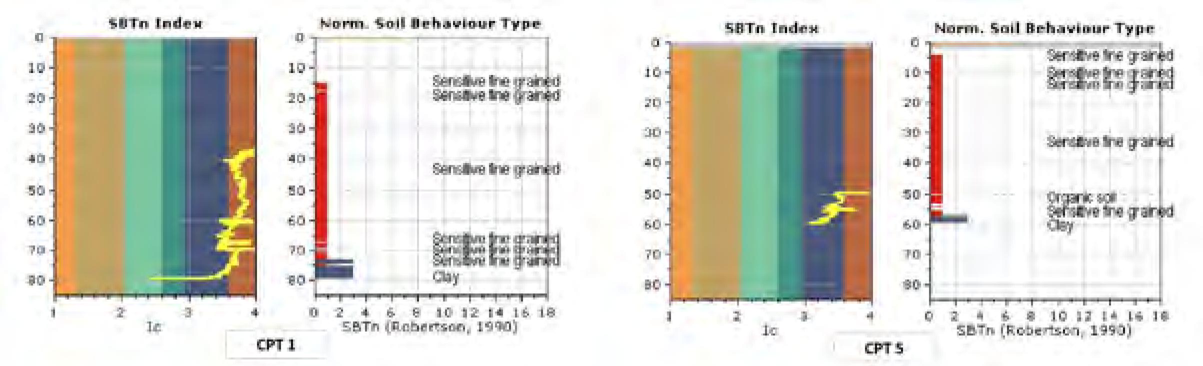


Figure 5-39: Group 1 SBT profile on the west of the Pit

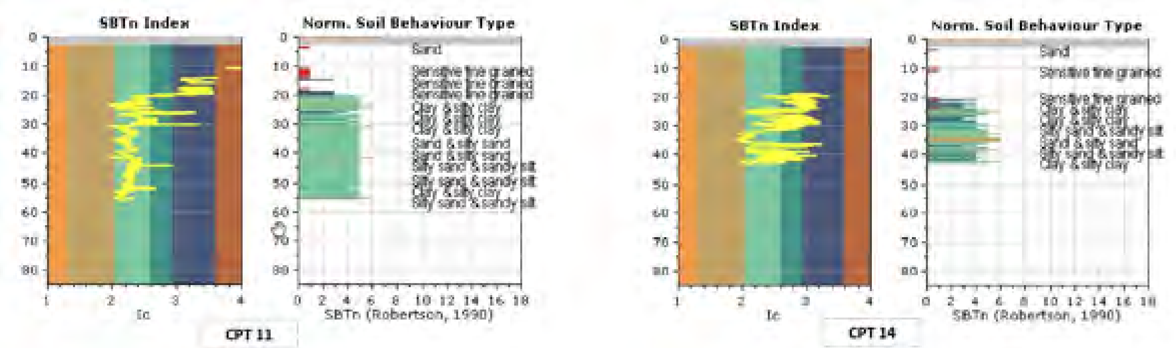


Figure 5-40: Group 1 SBT profile on the west of the Pit

The west, is greater than that obtained from the 2018 and 2019 (Figure 5-41), indicating that the in-situ density and undrained shear strength of the tailings have increased and thus pore pressure dissipation and hence consolidation of the tailings has occurred.

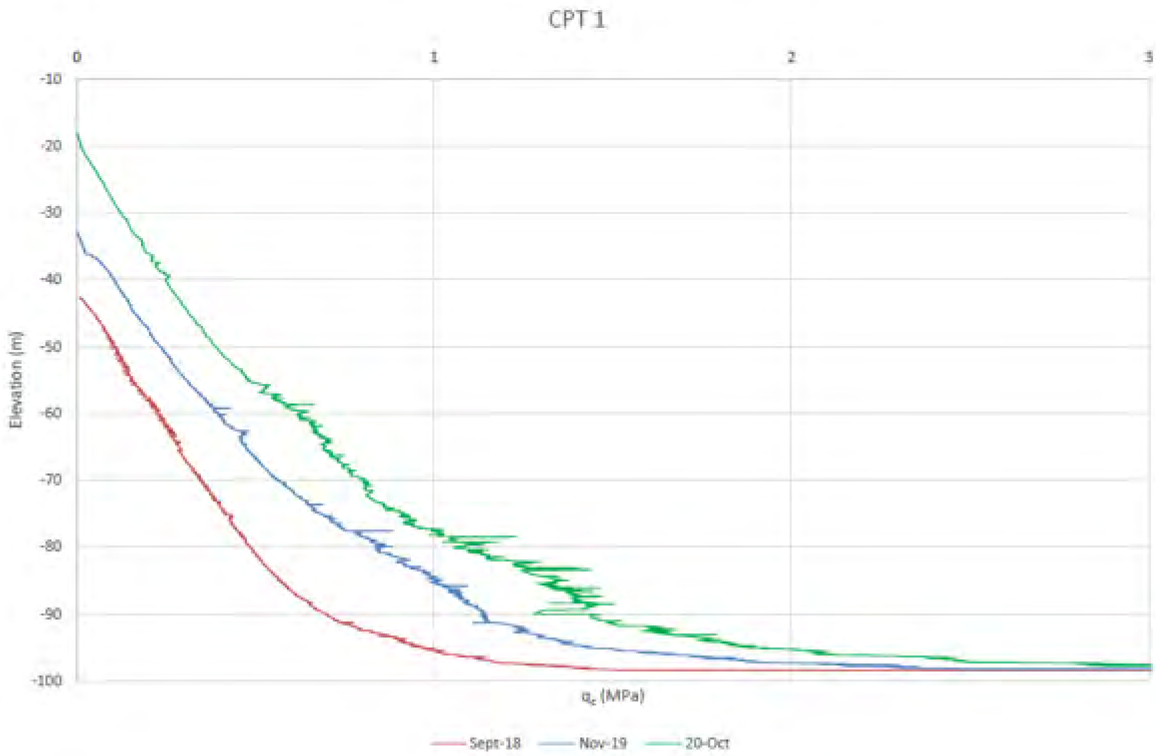


Figure 5-41: Typical 2018/2019/2020 cone resistance comparison

Some of the output from the consolidation model are the fine/coarse tailings boundary and excess pore pressure profile which are compared with the *in-situ* data in Figure 5-42 and Figure 5-43, respectively. It is noted that the measured excess pore pressure profile and fine/coarse tailings interface closely agree with those predicted by the consolidation model. An update of the consolidation model is occurring following the completion of trucked deposition of remnant tailings from the above ground TSF floor into the Pit.

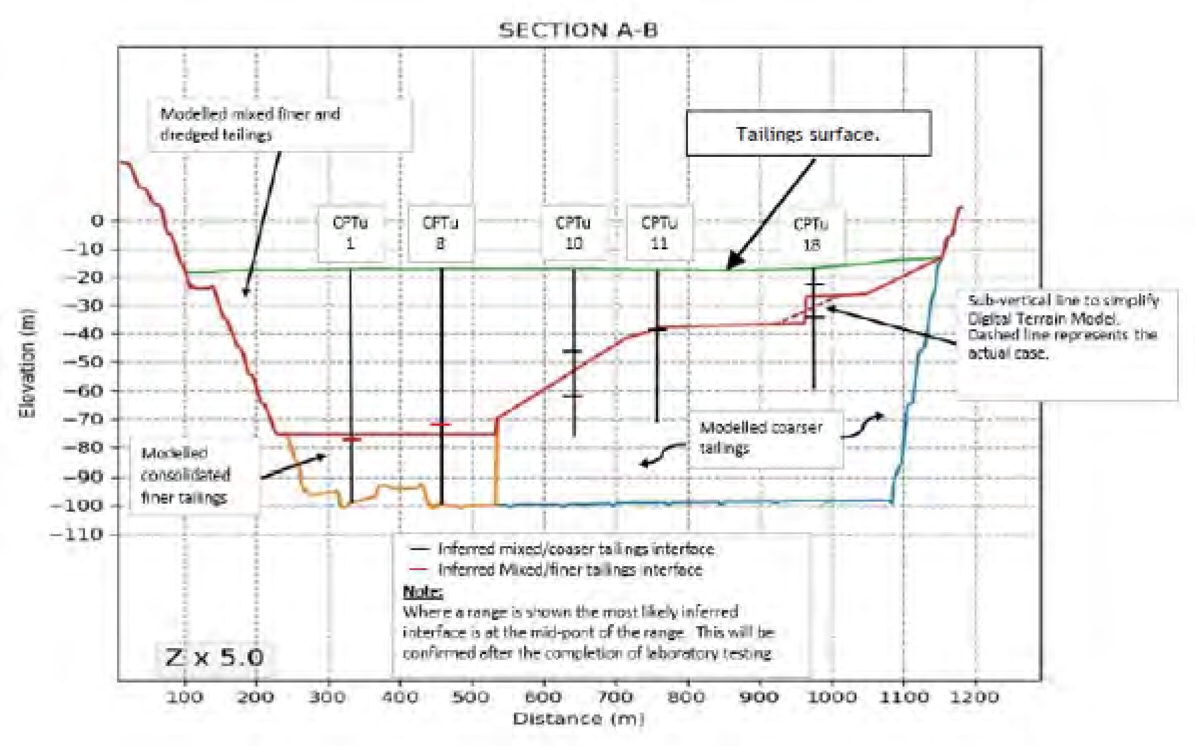


Figure 5-42: Predicted versus measured fine/coarse tailings interface

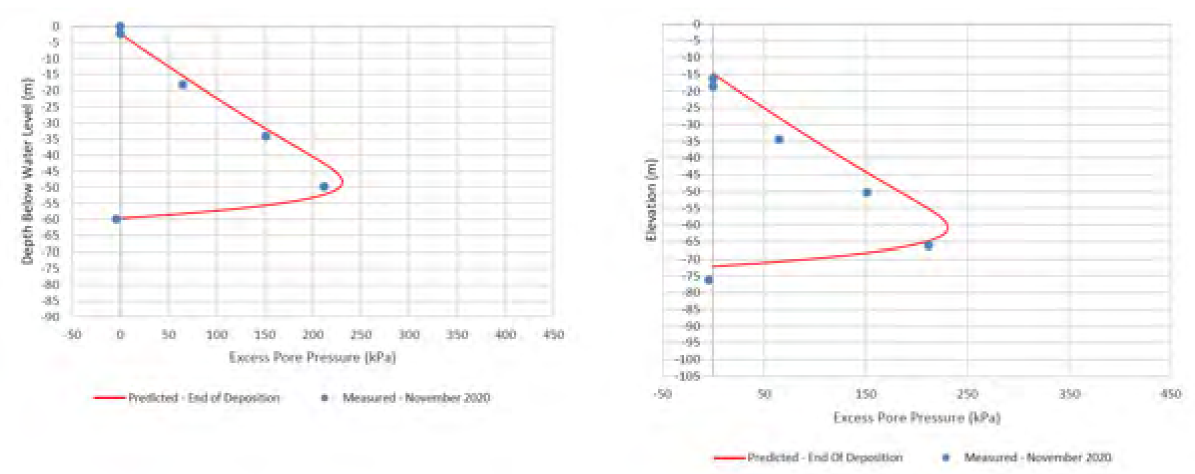


Figure 5-43: Measured versus predicted excess pore pressure profile

The 2022 CPT program was carried out from January to March, following completion of the remnant tailings transfer described in detail in Section 9, in December 2021. The aims of this program were to:

- Determine the impact that the deposition of remnant tailings had on the consolidation of tailings already in Pit 3; and
- Investigate the condition of the tailings in the vicinity of the proposed eastern platform to determine whether the area is suitable for construction (Fitton 2022).

This section describes the parts of the CPT program concerned with determining the impact of the remnant tailings placement on consolidation. The investigative works carried out in the vicinity of the proposed eastern platform are described in Chapter 9.3.2.2, as this program is more aligned with the implementation of Pit 3 closure activities.

CPTu probes 1, 5, 8, 10 and 11 were performed at the locations of previous investigations to compare results from the recent and earlier probes. These locations are provided in Figure 5-44.

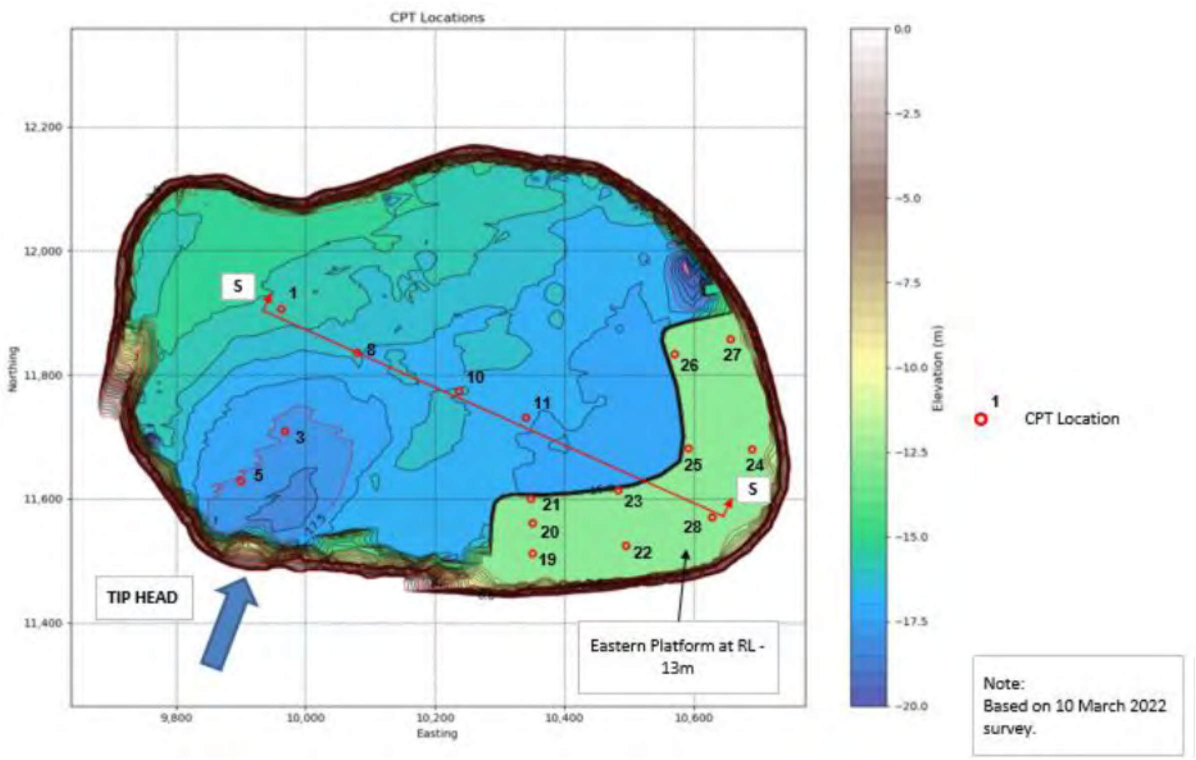


Figure 5-44: CPTu probe locations in relation to the Pit 3 tip head and proposed eastern platform

Cone resistance at common elevations, for all locations, has increased with time (Figure 5-45). This provides basic confirmation of ongoing consolidation (Fitton 2022). Locations 3 (Figure 5-46) and 5 (Figure 5-47) have been impacted by remnant tailings deposition. These locations show significantly higher cone resistance over very small depth intervals, likely a result of rocks entrained in the remnant tailings (Fitton 2022).

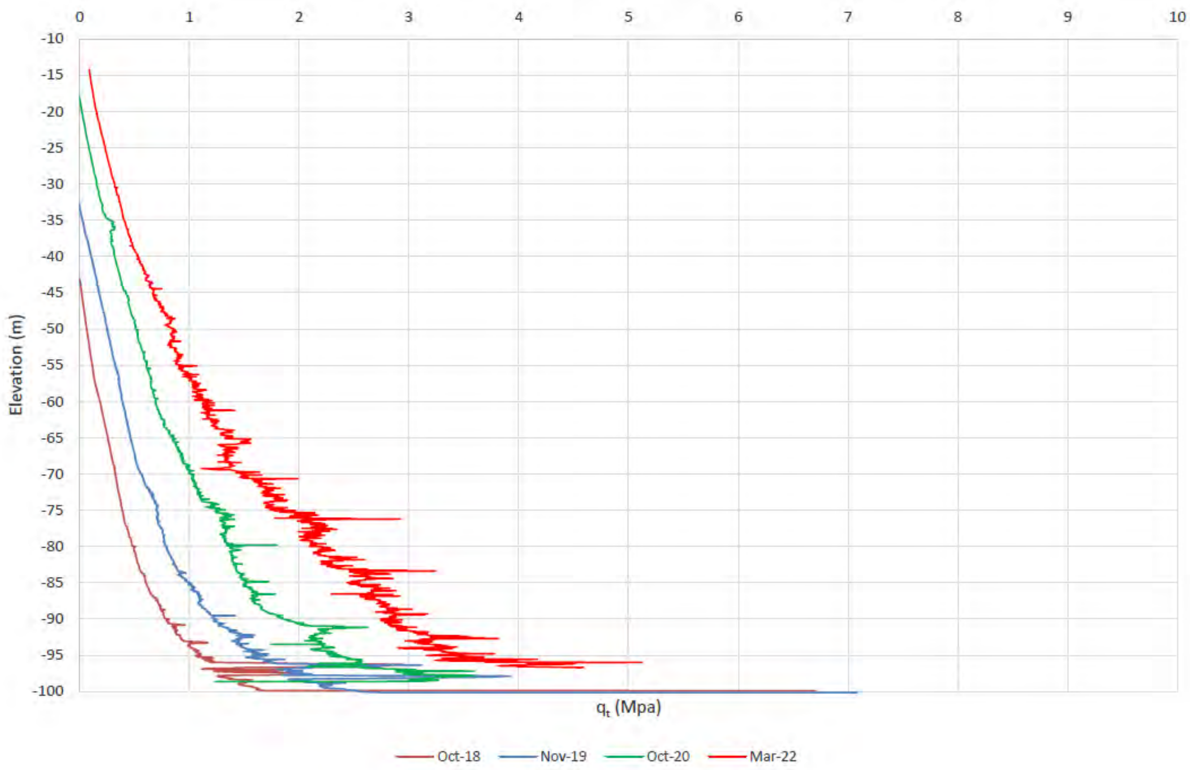


Figure 5-45: Comparison of corrected cone resistance at location 8

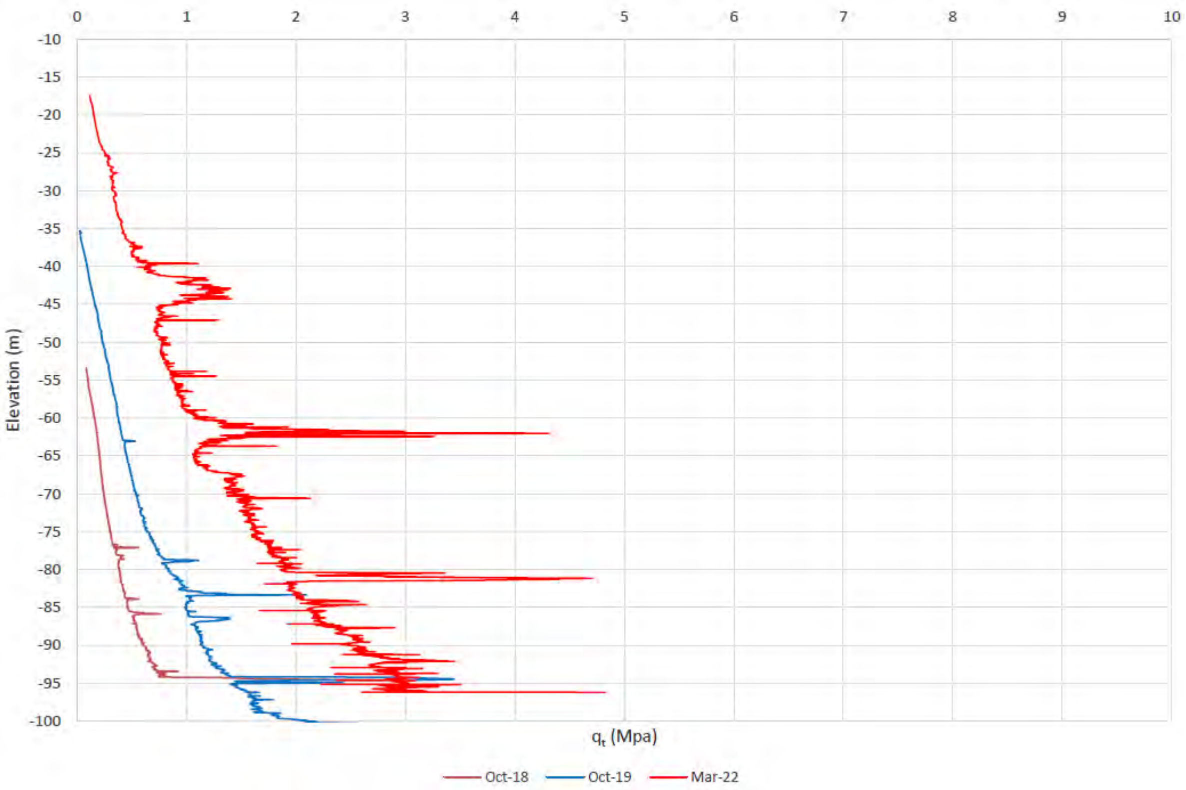


Figure 5-46: Comparison of corrected cone resistance at location 3

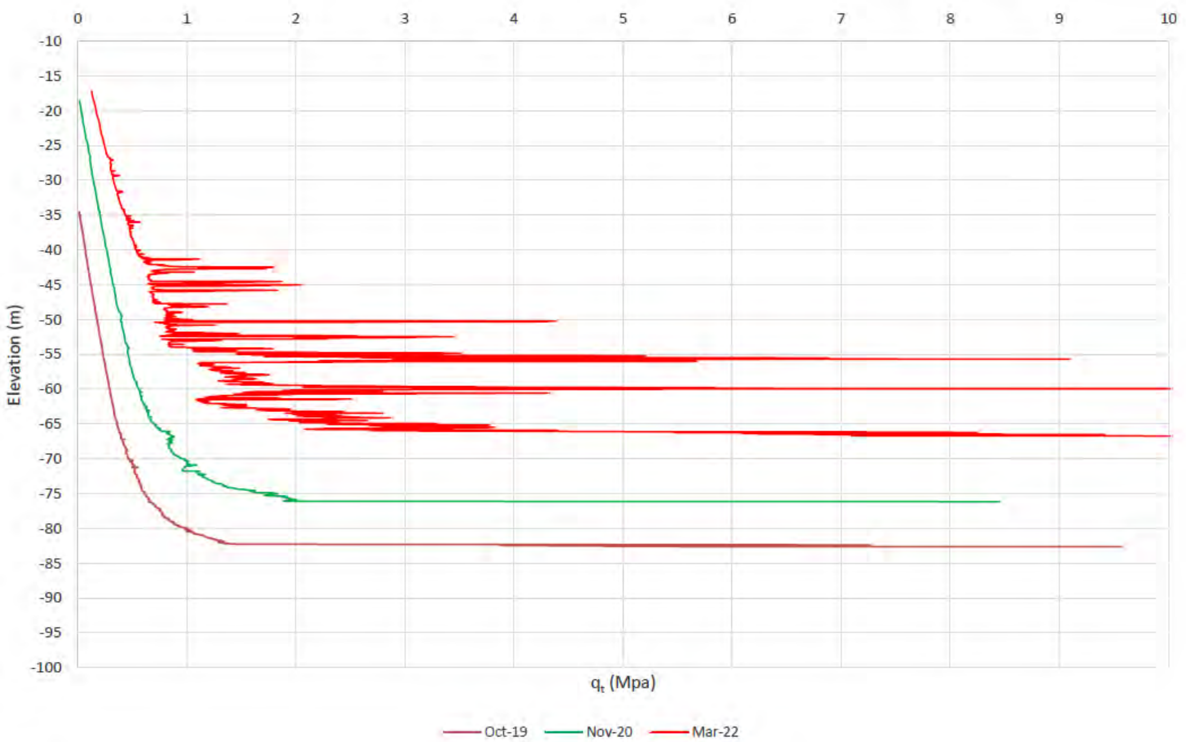


Figure 5-47: Comparison of corrected cone resistance at location 5

Excess pore pressures at locations 1, 8, 10 and 11 are largely unchanged (Figure 5-48). However, the excess pore pressures at location 5 (Figure 5-49) have increased considerably since late 2020 and the excess pore pressures at location 3 (Figure 5-50) are considerably higher than those predicted by consolidation modelling in 2020. Given that the 2020 predictions were generally accurate, it is likely that the excess pore pressures at location 3 are higher than would have been measured in 2020 (Fitton 2022).

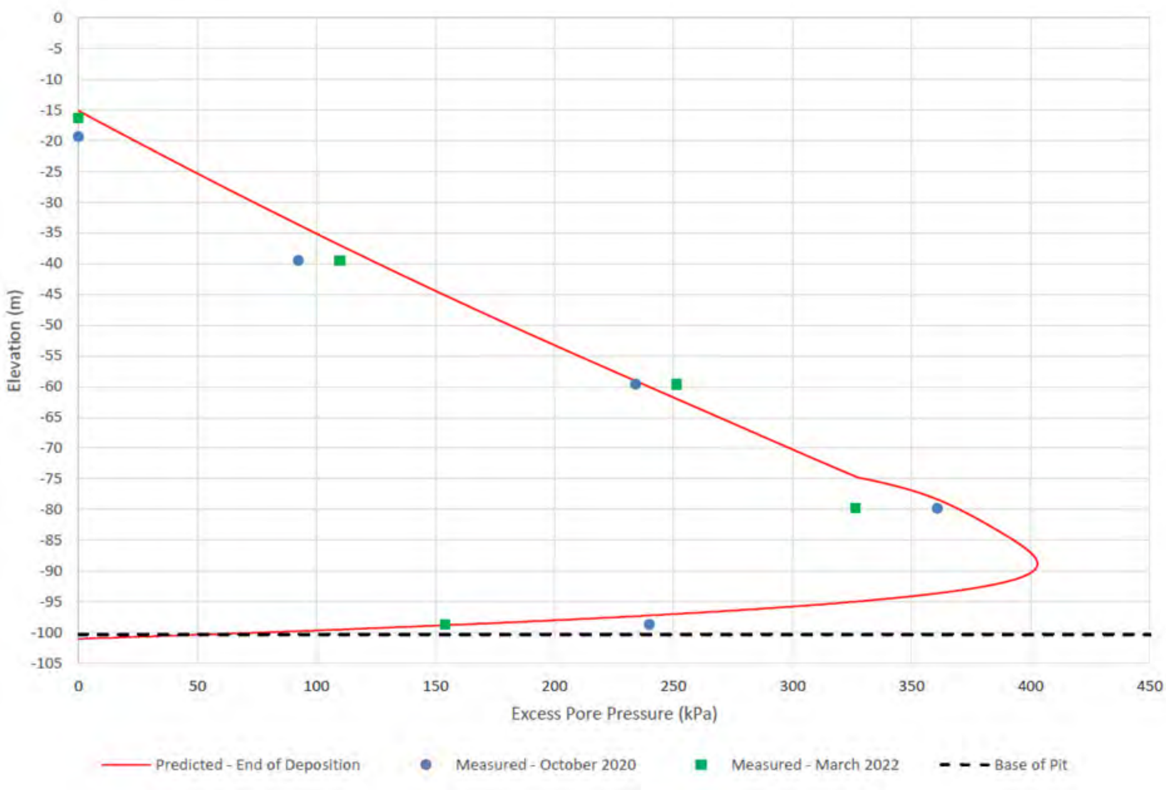


Figure 5-48: Comparison of excess pore pressures at location 8

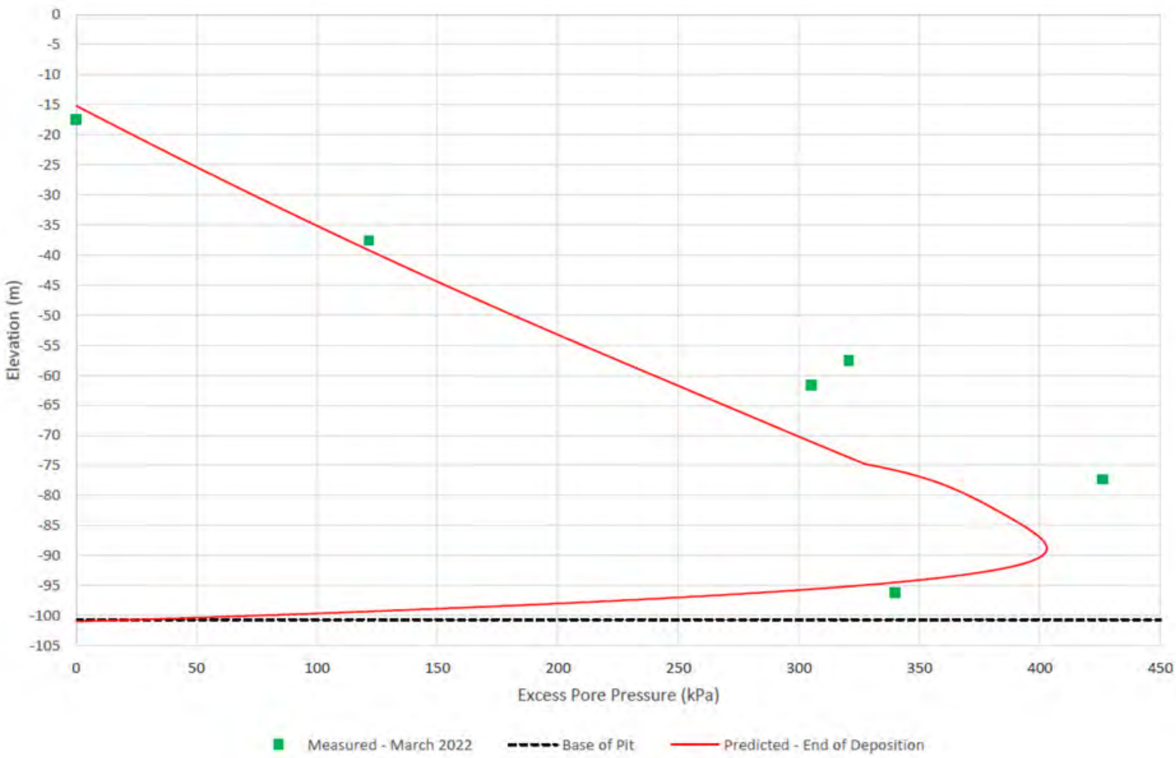


Figure 5-49: Comparison of excess pore pressures at location 3

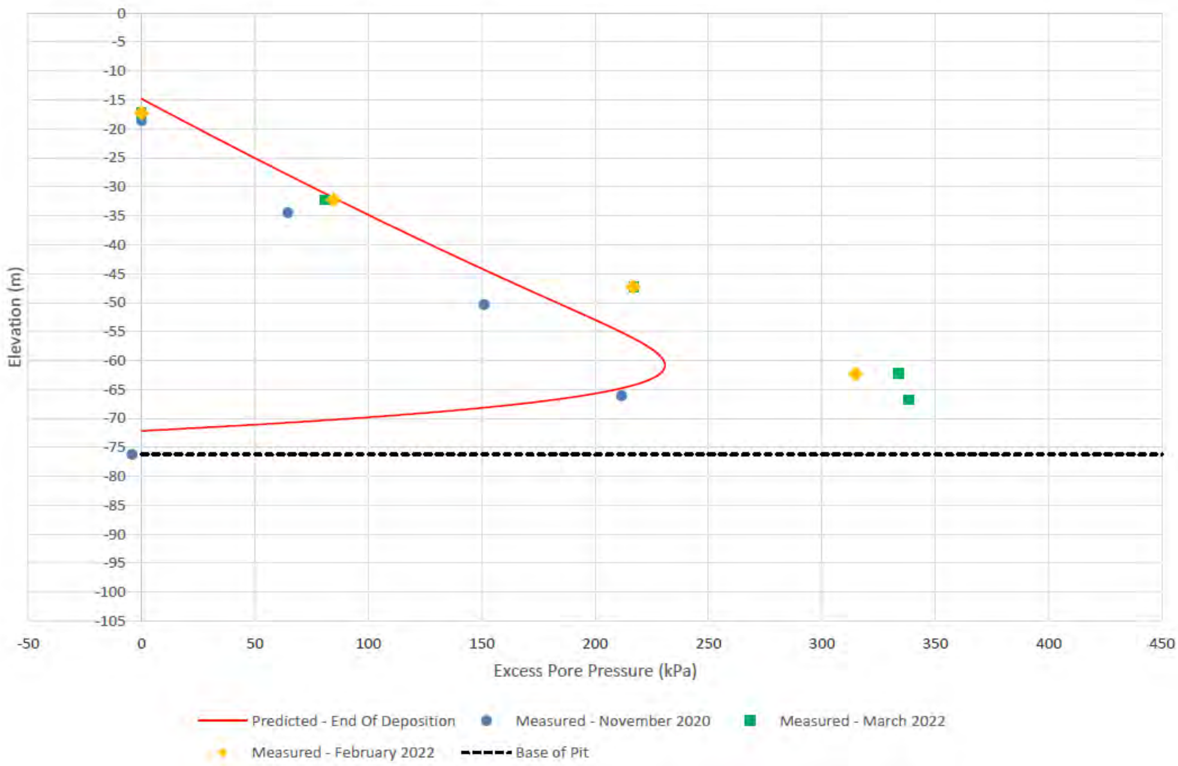


Figure 5-50: Comparison of excess pore pressures at location 5

The variable cone resistance response and increased excess pore pressures at locations 3 and 5 indicate that the impact of remnant tailings deposition is localised to the area in the vicinity of the tip head (Fitton 2022). The increase in excess pore pressure is due to the relatively rapid rate of tailings deposition (Fitton 2022).

This localised impact is supported by the results of the regular bathymetric surveys. These surveys indicate a general depression near the tip head and heave of the finer tailings radiating out from the tip head (Fitton 2022). The elevated coarser tailings in the south-east corner of the pit have been unaffected by TSF tailings deposition (Fitton 2022).

The Fitton (2022) report concluded that the placement of the residual TSF tailings in Pit 3 will have no impact on long term consolidation or closure of the pit.

5.1.3.10 Pit 3 geophysical surveys

Geophysical surveys were conducted in Pit 3 during 2018, 2019 and recently in 2021 by Fugro Australia Marine Pty Ltd (Fugro). The surveys determined the tailings distribution, including fine/coarse tailings interface, and their quantity within the pit as well as the quantity of water. The 2020 campaign comprised a bathymetric and seismic surveys. The bathymetric survey included Single Beam Echosounder (SBES) and the seismic survey included single channel seismic reflection (Boomer), sub-bottom profiling methods (Chirp) and parametric profiling. The volumes of tailings and water in the pit, established from the 2020 campaign are summarised in Table 5-15 and their surfaces are presented in Figure 5-51.

The volume of water, total tailings and total pit fill, estimated during the investigation, is 7.15 Mm^3, 31.66 Mm^3 and 38.77 Mm^3, respectively. The volume of water has increased from 0.55 Mm^3 to 7.17 Mm^3, and tailings from 24.19 Mm^3 to 31.66 Mm^3 since the last survey in 2019. It should be noted that the results from the geophysical surveys are used to augment the geotechnical investigation (CPT) data, especially the fine/coarse tailings interface and volume or mass ratio, to verify the consolidation model.

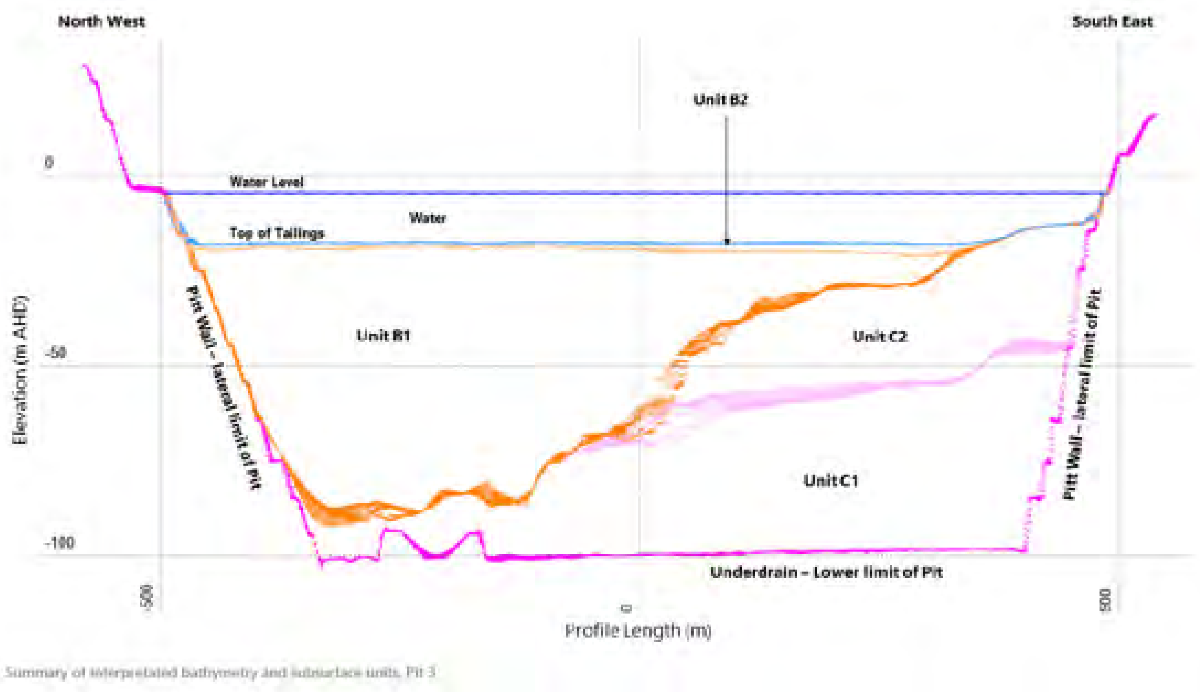


Figure 5-51: Cross section of tailings and water within the Pit

Table 5-15: Summary of Geophysical survey

No.	Volume	Est. Quantity [Mm^3]	Comment[A]
1	Total Pit Fill	38.77	The total pit fill volume estimated between the upper boundary provided by the water level (dark blue) and the lower boundary provided at the base of unit C1 by the Pit Shell and Underdrain (pink)
2	Water	7.15	The volume estimated between the upper boundary provided by the water level (dark blue) (-4.616 m AHD) and the lower boundary provided by the bathymetry level, interpreted to be the Top of the Tailings (light blue). The bathymetry levels have been interpolated to intersect the Pit Shell where the bathymetric coverage was limited at the perimeter of the site.
3	Unit B	13.64	The volume provided by sum of Unit B1 and Unit B2. The volume estimated between the upper boundary provided by the surface of the Top of Tailings (blue) and the lower bounds of Unit B1, provided by the interface with B1 (reflectors R2.0, R1.3, R1.2 and R1.1) and the Top of Tailings (orange).
4	Unit B1	12.94	A sub-unit of Unit B. The volume estimated between the upper boundary provided by the reflector surface *R3.0* (light orange) and the lower boundary provided by the lower bounds of Unit B1, provided by interface with B1 (reflectors R2.0, R1.3, R1.2 and R1.1) and the Top of Tailings (orange).
5	Unit B2	0.70	A sub-unit of Unit B. The volume estimated between the upper boundary provided by the reflector surface Top of Tailings (blue) and the lower boundary provided by the reflector *R3.0* (light orange).
6	Unit C	18.00	The volume provided by summing Unit C1 and Unit C2. The volume estimated between the upper boundary, provided at the interface with B1 (reflectors R2.0, R1.3, R1.2 and R1.1) and the Top of Tailings (orange), and the lower boundary provided by the *Pit Shell and Underdrain* (pink).
7	Unit C1	11.94	A sub-unit of Unit C. The volume estimated between the upper boundary, provided at the reflector *R1.0* (light pink) and the lower boundary provided by the *Pit Shell and Underdrain* (pink)
8	Unit C2	6.05	A sub-unit of Unit C. The volume estimated between the upper boundary, provided at the interface with B1 (reflectors R2.0, R1.3, R1.2 and R1.1) and the Top of Tailings (orange) and the lower boundary provided by the reflector R1.0 (light pink).
9	Total Tailings	31.66	The sum of the Unit volumes. Further, the volume is estimated between the upper boundary provided by the Top of Tailings (blue) and the lower boundary provided by *Pit Shell and Underdrain* (pink).
10	Delta Total Pit Fill	14.03	The difference between the total pit fill between December 2019 and May 2021. The total pit fill volume in December 2019 survey was 24.74 Mm^3 Note: • the difference in water volumes between December 2019 and May 2021 surveys is 6.60 Mm^3 • the difference in Total Tailings volumes is 7.43 Mm^3

A The reflectors are referenced from the drawings provided in Appendix H. The reflectors are summarised for interfaces of contiguous interpreted units and are referenced to the colours provided in Figure 2.6

5.2 Water and sediment theme

This section discusses the knowledge base of the aquatic ecosystems and a variety of historical and current water and sediment KKN related studies.

5.2.1 Aquatic Ecosystems background

BMT WBM (2010) describe the ecological character of the Kakadu NP Ramsar site, which now includes the entire national park. According to BMT WBM (2010) the site contains five major landscape types, including two found on, adjacent to, or immediately downstream of the RPA, i.e. Lowlands containing open woodlands and creeks, and Floodplains containing freshwater wetlands, creeks and billabongs. The terrestrial flora and fauna of Kakadu NP described in the Ecosystem rehabilitation KKNs discuss important water birds and semi-aquatic species.

On the RPA there are no listed or endangered macroinvertebrate or fish species, aquatic fauna species, rare or restricted distribution, environments of special significance including significant breeding sites, seasonal habitats or wetlands areas. Chapter 5.4 Ecosystem Restoration Rehabilitation Theme (ESR) KKNs disucsses several migratory bird species of international importance andthe vulnerable Merten's water monitor which have been recorded on the RPA.

5.2.1.1 Vegetation types

The lowland riparian and rainforest vegetation type represents denser vegetation of the lowlands, typically associated with streams, creeks and billabongs discussed in Chapter 5.4. This habitat type represented throughout the Kakadu NP Ramsar site covers approximately 1% of the RPA. Multiple reports of floodplain vegetation of the Magela Floodplain identify different numbers of classes suggesting high variability over time.

Rainfall volume and patterns affect inundation periods, water level, and soil moisture which combined with fire events impact species distribution seasonally and inter-annually (Whiteside and Bartolo 2014). Combining remote sensing and literature review, Whiteside and Bartolo (2014) identified twelve classes of vegetation on the Magela floodplain in May 2010 shown in Table 5-16. Time-series mapping by the SSB will build on this dataset and classification providing further information on vegetation dynamics on the floodplain.

Table 5-16: Twelve classes of Magela floodplain vegetation (Whiteside and Bartolo,2014)

Class name	Composition and occurrence	Area of cover on the floodplains in May 2010
Melaleuca woodland	Typically contains *M. cajaputi* and *M. viridiflora* in the northern regions and at the edges of the floodplain, and *M. leucadendra* in the backswamps that are inundated for most of the year. Open forest communities are typically inundated for 5–8 months of the year. This land cover was mostly located in the southern	10–50 % woody cover; covering 5039 ha
Melaleuca open forest		open forest communities have 50–70 % cover;

Class name	Composition and occurrence	Area of cover on the floodplains in May 2010
	reaches of the floodplain and around the perimeter.	covering 821.8 ha
Oryza grassland	Dominated by the annual grass, *Oryza meridionalis* towards the end of the Wet season. In the Dry season there is mostly bare ground or dead *Oryza*.	4040 ha
Hymenachne grassland	Dominated by *Hymenachne acutigluma* throughout the year. Other species that may occur include *Oryza meridionalis*, *Nymphaea spp.*, and *Pseudoraphis spinescens.*	3639 ha
Para grass	The weed grass, *Urochloa mutica* (Para grass), is an introduced invasive species. It forms dense monocultures and can outcompete native vegetation in communities of *Hymenachne*, *Oryza* and *Eleocharis*. The community cover on the floodplain was mostly in the central plains region.	2181 ha
Eleocharis	Dominated by the sedge, *Eleocharis dulcis* with larger areas mostly occupying the northern areas of the floodplain.	1054 ha
Leersia grassland	Floating mats of *Leersia hexandra.* Larger mats can be found on the western border of Red Lily Swamp.	967 ha
Pseudoraphis	Dominated by the perennial grass, *Pseudoraphis spinescens*. Particularly in the southern half of the floodplain.	943 ha
Pseudoraphis/ Hymenachne grassland	Co-dominated by *Pseudoraphis spinescens* and *Hymenachne acutigluma*.	375 ha
Mangrove	Mangrove community is located mostly bordering the Magela Creek as it enters the East Alligator River. (Species not described).	249 ha
Nelumbo herbland	This community is dominated by the water lilies, *Nelumbo nucifera* or to a lesser extent *Nymphoides* spp. These communities occur in permanent and semi-permanent wet areas. Other species that may be present include *Leersia hexandra*, *Hymenachne acutigluma*, *Nymphaea* spp. The largest community is found on the eastern extents of Red Lily Swamp (the open body of water in the western part of the floodplain).	243.3 ha
Salvinia	Dominated by the floating fern, *Salvinia molesta*. This declared Class-B weed can completely cover small areas of open water that are protected from wind. On larger stretches of open water, the fern can be found on the leeward edge.	107.5 ha

BMT (2019) describe the patterns, components, key species and primary productivity of the aquatic ecosystems, of the RPA and surrounds as presented the following sections.

5.2.1.2 Aquatic ecosystem patterns

The aquatic ecosystems of the RPA and surrounds are highly dynamic, with seasonal rainfall patterns being a major driver of temporal variability. While fine scale temporal patterns such as timing, duration, frequency and magnitude of rainfall events may vary from year to year, seasonal patterns in the physio-chemical and biological character of waters broadly follow predicable flood-drought cycles.

The wet season is characterised by large increases in aquatic habitat extent, and lateral and longitudinal connectivity, as floodwaters fill lotic and lentic waterbodies and inundate floodplains (Ward *et al.* 2016; Bunn *et al.* 2015). This leads to an explosion of aquatic ecosystem productivity. Most aquatic species have peak reproduction, recruitment and biomass during the wet season (e.g. Bishop *et al.* 2001; Douglas *et al.* 2005, Wharfe *et al.* 2011). Flows are also key drivers of physical (geomorphological) and biological processes that control the structure of aquatic habitats.

Surface water flows cease during the dry season, and aquatic ecosystems are comprised of isolated billabongs on the floodplain and in channels, and sub-surface groundwater-dependent ecosystems (GDE) in channels. In wetter years, substantial floodplain areas of the Magela Creek catchment may remain inundated well into the dry season (Bunn *et al.* 2015).

Shallow billabongs experience a decline in water levels and water quality, leading to local population crashes, or in the case of semi-aquatic species such as crocodiles, dispersal elsewhere. The dry season retraction in habitat and food resource availability reduces overall aquatic ecosystem biomass, and top-down biological interactions such as predation or competition become increasing important ecosystem controls. Water quality deterioration can lead to significant ecosystem stress, especially in shallow waterbodies (Wharfe *et al.* 2011). Shallow lowland billabongs do not represent important refugia due to their shallow nature and associated dry-season habitat and water-quality deterioration (Humphrey *et al.* 2016). Furthermore, wet seasons of low rainfall, when combined with an extended dry season may result in many shallow lowland billabongs completely drying out (Humphrey *et al.* 2016). Similarly, creek channels and seasonally inundated floodplain environments that completely dry out during the dry season do not provide refugia functions.

Deep permanent billabongs such as Mudjinberri Billabong generally have good water quality year-round. They represent important dry season refugia, providing a source for subsequent population replenishment during the wet season.

5.2.1.3 Aquatic ecosystem components

Biodiversity values, and associated cultural values, are comprised of a variety of ecological components at different hierarchical levels (i.e. species, assemblages, habitats/vegetation types, ecosystems). BMT WBM (2010) describe a number of critical and supporting ecosystem components of the Kakadu NP Ramsar site. That study and the Garde (2015) report describing culturally important species was reviewed to identify key species and groups which are indicators of Ramsar listed and cultural values (BMT 2019).

The key species and groups and their presence in relation to the RPA are described in Table 5-17.

Table 5-17: List of key species indicators of Ramsar and cultural values in relation to the RPA (BMT, 2019)

Category	**Species, Conservation Listing and or cultural value**	**Presence on the RPA or downstream aquatic environment**	**Species Group**
Threatened species	Yellow chat (Alligator Rivers) - *Epthianura crocea tunneyi* (EPBC Endangered)	Possible – occurs in palustrine wetlands and saltmarsh	Water birds
	Pig-nosed turtle - *Carettochelys insculpta* (IUCN Vulnerable)	Not present – not recorded in catchment	Reptiles
Locally endemic species	Kakaducarididae shrimps (*Leptopalaemon* and *Kakaducaris*) (Bruce 1993, Page *et al.* 2008). Endemic genus of isopod (*Eophreatoicus*) (Wilson *et al.* 2009). Seven of the nine *Leptophlebiidae* species (prong-gilled mayflies) in Kakadu are endemic to the Timor Sea Drainage Division (Finlayson *et al.* 2006).	Not present. Restricted to stone country	Macro-invertebrates
Species with large proportion of geographic range in Kakadu	See locally endemic species	Not present. Restricted to stone country	
	Exquisite rainbowfish *Melanotaenia exquisite*	Not present.	Fish
	Magela hardyhead *Craterocephalus marianae* Sharp-nosed grunter *Syncomistes butleri* Midgley's grunter *Pingalla midgleyi*	Present. Stone country and lowland areas	Fish
	Woodworker Frog *Limnodynastes lignarius*	Not present – restricted to stone country	Frogs
Species identified as having important populations in Kakadu based on Ramsar	Significant breeding aggregations of magpie geese *Anseranas semipalmata* and comb-crested Jacana *Irediparra gallinacea*	Present – billabongs and floodplain	Water Birds
	Resident water birds with >1% population criterion in Kakadu: Wandering whistling-duck *Dendrocygna arcuate,* Plumed whistling-duck *Dendrocygna eytoni,* Radjah shelduck *Tadorna radjah,* Pacific black duck *Anas superciliosa,* Grey teal *Anas gracilis,* Brolga *Grus rubicunda,* Black-necked stork	Present – billabongs and floodplain	Water Birds

Category	Species, Conservation Listing and or cultural value	Presence on the RPA or downstream aquatic environment	Species Group
	Ephippiorhynchus asiaticus		
	Migratory shorebird species with >1% of the East Asian – Australasian Flyway population size in Kakadu (Bamford *et al.* 2008): Marsh sandpiper *Tringa stagnatilis*, Little curlew *Numenius minutus*, Common sandpiper *Actitis hypoleucos*, Australian pratincole *Stiltia Isabella*, Sharp-tailed sandpiper *Calidris acuminata*	Present – billabongs and floodplain (mostly coastal)	Water Birds
Species of notable cultural significance and values	*Acacia holosericea*[7]*, Pandanus spp.*, *Melaleuca spp., Barringtonia acutangula* – resource	Present – billabongs and floodplain	Riparian and Floodplain Trees
	Water lily *Nymphaea* spp. fruit and seeds – food Aquatic macrophyte tubers – *Amorphophallus paeoniifolius, Aponogeton elongatus, Dioscorea bulbifera, Dioscorea transversa, Eleocharis dulcis, Eleocharis spp., Nelumbo nucifera, Nymphaea macrosperma, Nymphaea pubescens, Nymphaea violacea, Triglochin procerum* - food	Some species present – billabongs and floodplain	Macrophytes
	Mussels and freshwater prawns – food	Present – billabongs and floodplain	Aquatic Invertebrates
	Barramundi *Lates calcarifer*, Salmon catfish *Sciades leptaspis,* Black bream *Hephaestus fuliginosus*, Saratoga *Scleropages jardinii* – food	Present – billabongs and floodplain	Fish
	File snake *Acrochordus arafurae*, Water python *Liasis fuscus*, Crocodiles *Crocodylus porosus* and *C. johnstoni* eggs, Monitors *Varanus* spp., Turtles - *Chelodina oblonga* and *Elseya dentata* – food. See also *Carettochelys insculpta* above	Present – billabongs and floodplain	Reptiles
	Magpie goose *Anseranas semipalmata* – food (meat/eggs)	Present – billabongs and floodplain	Water Birds

The movement patterns and reproductive/recolonisation processes of several of the key species' groups listed in Table 5-17 are summarised in the following chapters by BMT (2019).

[7] Although this species is common on site due to use in early revegetation trials at the site, it is considered a native invasive in Magela Creek Catchment.

5.2.1.4 Aquatic invertebrates

Marchant (1982) describes patterns in the richness and abundance of aquatic macroinvertebrates in billabongs of the Magela Creek catchment. In shallow billabongs, the on-set of the wet season saw rapid increase in richness and abundance of invertebrates. The rapid resurgence of fauna early in the wet season suggests very fast growth and/or reproductive/recruitment rates. Both richness and abundance peaked in the late wet/early dry, which was two (richness) to five (abundance) times greater than recorded during the end of the dry season.

There were seasonal differences in composition in shallow billabongs, with high densities of Ephemeroptera, Trichoptera, Mollusca, Hemiptera and Chironomidae during the wet season, and Coleoptera (especially Dytiscidae), Tanypodinae chironomids, Ceratopogonidae, some Hemiptera and Gastropoda, and Macrobrachium prawn numerically dominant in the dry season. Many fewer common taxa occurred in variable abundance throughout the year. Marchant (1982) speculated that these changes were related to seasonal changes in aquatic macrophyte abundance, an important habitat for many aquatic invertebrates.

By contrast, deep channel billabongs did not show such strong seasonal variability, and maximal richness and abundance values were similar to that in shallow billabongs. Despite differences in habitat structure and wetting-drying cycles, fauna composition was largely similar between shallow and deep billabongs.

Marchant (1982) suggested that short life cycles (measured in weeks to months rather than 10s of months) and very fast rates of larval growth likely prevail in most invertebrate groups in the Magela catchment billabongs. These are necessary adaptations for organisms living in ephemeral environments subject to seasonal wetting and drying cycles (Williams 1987).

The seasonal patterns described by Marchant (1982) are summarised in Table 5-18.

Table 5-18: Seasonal patterns in aquatic macroinvertebrates in Magela catchment billabongs (BMT 2019 after Marchant 1982)

Taxa	Pattern
Gastropoda	Peak abundance of the common species in wet season Hibernate during dry season Planktonic larvae
Ostracoda and Conchostraca	Peak early to mid-wet
Atyidae and Palaemonidae	Atyidae - Dry season peak abundance and breeding (shallow), common year-round in deep billabongs Palaemonidae – dry season peak, absent early wet, breeds in estuary
Ephemeroptera	Peak in late wet/early dry in shallow. Emergence and reproduction continuous for many species
Odonata	Peak abundance in late wet/early dry for most species, but some species only found in early wet and late dry. Breeding peak in wet season for most species

Taxa	Pattern
	only found in early wet and late dry.
Hemiptera	Peak abundance in late wet/early dry for most species, but some uncommon species
Neuroptera	Wet season only, in association with sponges
Diptera	Emergence and breeding of Chironomids appeared to occur continuously while large numbers of larvae were present. Tanypodinae more abundant in dry season Ceratodontidae were more abundant in dry season, disappearing in early wet season
Lepidoptera	Most species only present in wet season, and in low numbers
Trichoptera	Peak abundance typically in early dry, but many species recorded throughout the year
Coleoptera	Adult Dytiscidae peak at the end of dry season, larvae mostly in wet season Except for the Hydrophilidae in the shallow billabongs, breeding of all families appeared to occur during the wet season

5.2.1.5 Fish

Bishop *et al.* (2001) examined the autecology of fish species in the Magela Creek system. Most fish species in the catchment undertake broad-scale movements for reproductive and feeding purposes. Many fish species disperse into lowlands and floodplains during the wet season for feeding and breeding purposes, resulting in high fish productivity during this period.

As water levels decline, fish move from seasonally inundated floodplain and sandy channel environments into dry-season refuges including permanent billabongs, or, for euryhaline[8] species such as barramundi to estuarine river channel environments. Sandy creek channels represent important fauna movement corridors during the recessional stage (i.e. late wet/early dry transition). Smaller fish move upstream along the slow-flowing edges of creeks, which was suggested to be due to lower water velocities on the edges of the creek, or as an evolutionary mechanism to avoid larger predators residing in deeper sections of creek channels (Bishop and Walden 1990).

From a reproductive ecology perspective, most species breed around the on-set of the wet, coincident with flooding and associated increase in habitat availability, nutrients and algae production, and food availability (Bishop *et al.* 2001). A small number of spawners can breed at any time of the year, but most of these species typically have a wet season peak.

Within the Magela Creek catchment the most important spawning habitat for most species were the lowland backflow billabongs, and several species breed exclusively in this habitat type (Bishop *et al.* 2001). The escarpment area and sandy creek bed

[8] Species able to tolerate a wide range of salinity.

habitats were also commonly used spawning sites for numerous species, with only a small number breeding exclusively in these habitat types (including *Neoarius erebi*, *Leiopotherapon unicolor*, *Neosilurus hyrtlii* and *Porochilus rendahli*). A small number of species are catadromous (migrate to sea to breed). Notwithstanding this, most catadromous species are large-bodied species that can be a dominant component of the fauna biomass, as many are important from a fisheries and cultural heritage perspectives – for example, barramundi, tarpon and eels.

5.2.1.6 Bird/Reptiles/Amphibians

Most bird species in the catchment undertake broad-scale movements for feeding and breeding purposes. During the dry season, water birds are very abundant and diverse (Morton *et al.* 1991). Water birds prefer habitat with varying water depths, however towards the end of the dry season with receding water levels, water birds congregate in high abundances wherever water remains. These areas include the upper floodplain, the western part of the plain and channels through the Melaleuca swamps in the central plain). As flooding of the floodplain increases during the wet season, water birds fly away to other areas and become less abundant (Morton *et al.* 1991).

Migratory birds migrate to the catchment prior to and just after the wettest months (January–March). The most common migratory water bird species include the little curlew (*Numenius minutus*), oriental plover (*Charadrius veredus*), large sand plover (*C. leschenaultii*) and the Mongolian plover (*C. mongolus*) (Morton *et al.* 1991).

There are few water bird species that breed in significant numbers within the Magela Creek system, however, the Comb-crested Jacana (*Irediparra gallinacea*) breeds in abundance (Press *et al.* 1995). The main breeding period of the Comb-crested Jacana is during the late wet season, between the beginning of March to April.

Most reptiles are abundant during the wet season, while in the dry season they are concentrated to remnant waterbodies, such as billabongs (Gardner *et al.* 2002). Some species, such as freshwater turtles, bury themselves in mud as the water dries up during the end of the dry season.

Most frog species breed at the onset of the wet season before the floodplain is completely inundated (Tyler and Crook, 1987). During the dry season, most frog species are totally inactive, with some species burrowing underground, while others are restricted to billabongs.

5.2.1.7 Trophic processes and ecosystem productivity

Based on data in Adame *et al.* (2017), macrophytes represented the dominant primary producers in the freshwater reaches of the Kakadu wetlands (1870 - 2892 mg C/m^2/day) during the wet season, followed by terrestrial inputs (e.g. 970 mg C/m^2/day for Melaleuca litterfall; Finlayson *et al.* 1993), phytoplankton (122-334 mg C/m^2/day) and periphyton attached to macrophytes (13-219 mg C/m^2/day). This agrees with estimates of the relative contribution of primary producer groups in other tropical floodplains (Adame *et al.* 2017). The deeper floodplain backswamp areas had the highest periphyton and macroalgae productivity; these areas also hold water the longest, remaining productive into the dry season (Bunn *et al.* 2015).

Adame *et al.* (2017) found that while primary production in Kakadu wetlands was high compared to many other ecosystems, the wetlands were heterotrophic. This reflects the high inputs of organic matter to the system, such as dead macrophytes, fish carcases and other organic matter during the dry season (Adame *et al.* 2017). The decomposition of organic matter during the following flooding season can results in anoxia in places (Adame *et al.* 2017).

While macrophytes are highly productive, isotope analysis indicates that algae (periphyton and phytoplankton) can be the dominant internal source of carbon to aquatic fauna in the wet-dry tropics (Douglas *et al.* 2005). Douglas *et al*. (2005) suggested that much of the biomass of macrophytes may enter a detrital pool with a microbial 'dead-end' for aquatic ecosystems. Macrophytes do represent important habitats for the periphyton assemblages that sustain aquatic ecosystems (Bunn *et al*. 2015; Adame *et al*. 2017), and are important to the diets of some semi-aquatic and terrestrial fauna (Douglas *et al*. 2005), especially water birds (e.g. magpie goose; Frith and Davies 1966).

Isotope analysis by Bunn *et al*. (2015) in the ARR found that while insects, crustaceans and small fish can be sustained by 'internal' producers from the within the waterhole, external food sources from outside the home waterhole are critical to larger animals such as saratoga, barramundi and crocodiles. External sources can include marine fish and invertebrates (e.g. crabs, prawns, molluscs), small floodplain-associated freshwater fishes, and, in the case of the crocodiles, land mammals such as wallabies and pigs. Bunn *et al*. (2015) concluded that "the greater importance of external sources with increasing body size is a common feature of Kakadu food webs".

Figure 5-52 depicts a food web for aquatic ecosystems in the Magela Creek catchment[9]. Diet data of fishes from Magela Creek, and tropical rivers in northern Australia more broadly, show little evidence of dietary specialization. For example, Bishop and Forbes (1991) found that fish assemblages in Magela Creek were largely omnivorous (20-50%, depending on habitat). Because many fish and many other aquatic vertebrates feed on a broad range of items, food webs are short, diffuse, and highly inter-connected (Douglas *et al*. 2005).

Douglas *et al*. (2005) notes that a key characteristic of aquatic foodwebs in the Australian wet-dry tropics is that a 'few large bodied consumers control the flows of energy and matter into and through the animal community. Strong top-down control by such macroconsumers is emerging as a characteristic feature of tropical streams and rivers with fish and shrimp capable of exerting a disproportionately large influence on benthic sediments, detritus, nutrient demand and algae and invertebrate communities'. Predation by birds and fish is a key top-down control on aquatic productivity at low water levels. High mortality rates can occur in refuge areas due to reduced resources and high rates of predation. During the wet season, bottom-up processes are thought to be more important.

[9] Notes: there are differences between seasons. In dry seasons the system is more closed. Wet seasons the system is open and connected. Most organisms are omnivorous feeding on a range of different items. This is important and makes them less susceptible to small changes to food species

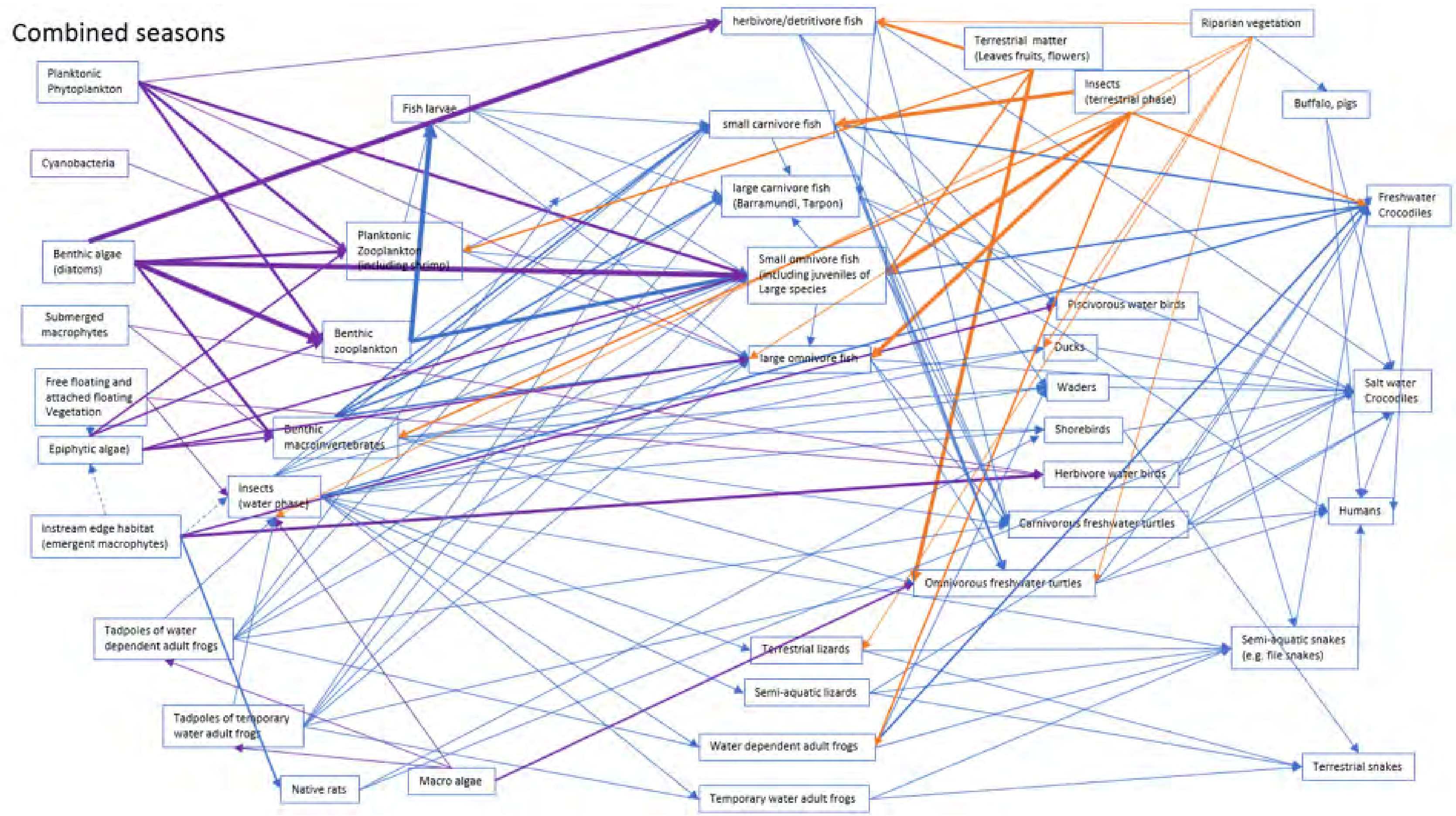


Figure 5-52: Food web for aquatic ecosystems in the Magela Creek catchment (from BMT 2019)

5.2.2 Water pathway risk assessments (release pathways onsite)

As part of the environmental studies required for closure of Ranger Mine, an assessment of the risks associated with contaminants across the site transported via water pathways was conducted.

The Water Pathways Risk Assessment project was conducted by ERA and BMT Ltd to develop a risk assessment tool to identify the risks posed from the different contaminants and sources on the mine site, or predicted to come from the site. While these risks are primarily predicted to arise during the monitoring and maintenance period of the closure processes, the risks also apply to the activities undertaken during the closure phase. The risk management classification is useful to identify which contaminants need to be managed and where further information is required for the next level of assessment. These findings represent Phase 1 of the aquatic pathways risk assessment, which will be used to further inform the assessment of potential impacts from closure activities for contaminants and water bodies on the RPA and the development and implementation of management plans. The following summarises the work undertaken in the Phase 1 processes and how this links into other assessment and management processes.

5.2.2.1 Phase 1 of the water pathways risk assessment

The initial phase of the risk assessment was the development of a conceptual understanding of the system which included determining sources, pathways, receptors and processes and aligning these with values relating to the broader environment in the surrounding landscape. The values reflect the Commonwealth ERs and the broader concerns of stakeholders about the long-term impact of the mine and relate to what they hope to see achieved following the mine rehabilitation process.

The conceptual underpinning was derived from a range of previous conceptual models for various solute pathways that were refined during the ecological risk assessment for mine closure (Pollino *et al.* 2013; Bartolo *et al.* 2013). While those models were developed to identify assessment end points and knowledge gaps, the focus of the integrated conceptual model for this assessment was the influence of the contaminant sources on values. Figure 5-53 below shows the integrated conceptual impact pathways model for this assessment along with the assessment methods used and what aspects were included or excluded from the phase 1 assessment.

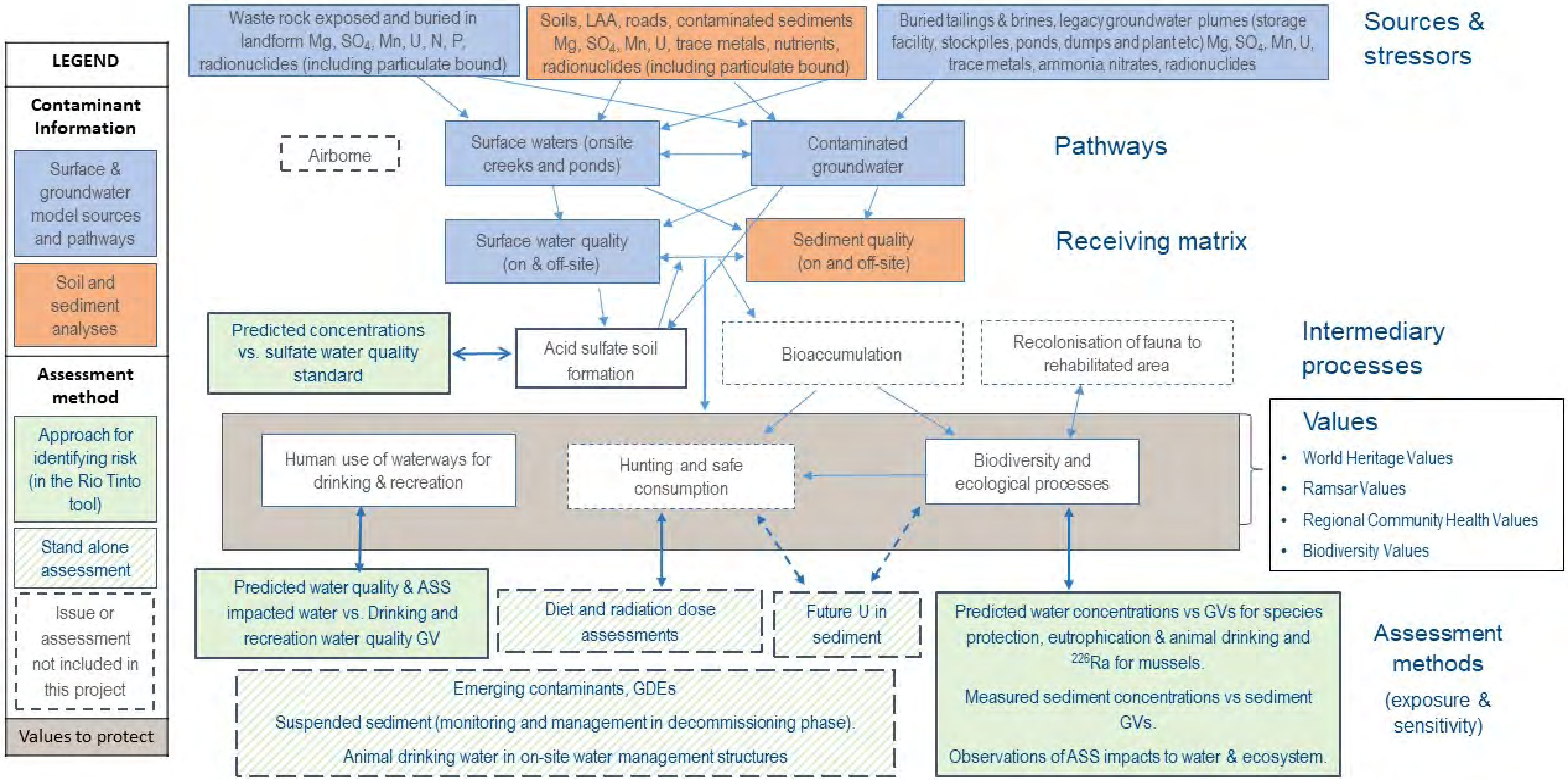


Figure 5-53: Aquatic source pathway receptor model and risk assessment approach

A workshop was held in March 2020 to:

- Compare water and sediment quality (measured and predicted) to endpoints identified in conceptual models developed in previous stakeholder risk assessments to reflect the community values and Commonwealth ERs for protection of people and the biodiversity of the region.
- Test and revise descriptors and/or the proposed assessment approach
- Classify and rank risks to receptors offsite and in the four sub-catchments on-site where adequate information was available
- Identify any additional information available/required to support the assessment.

Representatives from ERA, BMT and SSB were present with the NLC attending in a an observing role). The risk scoring was completed by ERA and BMT following the workshop with consultation with SSB on descriptors and evidence interpretation.

The assessment using the ERA risk assessment tools modified to:

- tailor risk questions and descriptors of likelihood and consequences to align with the conceptual model of aquatic risks and available evidence and guideline values,
- adopt improved assessment approaches recommended in national guidance documents on acid drainage prevention or acid sulfate soils (ASS) assessments,
- enable results to be displayed by contaminant sources, receptors and values, and
- include a numeric score for each risk to assist in prioritising management actions.

Predicted future water quality from RSWM and data from sediment sampling and poor water quality events caused by exposure of ASS was compared to guideline values for the protection of (i) people using the water for drinking and cultural/recreational purposes, (ii) aquatic and benthic species protection, and (iii) animals drinking the water. Information from monitoring and studies of exposed ASS in a billabong on site were used to assess the risks to human use of the water and biodiversity.

The evidence base for the risk assessment, what pathways and risks the evidence relates to and how it was used is summarised in Table 5-19. The phase 1 report describes the evidence base, how it was used in the assessment process, the confidence in the evidence base and the implications of that to the outcomes.

Table 5-19: Summary of information sources and how used in the risk assessment

From conceptual model and threat questions				Exposure		Sensitivity
Threat	**Source**	**Pathways**	**Receptors**	**Exposure evidence**	**Likelihood assessment logic**	**Human health or biodiversity consequence assessment process**
Poor water qaulity impacts on cultural land use (human health) and ecosystems	All solute transport model source terms (metals, ions, nutrients from tailings, brine, waste-rock, groundwater plumes, etc.).	Ground and surface water. Groundwater - surface water interactions.	Aquatic ecosystems (surface water) Humans (drinking & recreation) Wildlife (drinking) Sediment (U accumulation)	Surface water model water predictions Water Solutions (2021)	Probable; P50 loads from groundwater model used in surface water model.	On and offiste descriptor matrix of SWM exceedence probabilites vs Water quality GVs for species protection, drinking water, recreational water, wildlife/livestock drinking water.
Elevated nutrients cause eutrophication	Nutrients from all solute transport model source terms	As above	Aquatic ecosystems (surface water)		Probable; P50 loads from groundwater model used in surface water model.	Site specific thresholds based on nutrient concentrations corresponding to trophic bands for January to May. Thresholds compared to median SWM prediction for creek sites and 75th and 90th percentile SWM predictions for billaong site (to be reviewed once predictions for Jan-May period only available for billabongs)
Elevated sulfate in water creates future ASS and impacts ecoystem	Sulfate from all solute transport model source terms	As above, plus water and sediment interactions.	Aquatic ecosystems via future ASS formation in aquatic sediments		SWM exceedence probability vs Site-specific sulfate water quality threshold for ASS protection	Consequences for current ASS applied to future ASS.
Elevated uranium in water accumulates in sediments and impacts biota	*Uranium from all solute transport model source terms*	*As above, plus water and sediment interactions.*	*Sediment biota via future U accumulation*		*Probable; P50 loads from groundwater model used in surface water model.*	*U in water concentration equivalent substitued into sediment consequence descriptors. Not included at this stage. Problem with applying algorithm for U partitioning being addressed.*

From conceptual model and threat questions				Exposure		Sensitivity
Threat	**Source**	**Pathways**	**Receptors**	**Exposure evidence**	**Likelihood assessment logic**	**Human health or biodiversity consequence assessment process**
Metal contaminants in sediments impact biota	Contaminated sediment	Insitu exposure	Sediment biota	Sediment sampling results (ERA datasets and ERA 2021a)	Probability (%) of sediments exceeding default or site specific GV (based on timeseries plots of metals in sediments).	Matrix of thresholds; natural distribution, national default sediment GVs, site-specific U GV vs mean value for waterbody.
Poor water qaulity from ASS impacts on cultural land use (human health) and ecosystems	Acid sulfate soils	Flux of contaminants from sediments to water column	Aquatic ecosystems (surface water) Humans (drinking & recreation) Wildlife (drinking)	Sediment sampling results and Coonjimba Billabong data & studies (ERA datasets and ERA 2021b, ERA LIMS water quality data, SSB 2020)	Frequency of events likely to cause consequence. Likelihood of acidity hazard factored into assessing consequences of sediment contamination to biota	Data from past ASS at Coonjimba Billabong effecting water quality and biodiversity. Extraploation to other sites considering processes relative to CB. *Consequence at End of RPA (no sediment ASS data) captured in ASS summary table.*
Sediment bound contaminants in LAAs cause poor water quality that impacts cultural land use (human health) and ecosystems	Contaminants bound to LAA soils	Surface water transport (particulate/dissolved) (ground-water path included in SWMI)	Aquatic ecosystems (surface water) Humans (drinking & recreation) Wildlife (drinking)	Soil sampling results & potential for transport to waterbodies (ERM 2020)	Conceptual model and risk of transport at each LAA reported in ERM 2020.	

This phase I assessment identified 57 threats; 51 of those had enough information to evaluate the risks (Table 5-20, Figure 5-54 and Figure 5-55). Of the 51 risks, 29 were Class 1 (low) risks, seven were Class 2 (moderate) risks, five were Class 3 (high) risks, and ten were Class 4 (critical) risks. This assessment of threats is based on the information and assumptions based on modelling available at the time of the Phase 1 processes and does not include additional threats which may arise in relation to matters excluded from the Phase 1 processes.

The initial assessment of the 10,000 year risks found 19 that were Class 1 (low risks) and two that were Class 4 (critical risks).

Table 5-20: Results of risk assessment

Risk Class	Class I	Class II	Class III	Class IV
Risk	**Low**	**Moderate**	**High**	**Critical**
Overall	29	7	3	10
10,000 Years	19			2

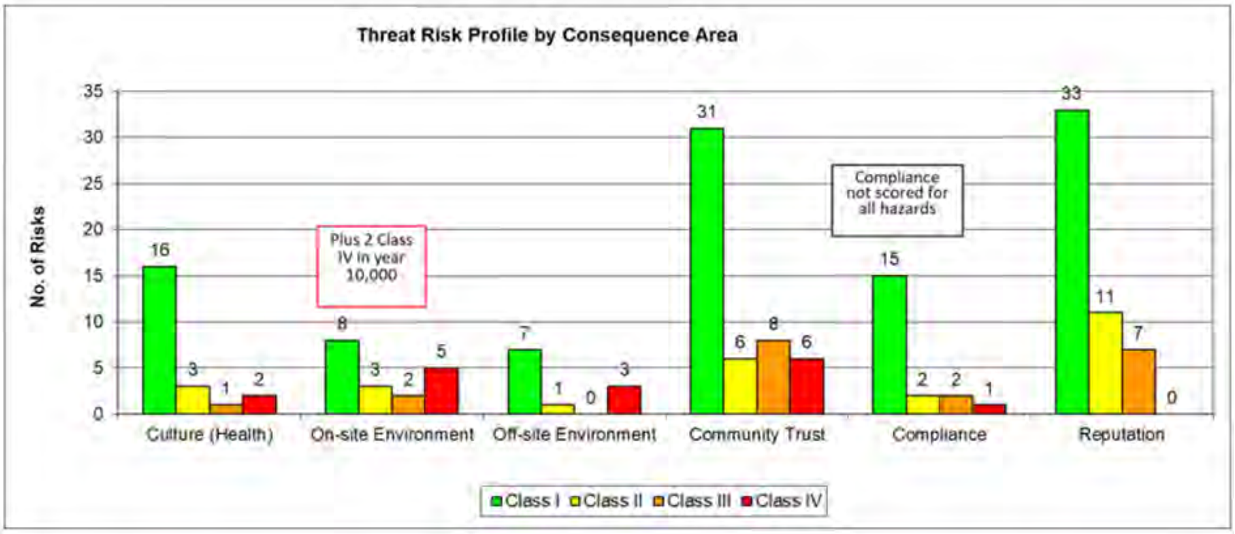


Figure 5-54: Risks by consequence category

A breakdown of risks by contaminant source (Figure 5-55) shows that of the class 3 and 4 risks (the classes that require active management), one is from exposure of ASS in the Coonjimba catchment, and the others are associated with the predicted future water quality from a several sources:

- five relate to different COPC within the Pit 3 tailings flux;
- three relate to different COPC within the TSF plume or waste rock vadose zone in Coonjimba catchment;
- two relate to different COPC within the Pit 1 tailings flux; and

- two are associated with the modelling scenario for 10,000 years from a combination of contaminant sources.

The risks are based on modelling of predicted future water quality using conservative assumptions regarding quantities and behaviour of contaminants. Many of the COPC are reactive and are expected to attenuate during transport, thus the models over predict the concentrations that may occur and therefore the risk is also overestimated at this stage.

The use of conservative assumptions in the risk assessment enables the identification of which COPC, at which sites, present higher risks. Subject to the consideration of additional threats outside the scope of the risk assessment, the Phase 1 findings enable further assessment and management measures to be focussed on those activities and COPCs of greater risk with lower focus being required for those COPCs considered unlikely to present a material risk.

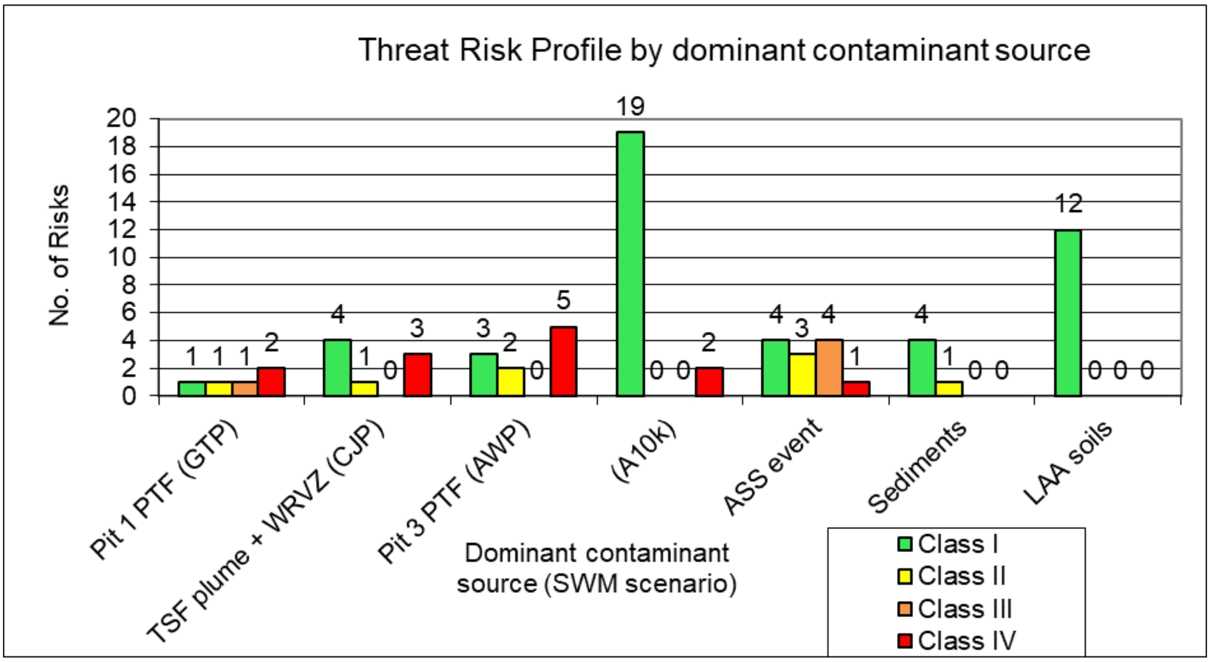


Figure 5-55: Threat risk by dominant contaminant source. The first four sources (from the right side) are contamination sources predicted by the surface water model (SWM) to enter the surface water after closure. The last three sources are associated with current contaminated soils and sediments.

Table 5-21 summarises the 10 Class IV risks identified in the Phase 1 Assessment. It is noted that the Class IV risk ratings are based on the conservative assumptions used in modelling and are considered preliminary assessments only. In particular, the assessment assumes a 350ML PTF volume in Pit 3, which is significantly higher than is proposed. Further refined assessment of these threats will be included in future assessments and combined with additional management controls to be identified and/or considered, these risk rankings are likely to reduce.

Table 5-21: Ten highest ranked threats identified in the risk assessment

Rank	Threat ID	Detail
1	TJ07-17	Water quality: Eutrophication consequences very high GTCk ammonia (> GV at 10,000 years)
2	TJ07-23	Water quality: Very high species protection consequence score at Gulungul Billabong from slight exceedances of Mn and Cu AWP scenario only
3	TJ07-02	Water quality: Eutrophication consequences from ammonia: End of RPA Very high
4	TJ07-01	Water quality: Offsite 99% species protection GV exceeded at End of RPA site for Mg, Mn, Cu, U.
5	TJ07-08	Water quality: Coonjimba Billabong species protection consequences V.High - Mg, Mn, Cu, Zn, U, Pb, Ni; Mg high consequences extend to 10,000 years
6	TJ07-16	Water quality: GTCk Very high species protection consequences for Mg, Mn, TAN, Zn and GTB for Mn. Mn consequences at GTCk extend to 10,000 years.
7	TJ07-01	Water quality: Offsite drinking water slight Mn exceedances at End of RPA
8	TJ02-03	Water quality: Coonjimba Billabong drinking water Mn and U exceedances at CB.
9	TJ07-10	Water quality: Coonjimba Billabong sulfate > ASS GV
10	TJ07-15	ASS exposure: Ecosystem consequences at Coonjimba Billabong

Based on the Phase 1 assessment, the following actions have been assigned for all class 3 and 4 risks (several have commenced):

- Improving confidence in the evidence and assessments that underpin the risk assessment (such as reviewing and fine-tuning sources and reactive transport modelling, assessing the sensitivity of the model to certain drivers to help identify where management plans are required) and communication of the conservative nature of the models used in the assessment.
- Development of targeted management plans and/or further studies to address on-site contamination sources and ASS, naturally occurring and possible development of PASS.
- Understanding the implications of climate change on certain drivers.

- Consultation with Traditional Owners to better understand cultural water use and to integrate this understanding of appropriate assessment criteria relevant to these uses, including any temporal constraints on use.

In considering risks for a 10,000-year time horizon it is noted that there are large uncertainties with all input variables to models and in the outputs of models and results should be considered indicative at best. However, identifying such long-term risks can be used as further evidence of contaminants that are likely to remain as issues of concern for long time periods and must be managed.

ERA are also considering comments raised by SSB on the report provided on the Phase 1 risk assessment and this will be discussed with an aim to resole to phase 1 assessment in late 2022. The SSB comments will also be considered in the application of the Phase 1 Risk Assessment in the Pit 3 Backfill Application assessment.

The second phase(s) of the risk assessment will be undertaken as part of the detailed assessment of closure activities and will consider new information and address initial stakeholder feedback on this tool. The risks relating to other closure activities (Final landform, TSF deconstruction) will be further assessed based on refined modelling and design inputs as part of their respective regulatory applications.

5.2.3 WS1 Characterising contaminant sources on the RPA

KKN title	Question
WS1. Characterising contaminant sources on the RPA	WS1A *What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?*
	WS1B *What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?*

5.2.3.1 Background contaminants on the RPA

Background COPCs require characterisation to identify the natural range of concentrations in different HLUs across the site. HLUs for Ranger are discussed further in the conceptual site model (KKN WS2) Characterisation of the background COPCs enable a better understanding of the site source terms which inform solute transport modelling described in further in KKN WS2.

Previous background concentrations of COPCs in groundwater were presented by Esslemont (2015) and were updated in 2017 (Esslemont 2017). These background concentrations were based on a limited COPC list and only included data up to 2013. Substantial updates to the Ranger conceptual model, major expansion of the Ranger bore network and an improved analytical database, enabled ERA to re-assess the background COPCs.

Environmental Resource Management (ERM) was engaged by ERA to undertake the re-assessment of the site background COPCs. At the time, no prescriptive approach was suggested, and as such a combination of a population partitioning approach followed by a weight of evidence evaluation was undertaken. Extraction of a background dataset from a larger site investigation dataset has support from various guidance documents (US Navy 2004; ITRC 2013; USEPA 2014). The dataset used extended from July 1980 through August 2019.

A key requirement of the study was the development of a consistent and transparent decision framework which is outlined in Figure 5-56, in Figure 5-57 and Figure 5-58.

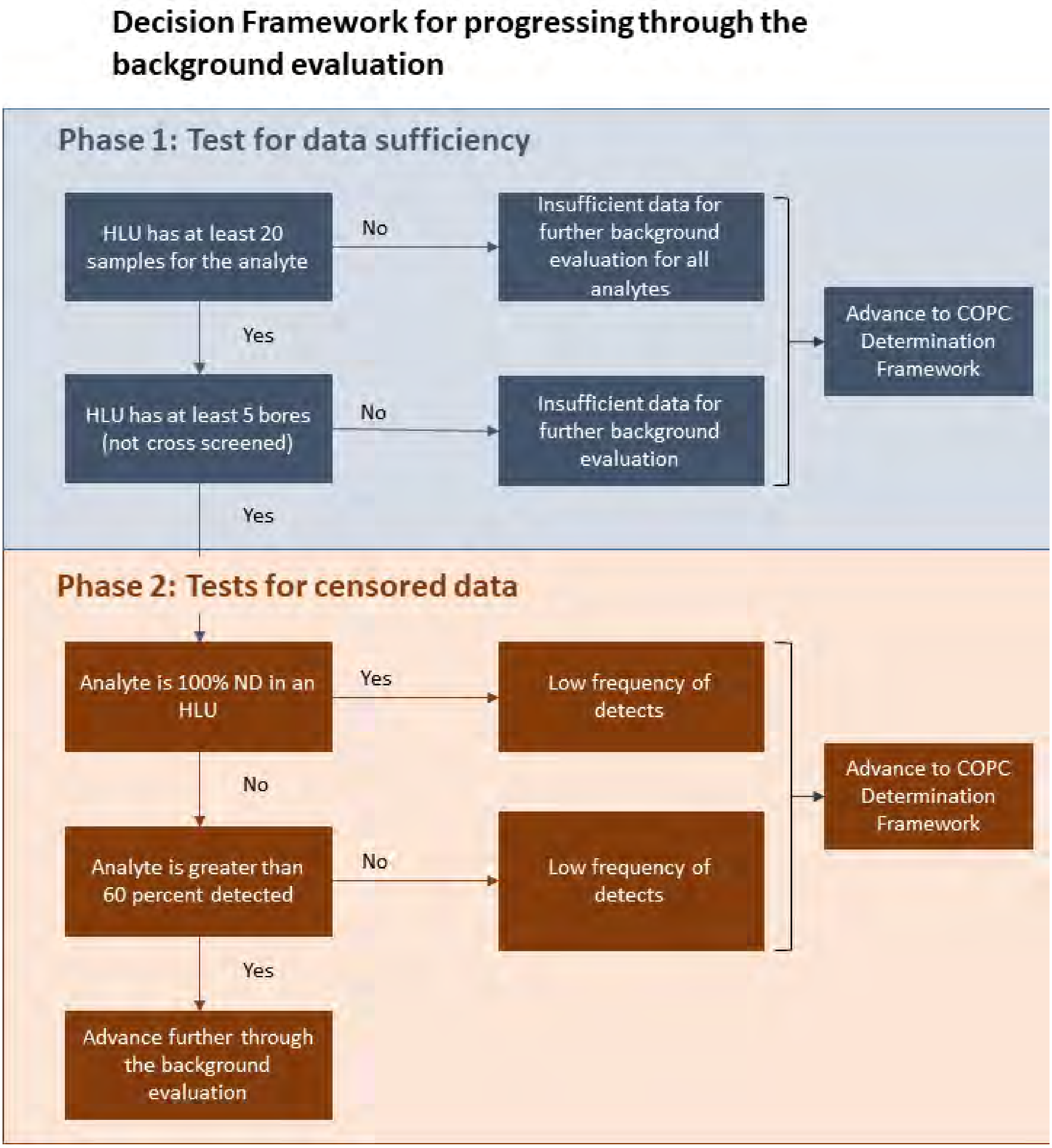


Figure 5-56: Decision framework for determining data sufficiency, ERM (2020c)

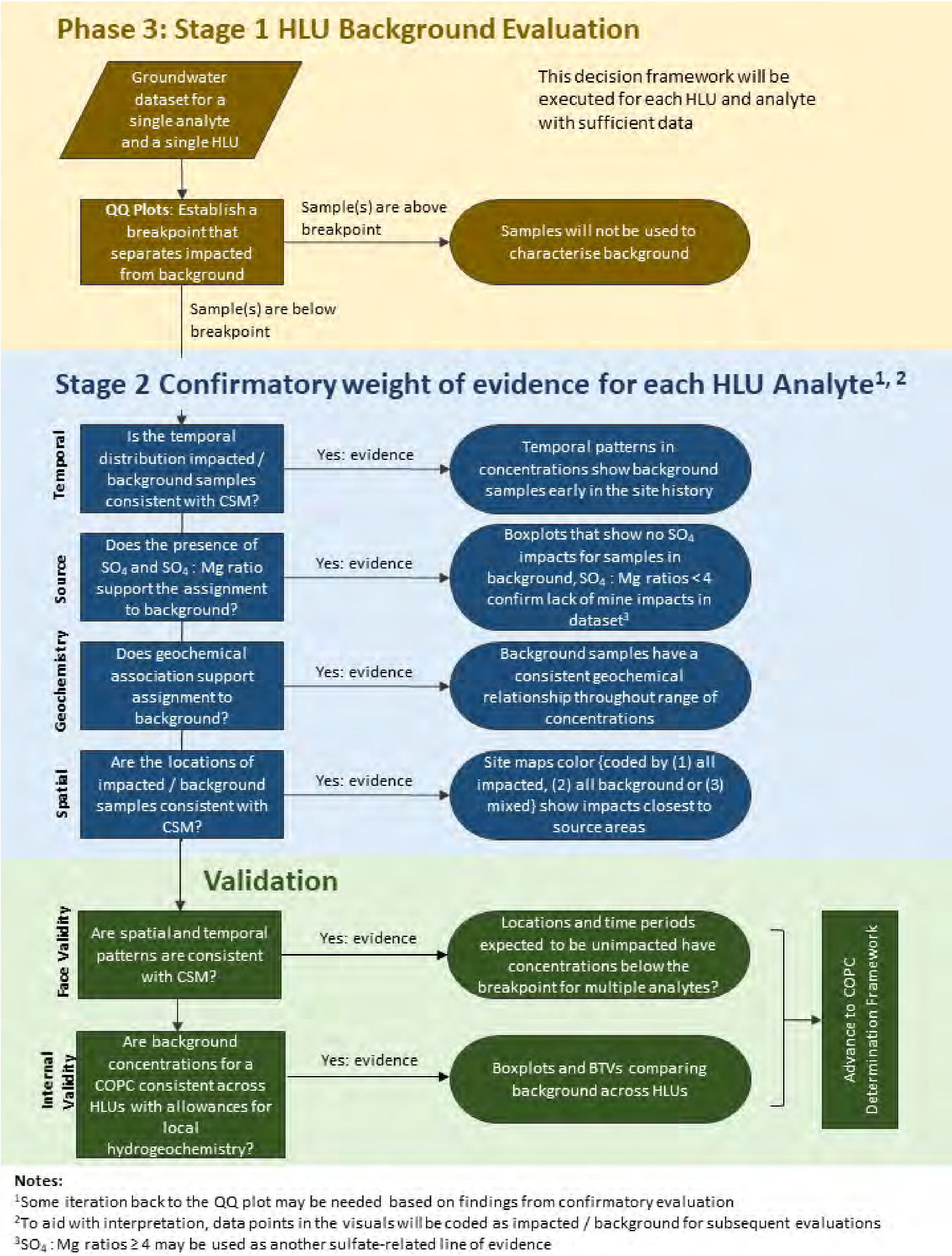


Figure 5-57: Decision framework for extracting and establishing background using weight of evidence, ERM (2020c)

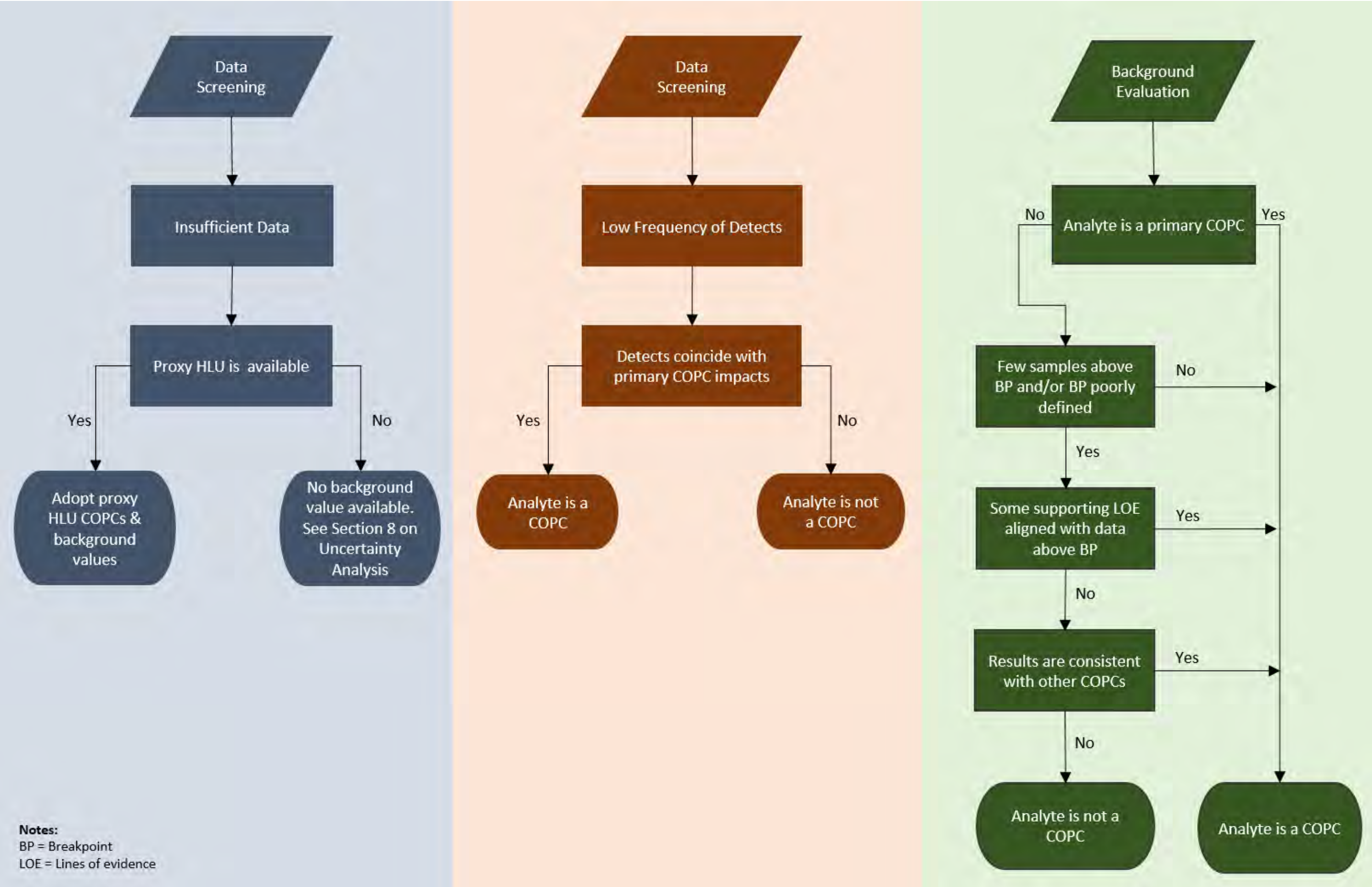


Figure 5-58: Framework for developing background for datasets with insufficient data, ERM (2020c)

Following the development of the site-specific background COPC datasets, background threshold values (BTV) were determined. Where there was sufficient data, 95/95 Upper Tolerance Limits (UTL) were set for each HLU and analyte combination, shown in Table 5-22. Where there was insufficient data either proxy HLU's were utilised where there was supporting rationale, or in the case where all samples for the HLU analyte combination were below laboratory limit of reporting, the limit of reporting was used as a surrogate BTV.

This background evaluation process has refined the COPC list for the site, established background datasets for HLUs and analytes, and calculated BTVs for analytes and COPCs on an HLU-by-HLU basis. The BTVs were established using an objective decision framework that supported a defined process that was generalisable and repeatable across analytes and HLUs. This resulted in a transparent and defensible process and the uncertainty evaluation did not identify material inconsistencies in the data or the approach that would need to be considered when using the resulting BTVs to inform site closure decisions. The results were supported by multiple forms of validation that help to create a high level of confidence in the conclusions.

In support of the final report (ERM, 2020c), nine interactive html dashboards were developed allowing for full interrogation of the dataset and statistical analysis undertaken to develop the BTVs. The study effectively refined the COPC list and identified the background dataset, established site-specific background datasets where minimum data criteria were met, and established BTVs for COPCs in groundwater at the Ranger Mine.

The COPC BTVs have been used to inform the site source terms by providing a concentration threshold to identify where groundwater quality has been influenced by mining activities and where the water quality is representative of no mining impacts. This is vital for delineating the extent of impact and quantifying the solute source terms. The site source terms are discussed further in the next section.

5.2.3.2 Characterising mine derived contaminant sources on the RPA

Conceptual models and COPC concentrations for groundwater source terms are a required input for numerical groundwater modelling of post-closure solute loads from groundwater to surface water receptors for assessment of environmental impacts from Ranger mine closure and rehabilitation. The solute source term conceptual model details the contaminants present, and the concentration or mass of the contaminants present for all the major contaminated locations on the RPA as required by WS1A. The solute source term also includes reference to any geochemical processes that result in mobilisation of COPCs from the waste rock landform. Previous models developed solute source term conceptual models for the major contaminant sources on the RPA for the INTERA (2014) and INTERA (2016) post closure solute transport modelling. This modelling considered vadose zone waste rock leachate and tailings-derived materials as sources, focused primarily on a single solute (magnesium [Mg]) transport, and provided a single deterministic result. These conceptual models required update to expand the list of possible sources, expand the list of COPCs that were assessed and were appropriately characterised for inclusion in the uncertainty analysis component of the post closure solute transport modelling.

Table 5-22: Calculated BTVs for HLUs and Analytes in the Background Evaluation where data sufficiency requirements were met, ERM (2020c)

Analyte	Unit	Shallow Bedrock Cahill	Deep Weathered Cahill	Shallow Weathered Cahill	Shallow Bedrock Nanambu	Deep Weathered Nanambu	Shallow Weathered Nanambu	MBL Zone (UMS subunit)
Aluminium	ug/L			27.6	14.4[a]	24.9	19.3	
Ammonia	mg/L				0.88	0.312	0.43	
Arsenic	ug/L				0.25	8	4.5	
Boron	ug/L				30	55	25	
Copper	ug/L			3.8		4	6.15	
Lead	ug/L			0.9			2.05	
Magnesium	mg/L	21.7	57.9	11.1	39.8	26.7	52.3	40.5
Manganese[b]	ug/L	190	87.5	483	1420	401	890	18
Nickel	ug/L				2.3	4.9	11.5	
Nitrates	mg/L		0.554	3.17				0.554
Radium	mBq/L	130	50	27.3[c]	130[c]	90	30	37.3[c]
Sulfate	mg/L	1.5	4.3	1.88	2.5	7.6	1.6	1.6
Uranium	ug/L	7.74	21.9	3.03	5.76	5.7	3.37	1.92
Vanadium	ug/L					3		
Zinc	ug/L			13	3	16.5	11.5	

[a] This BTV was calculated using Lognormal 95/95 UTL (Upper tolerance limit with 95% confidence and 95% coverage)

[b] Evaluating data against the manganese BTV requires the use of two criteria: concentrations must be below the manganese and sulfate BTV to be considered unimpacted

[c] Although Radium is a primary COPC, the background evaluation did not indicate this was the case for the Shallow Weathered Cahill, Shallow Bedrock Nanambu and MBL Zone.

Notes:

Greyed out BTVs are for analytes that are not COPCs in that HLU.

UTLs were calculated using a Nonparametric Binomial 95/95 UTL.

Depending on the sample size, 95% confidence was not always achieved, but the achieved confidence was never less than 74%.

No BTVs were calculated for Pit 1 as this HLU was entirely impacted.

Statistical methodology follows United States Environmental Protection Agency (USEPA) Guidance (USEPA 2015)

The solute source term conceptual model update in itself does not directly address any specific ERs, however it does form a critical part in a number of groundwater and surface water studies that do, including the post closure solute transport with uncertainty analysis and the Ranger surface water modelling.

The solute source term update consisted of a data-driven approach to determine COPC concentrations and uncertainties for inclusion in the post closure solute transport modelling with uncertainty analysis. A log-normal probability distribution described by moments (concentration mean and standard deviation) was assumed for the source terms. The moments were defined using source-specific data when available and solute relationships based on surrogate data in the absence of source-specific data. Site specific data consisted of groundwater quality data, contaminated sites investigations, site specific investigations, operational water quality data, tailings sample data and water treatment modelling predictions.

Mining activities have resulted in groundwater source terms associated with active mine operations and site closure activities will result in post-closure groundwater sources. The operational period groundwater source terms that were identified and characterised are:

- The groundwater solute plume developed from seepage of tailings pore fluid from the TSF.
- The groundwater solute plume associated with the ore processing and other operations conducted in the plant processing area (PPA).
- The groundwater solute plume developed from rainfall infiltrating through the historical stockpiles (Stockpile Plume).
- The groundwater solute plume developed through seepage from retention pond 2 (RP2).
- The groundwater solute plumes at land application areas (LAAs) developed from application of RP2 pond water.

The post-closure groundwater source terms are:

- Tailings located in Pit 1.
- Tailings located in Pit 3.
- Pit tailings flux (PTF) remaining in Pit 1 after cessation of decant operations (Pit 1 PTF).
- PTF remaining in Pit 3 after cessation of decant operations (Pit 3 PTF).
- Leachate from the waste rock vadose zone in the final landform, including shallow waste rock backfill in the pits (VZ WR leachate).

- Residual mass in waste rock located below the water table in the final landform, including the shallow waste rock in the pits, saturated zone waste rock (SZ WR).
- High density sludge (HDS) (three source terms)
    - Deposited in Pit 3 (HDS in Pit).
    - Consolidated sludge in an HDS out-of-pit disposal cell (HDS OOP cell consolidated sludge).
    - Fluid expressed during consolidation of the HDS out-of-pit disposal cell (HDS OOP cell expressed fluid).
- Brine located in the Pit 3 underfill.

The post-closure source terms include those that will be initially present at site closure but will not be long-term sources and those that will continue to release solutes to the groundwater for a long time after site closure. The initial source terms are the pit tailings flux in Pits 1 and 3, TSF plume, residual mass in the saturated waste rock, the expressed fluid from the HDS out-of-pit disposal cell, and brine. The long-term sources are tailings, leachate from the waste rock vadose zone, HDS deposited into Pit 3, and the consolidated sludge in the HDS out-of-pit disposal cell.

A number of targeted studies have also been completed to improve the substantial data set used in the source term update study. In November 2019 through to January 2020, a targeted drilling campaign was undertaken to address data gaps identified within the 2018 Feasibility Study (ERA, 2021c). Some locations were subsequently converted into groundwater wells to facilitate future closure monitoring. Data obtained through this campaign informed the operational period groundwater source terms (TSF, PPA, and the Stockpile Plume).

Updating the source term conceptual models considered 20 solutes as potential COPCs: aluminium (Al), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), nickel (Ni), nitrate (NO3-N), lead (Pb), total phosphorus (P total), polonium-210 (210Po), radium-226 (226Ra), selenium (Se), sulfate (SO4), total ammoniacal nitrogen (TAN), uranium (U), vanadium (V), and zinc (Zn). A screening process utilised groundwater background threshold concentration values (BTVs) described in the previous section (ERM 2020c), to identify the solutes considered to be COPCs for each source term.

A summary of the solutes identified as COPCs for the Ranger source terms are shown in Table 5-23.

Table 5-23: Summary of solutes identified as COPCs for the Ranger solute source terms

Solute	Source Terms													
	Pit 1 tailings & PTF	Pit 3 tailings & PTF	VZ WR leachate	SZ WR	TSF Plume		Stockpile Plumes	PPA Plume	RP2 Plume	LAAs	HDS in Pit	HDS OOP cell consolidated sludge	HDS OOP cell expressed fluid	Brine
					Inside Footprint	Outside Footprint								
Al	x	x			x	x		x			x			x
Ca	x	x	x	x	x	x	x	x	x		x	x	x	x
Cd	x	x			x	x			x			x		x
Cr	x	x			x	x		x	x		x			x
Cu	x	x			x	x		x			x			x
Fe	x	x	x	x	x	x	x	x	x		x			x
Mg	x	x	x	x	x	x	x	x	x		x	x	x	x
Mn	x	x		x	x	x	x	x	x		x			x
Ni	x	x		x	x	x		x	x		x			x
NO3-N	x	x			x	x		x						x
P-total	x	x	x	x	x	x			x		x			x
Pb	x	x			x	x		x						x
Po210	x	x	x	x	x	x	x	x	x		x	x	x	x
Ra226	x	x		x	x	x	x	x	x		x	x	x	x
Se	x	x			x	x		x	x		x			x
SO4	x	x	x	x	x	x	x	x	x	x	x	x	x	x
TAN	x	x		x	x	x		x					x	x
U	x	x		x	x	x	x	x	x		x			x
V	x	x			x	x		x	x					x
Zn	x	x			x	x		x			x			x

x – solute identified as a COPC
green highlighted cell – concentration developed based on source-specific data
yellow highlighted cell – concentration estimated, typically from a ratio in a surrogate source
unhighlighted cell – solute not a COPC
OOP – out-of-pit

Follow up review of the study by SSB identified that shallow groundwater, below and downstream of RP1, could also be considered as an initial condition post closure source but were not included in the source term study. ERA undertook a desktop assessment to review available data and assess the potential environmental risk, (ERA 2021a; ERA 2021b). These assessments concluded that while the shallow groundwater source was not included in the updated solute source term model, the potential source size and resultant comparable impact identified that if the source was included, it would not influence the results of the post closure solute transport modelling with uncertainty analysis. The assessment also identified that if the initial-condition, elevated solute concentrations in shallow groundwater are associated with mining activities, then the source would be associated with historical waste rock stockpiling which is included as a post closure source.

The solute source terms were used as input to the post closure solute transport groundwater modelling with uncertainty analysis discussed in WS2.

5.2.3.3 Literature review on contaminant mobility

Factors influencing contaminant mobility in the sources and several pathways are covered by multiple KKNs. Literature reviews inform each of the projects in these KKNs. The activity titled *Literature review on contaminant mobility* relates to summarising how this information has been used in modelling and identifying information that could be used to support future modelling or understand contaminant behaviour for assessing risks.

Details relevant to each KKN are described below. Several of these have been closed during the MCP reporting period leaving the focus of this activity being the surface and groundwater pathways.

KKN	Compartment	Why factors controlling mobility need to be understood	Status
WS1B	Sources	Contributes to whole-of-site contaminant transport modelling to predict post-closure water quality. Inform the rehabilitation and risk management of the site.	ERA undertook a literature review of contaminant mobility in the sources and the groundwater and surface water pathways in 2020. SSB reviewed this work and suggested reviewing the need for additional information once final scenarios for predicting post-closure surface water quality are completed. The water pathways risk assessment showed which predicted post-closure COPC concentrations are not acceptable. Actions to review the reactive nature of those COPC have been raised and will provide the scope for completing the review of contaminant mobility.
WS2B	Groundwater pathway	Is conservative modelling or reactive modelling required? What factors are important?	
WS3C	Surface water pathway		
WS3G	Surface water –sediment interactions	To determine if closure criteria will protect both environmental compartments	U & S identified as sediment CoPEC (contaminant of potential environmental concern). McMaster *et al.* (2020)

KKN	Compartment	Why factors controlling mobility need to be understood	Status
			developed and algorithm for predicting concentrations of U in sediment based on water quality and showed that the SSB U rehabilitation standard for water protects biota in both the sediment and water matrices. The SO_4 rehabilitation standard derived by SSB to protect ASS forming is based on the water quality associated with the formation of ASS at Coonjimba Billabong and RP1. ARRTC closed this KKN in November 2020.
WS3E	Groundwater – surface water interactions	Potential to limit or increase their concentrations from groundwater to surface water. Which could affect surface water quality predictions.	Based largely on INTERA (2021a) ARRTC closed this KKN in May 2021 noting that the focus was now moving to adaptive management and monitoring.
WS5B	Bioavailability and toxicity of sediments contaminants	Bioavailability mentioned in KKN title not in question. Question is about the Influence of toxicity modifying factors to enable (U) guideline value to be adjusted if sediments different from Gulungul Billabong.	Sediment was one of the sources reviewed in the draft contaminant mobility report reviewed by SSB. Relevant reports were provided to SSB who completed work on this project (McMaster *et al.* (2020). ARRTC closed this KKN in November 2020.
RAD9B	Concentration factors for bushfood	Quantify transfer from the environment (e.g. soil and water) to food items.	This is a SSB KKN.

5.2.4 WS2 Predicting transport of contaminants in groundwater

KKN title	Question
WS2. Predicting transport of contaminants in groundwater	WS2A *What is the nature and extent of groundwater movement, now and over the long-term?*
	WS2B *What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?*
	WS2C *What are predicted contaminant (including nutrients) concentrations in groundwater over time?*

5.2.4.1 Groundwater movement and modelling

The tropical, monsoon climate of the NT creates seasonal changes that drive groundwater flow into and out of the Ranger Mine area. Groundwater occurrence and flow through the RPA consists of a shallow groundwater flow system, within the relatively permeable alluvium and weathered rock, and a deeper bedrock groundwater flow system with relatively low permeability, in which groundwater is encountered within faulted, sheared, cracked and brecciated rocks. Groundwater also occurs in intermediate layers of weathered bedrock between the shallow and deeper groundwater flow systems.

The alluvial and weathered rock aquifers are more connected to each other than to the deeper, fractured rock aquifer, and show similar seasonal variations in groundwater levels and quality (INTERA 2016). Groundwater within the fractured rock aquifer is weakly connected to near-surface processes, particularly rainfall-recharge, and there is limited mixing of groundwater between the shallow and deep aquifer units.

Groundwater generally flows northward across the minesite towards Magela Creek (Salama & Foley 1997, Weaver et al. 2010). Figure 5-59 shows the annual groundwater level behaviour illustrating fluctuations that follow a similar, distinctive wet season – dry season oscillation akin to, but in a more subdued form than the typical surface water flow hydrograph, typically peaking following wet season recharge and declining during the dry season recession (INTERA 2019a).

In general, groundwater heads appear to increase several metres during the first one to two months of the wet season and then decrease several metres within the first two to three months of the dry season. Along Magela Creek, water exchange between the subsurface and flowing creek depends on groundwater and surface water dynamics (INTERA 2016). When surface water flow ceases in Magela Creek and Corridor Creek, subsurface groundwater flow continues through the deeper alluvial sediments of the creek beds throughout the dry season (Ahmad et al. 1982).

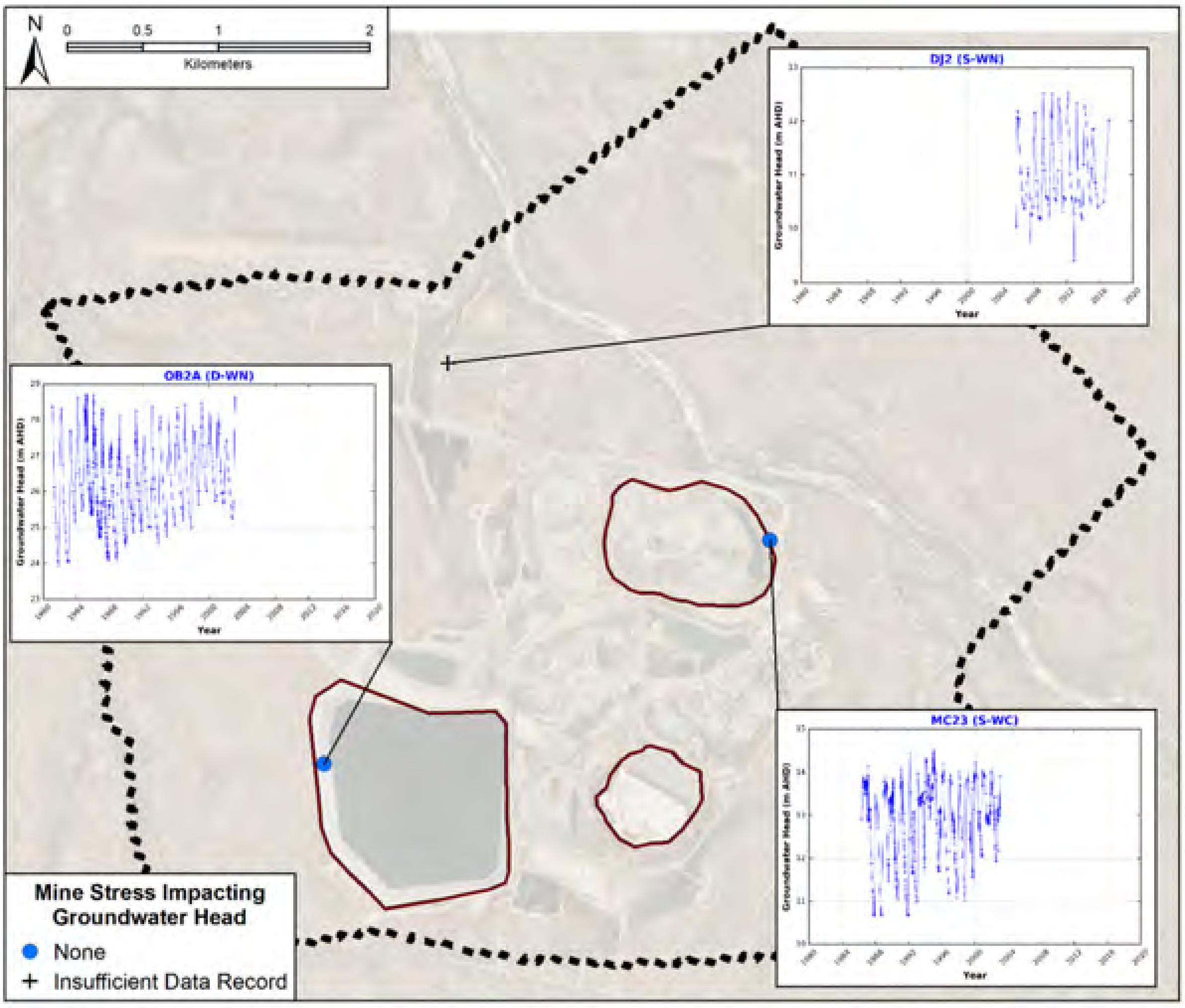


Figure 5-59: Hydrograph showing examples of seasonal groundwater head fluctuations (INTERA 2019a)

5.2.4.2 Ranger Conceptual Model

The calibrated flow model is intended to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions. The Ranger Conceptual Model (RCM) report describes the data, methods, and results for the site wide hydrogeological conceptual model update; construction, calibration, and sensitivity analysis of the site wide groundwater flow model; and completion of a preliminary groundwater flow model for post-closure conditions. The executive summary from the 2019 Ranger Conceptual Model report is provided below.

The conceptual model for the new site wide domain was iteratively updated through compilation and examination of all available climate, surface water, groundwater, geologic, and bore data to provide the highest level of detail and confidence in accordance with the modelling objectives and available resources. The updated conceptual model describes the most important hydrogeologic elements governing groundwater flow and transport at the

Ranger Mine. The work produced data sets from nearly 2,000 exploratory bores, many hundreds of monitoring and other bores, many dozens of pump and slug tests, all major geologic contacts, more than 80,000 individual groundwater head measurements collected at more than 450 monitoring bores across the sitewide domain, and information about rainfall, evapotranspiration (ET), and creek stages spanning 37 years from 1980 to 2017.

The Ranger Conceptual Model domain was expanded to encompass all available information both upstream and downstream of the Ranger minesite. The conceptual model domain is larger than that for the calibrated groundwater flow model in order to use data outside of the model domain to constrain the HLU extents at the model boundaries and to define HLUs for an area large enough to fall within an appropriate extent for post-closure groundwater flow and transport modelling. The model domains are presented in Figure 5-60.

The RPA contains three distinct regional HLU zones: alluvial, weathered and bedrock. These HLU zones are discretised into specific HLUs, which describe the geological, groundwater flow and transport characteristics of that unit.

A HLU can consist of a single geologic unit, part of a geologic unit, cross geologic units and mining related units in the subsurface that will be in contact with groundwater. HLUs can be aquifers or aquitards depending on their permeability. All material in which groundwater flows is assigned to an HLU, and the HLUs are the building blocks for the material components of the groundwater flow model.

The HLUs were originally conceptualised as part of the development of the Ranger conceptual model in 2016 by INTERA (INTERA, 2016). The HLU's were reviewed and updated as part of the Ranger Conceptual Model update (INTERA 2019a). Further review and update of the HLUs were undertaken as part of the solute transport modelling with uncertainty analysis (INTERA 2021b) to support Key Knowledge Need (KKN) WS2. A breakdown of the Ranger Mine HLUs is shown in Table 5-244.

Table 5-24: Ranger Conceptual Model HLUs, INTERA (2021b)

Shallow HLUs	**Deeps HLUs**
Magela Creek sediments (MCS)	Shallow bedrock Cahill (S-BC)
Other creek sediments (OCS)	Shallow bedrock Nanambu (S-BN)
Higher-K zone of deep weathered Nanambu in the north of TSF	Higher-K zone of shallow bedrock Nanambu in the north of TSF (D-WN-H)
Shallow weathered Cahill (S-WC)	MBL zone (MBL)
Deep weathered Cahill (D-WC)	Depressurised UMS (D-UMS)
Zone C weathered carbonate (ZCWC)	Zone C shallow bedrock (ZCWC)
Pit 1 permeable zone (Pit1-P)	Hanging wall sequence (HWS)
Depressurised UMS confining unit (D-UMS-C)	Upper mine sequence (UMS)
Shallow weathered Nanambu (S-WN)	Lower mine sequence (LMS)
Higher-K zone of shallow weathered Nanambu in the west of TSF (S-WN-HW)	Lower-k deeps water-producing zone (DWPZ-L)

Shallow HLUs	Deeps HLUs
Higher-K zone of shallow weathered Nanambu in the north of TSF (S-WN-HN)	Higher-k deeps water-producing zone (DWPZ-H)
Deep weathered Nanambu (D-WN)	Nanambu Complex (Nam)
Djalkmara sands (DS)	

Figure 5-60: Spatial domain of the hydrogeological Ranger Mine conceptual model relative to the domain of the calibrated groundwater flow model.

Updates to the conceptual model focused on extending and improving the HLUs and hydrogeologic framework as well as determining site-specific estimates of recharge and ET. The extensive data sets from bores, geologic mapping, and hydraulic testing were used to modify existing HLUs and add new HLUs. Estimates of recharge and ET were calculated using observed seasonal changes in groundwater heads at shallow bores distributed across the Ranger mine site.

The calibration of the groundwater flow model incorporates the major stresses applied to the Ranger Mine groundwater flow system at Pit 1, Pit 3, and the TSF over the 40 years of operation. Mining of Pit 1 and associated pumping of a dewatering bore, and mining of Pit 3, caused very large head decreases in the adjacent HLUs over many years. Partial backfilling locally raised the heads in the pits in relatively short times. For more than 37 years, process water storage in the TSF applied a head increase on the footprint of the TSF. These mining activities stressed large volumes of the shallow and deep Ranger Mine groundwater flow systems to a far greater degree and spatial extent than any long-term pump tests.

To accommodate all the changes in pit materials and stresses over time, the calibrated flow model is sub-divided into five sequential models: a pre-mining, steady-state model, and four transient models covering the time periods 1980 to 1996, 1997 to 2005, 2006 to 2012, and 2013 to 2017. To enable reasonable calibration model run times, annual stress periods representing water years were used for 33 of the 37 water years simulated. For four water years, monthly stress periods were used to calibrate the model to observed seasonal fluctuations in groundwater heads. Recharge, ET and surface water stages are also included as stresses.

The numerical groundwater flow model was constructed using the MODFLOW-NWT code to encompass the Ranger Mine, all surface water receptors downgradient of the mine, all important areas driving groundwater flow to the receptors from the mine area, and all HLUs from shallow to deep. The calibrated model covers about 29 km2 and vertically spans nearly 800 m, making it the largest Ranger Mine groundwater flow model to date. Discretised into 30 m by 30 m grid cells in the horizontal plane and 19 layers, the model grid contains roughly 612,940 active cells. The model simulation period encompasses a pre-mining, steady-state period and the 37-year mining period, which is far longer than in any previous Ranger Mine calibrated flow model.

The transient groundwater flow model, INTERA (2019a), was calibrated by compiling calibration head targets and iteratively using manual and automated methods to adjust model parameters, compare simulated and observed head targets, and calculate calibration statistics. From examination of the available groundwater head data from more than 450 bores, about 100 head targets were estimated for the pre-mining, steady-state calibrated flow model and more than 8,500 head targets were developed for the transient calibrated flow model. A manual or trial-and-error process was used to define, modify, and refine the spatial extents of model zones representing key HLUs. Calibration of zone hydraulic properties for all appropriate HLUs was conducted by coupling parameter estimation tool (PEST) software with MODFLOW-NWT. Calibration statistics, hydrographs, and other standard metrics were used to quantify whether the change in zone properties improved the match between observed and simulated heads.

Results from the flow model calibration undertaken in 2019 revealed that the model adequately simulates groundwater flow with small average error relative to measurement errors and captures temporal groundwater head variations. Further transient model calibration was undertaken as part of the preparation task of the groundwater modelling of the uncertainty analysis study, INTERA (2021b). This calibration was undertaken as an additional 1469 calibration targets were available due to the time passed since the previous model calibration which ensured all available data was used to support the uncertainty analysis. The calibration statistics are provided in Table 5-25 for all HLUs with the exception of HLUs with less than 25 calibration targets due to insufficient data to provide meaningful statistics.

Simulated monthly heads at many bores adequately represent observed seasonal head changes in both timing and magnitude and simulated annual average heads at most bores adequately represent year-to-year changes. Scatter plot of simulated versus observed heads depict random scatter about the 1:1 line for both the entire model and most individual HLUs, indicating negligible bias, as shown in Figure 5-61. Overall, the calibration metrics indicate that both the pre-mining, steady-state and transient models are well calibrated to the observed data. Water balance errors are negligible for the pre-mining, steady-state and transient calibrated flow models and the water balances show good agreement with conceptualisation.

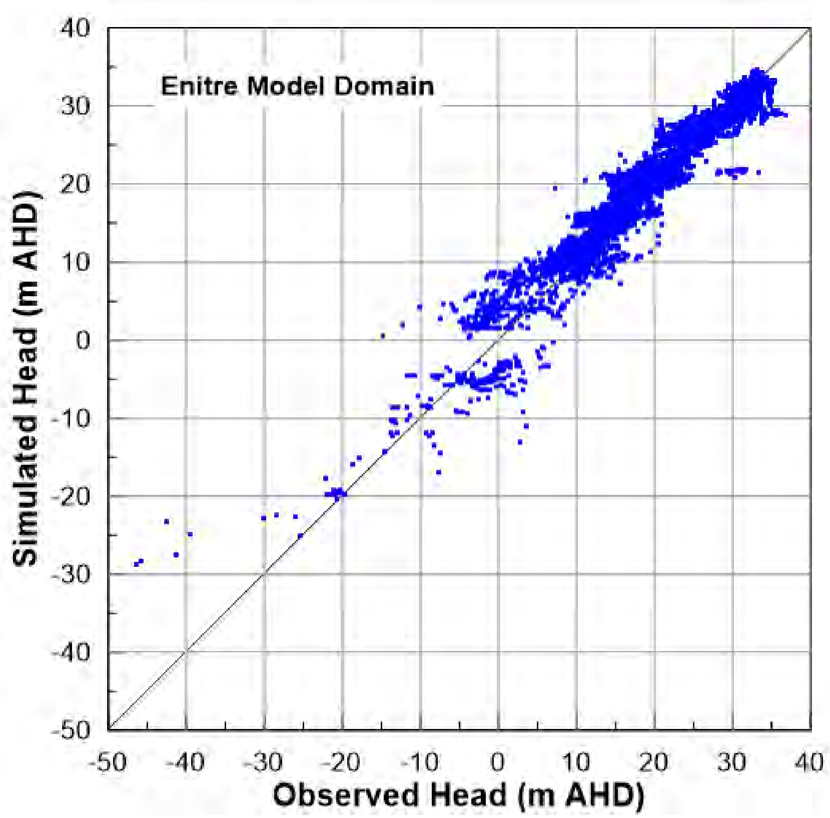


Figure 5-61: Scatter plot of simulated versus observed groundwater heads for all calibration targets in the entire calibrated model domain for the updated transient model, INTERA (2021b)

Table 5-25: Calibration statistics for the updated transient groundwater flow model, INTERA (2021b)

HLU	Count	Mean Error (m)	Mean Absolute Error (m)	Root Mean Square Error (m)	Absolute Minimum Residual (m)	Absolute Maximum Residual (m)	Measured Range (m)	RMSE/ Range (%)	MAE/ Range (%)
Model Domain	10,118	-0.48	1.55	2.2	0	19.08	83.07	3	2
Shallow HLUs									
All	6,432	-0.49	1.26	1.76	0	14.26	44.99	4	3
Djalkmara sands	98	-0.04	1.14	1.65	0.02	6.3	9.73	17	12
shallow weathered Cahill	193	-0.25	0.91	1.24	0.01	3.92	10.35	12	9
deep weathered Cahill	1,012	-0.77	1.56	2.14	0	14.26	33.82	6	5
Zone C weathered carbonate	156	-0.38	1.73	2.38	0.01	5.86	21.77	11	8
Pit 1 permeable zone	378	-1.8	1.96	2.37	0.02	6.37	7.94	30	25
shallow weathered Nanambu	1,766	-0.07	0.82	1.08	0	4.65	28.97	4	3
higher-K zone of shallow weathered Nanambu in the west of TSF	88	-0.9	1.04	1.69	0.04	12.16	19.23	9	5
higher-K zone of shallow weathered Nanambu in the north of TSF	162	-0.45	1.27	1.58	0	9.35	10.92	14	12
deep weathered Nanambu	2,459	-0.57	1.37	1.87	0	7.33	25.85	7	5
higher-K zone of deep weathered Nanambu in the north of TSF	120	0.68	1.09	1.39	0.01	3.66	7.23	19	15
Deep HLUs									
All	3,686	-0.46	2.05	2.8	0	19.08	83.07	3	2
shallow bedrock Cahill	450	-2.66	2.85	3.48	0.02	9.55	24.56	14	12
shallow bedrock Nanambu	1,425	0.66	1.66	2.33	0	11.76	22.82	10	7
higher-K zone of shallow bedrock Nanambu in the north of TSF	334	-2.04	2.2	2.57	0.03	7.76	8.85	29	25
MBL zone	1,161	-0.88	1.81	2.41	0	8.42	23.25	10	8
depressurised UMS	262	1.37	3.59	4.77	0.02	19.08	61.65	8	6
Zone C shallow bedrock	43	-1.47	2.37	4.32	0.07	15.15	30.31	14	8

Model validation, through comparison of simulated and observed inflows to the Ranger 3 Deeps (R3D) decline over roughly 5 years, reinforces the high level of confidence in the conceptual and calibrated flow models. The calibrated groundwater flow model was updated to include the stress on the groundwater system from the excavation of the R3D decline and was used to simulate inflows into the R3D decline for comparison to observed data from start of excavation in 2013 through August 2017 (end of transient model calibration period). This implementation of the model provided a check on the calibrated hydraulic properties for both shallow and deep HLUs intersected by the decline. Inflow to the decline modelled using the calibrated hydraulic properties yielded a good match to the observed inflows. This simulation of inflows to the R3D decline serves as validation for the calibrated flow model and shows that the model calibration process incorporated both groundwater head and flux data.

A thorough sensitivity analysis was performed on the INTERA (2019a) calibrated model to determine how model predictions varied with changes to model parameter values and boundary conditions. A sensitivity analysis is a widely accepted means of formally describing the change in model outputs (predictions) caused by changes in specific model inputs or groups of inputs (parameters). The sensitivity analysis on the Ranger Mine calibrated flow model first systematically increased and decreased individual model input parameters for hydraulic properties and boundary conditions from their calibrated values whilst all other input parameters remained constant, ran the model and recorded changes in model predictions for the pre-mining, steady-state model and the transient model. The sensitivity analysis also looked at how model predictions were affected by changing the properties of the Ranger Fault used to define the model southern boundary and by changes to the amount of recharge applied to the waste rock stockpiles.

The analysis revealed that the calibrated flow model is sensitive to a sizeable number of model parameters, demonstrating that the site-specific data used to build and calibrate the flow model do constrain the values of the model parameters. The real-world constraints on the parameters effectively decrease the uncertainty in the parameter values, which in turn means there is increased confidence gained through the calibration process. In particular, the sensitivity analysis shows that the calibrated groundwater flow model for the Ranger Mine is sensitive to many of the parameters previously identified to be important for evaluation of post-closure solute loading to receptors. Removing the Ranger Fault as a low-permeability barrier to groundwater flow did not affect the calibration statistics. A large increase in the amount of recharge applied to the waste rock stockpiles also did not affect the calibration statistics.

The hydraulic stresses driving groundwater flow during the post-closure period are essentially the same as those in the pre-mining period. For the purpose of this task, and consistent with previous modelling, the stresses driving groundwater flow during the 10,000-year assessment period were represented as steady driving forces based on long-term averages. The steady flow stresses were calculated using the same 37-year historical record that was used to develop the pre-mining, steady-state stresses for the INTERA (2019a) calibrated flow model.

Simulated shallow and deep groundwater heads demonstrate that the post-closure groundwater flow model is a topographically driven flow system. Heads are highest where the topography of the final landform waste rock is highest, and groundwater flows from the higher elevation recharge areas to the lower elevation discharge points in the creeks. Vertical groundwater head gradients are also consistent with topographically-drive flow, with downward gradients in topographically higher areas and upward gradients in topographically lower areas.

Development of the post-closure groundwater flow model consisted of modifying the calibrated groundwater flow model to represent backfill, landform conditions, and the time scale of post-closure hydrogeologic conditions. The HLU assignments for the post-closure flow model mostly follow those from the calibrated model except where additional backfill materials were included in the pits and where waste rock will be placed to create the final landform.

The Ranger Mine site wide modelling process and conceptual and numerical flow models were examined to determine compliance with the relevant guiding principles from the Australia groundwater modelling guidelines. The examination demonstrated that the Ranger Mine site wide modelling process complies with the guiding principles from the Australian Groundwater Modelling Guidelines. Agreement of the calibrated Ranger Mine groundwater flow model with the applicable guiding principles demonstrates that the planning, conceptualisation, design and construction, calibration and sensitivity analysis, and reporting of the Ranger Mine conceptual and numerical calibrated flow models were completed appropriately and provide the model with a very high level of confidence. The Ranger Mine groundwater calibrated model will meet all indicators for the Level 3 confidence level (highest confidence level).

The Ranger conceptual model has undergone multiple independent reviews and was found to be a significant improvement over past models with the only major outstanding concerns at the time relating to the lack of a formal uncertainty analysis which has since been completed and discussed in the next section. The Ranger conceptual model was found to meet appropriate industry standards and is fit for purpose.

5.2.4.3 Post-closure groundwater solute transport modelling with uncertainty analysis

A calibration-constrained, predictive groundwater model with uncertainty analysis, based on an updated Ranger flow calibration model (INTERA 2019a), has been developed to provide COPC loads at selected probability values for input to a predictive surface water model (SWM), to address KKN WS2 and inform WS3. INTERA were engaged by ERA to complete the modelling study following the development and update of the RCM, INTERA (2016) and INTERA (2019a), and update of the Ranger Solute Source Terms, INTERA (2020a) described in previous sections. The predictive Ranger groundwater model with uncertainty analysis (Ranger GW UA) study was completed in 2021, INTERA (2021b). The Ranger GW UA provides probabilistic simulations of solute loads to the creeks for 20 COPCs: magnesium, uranium, manganese, radium-226, total phosphate, nitrate as nitrogen, total ammonia as nitrogen, polonium-210, iron, copper, lead, cadmium, zinc, chromium, vanadium, calcium, nickel, selenium, aluminium, and sulfate.

The Ranger GW UA comprised three sets of tasks: preparation, implementation, and results compilation. The development of conceptual models for COPC sources for the Ranger GW UA is described in a separate report, INTERA (2020a), to support KKN WS1. All tasks were carried out with review and input from the SSB and IGS, during a series of eight presentations in conference calls that began at project kick-off in December 2019 and ended in October 2020.

The preparation tasks focused on:

- Identifying and compiling relevant information to define prior parameter probability density functions for all randomly varied model parameters,
- Updating and re-calibrating the Ranger sitewide groundwater flow model, and
- Constructing and testing the predictive flow and transport model.

The implementation tasks focused on:

- Create prior probability density functions, which include expert and site-specific knowledge, for all model parameters after identifying and compiling site-specific data and relevant information from the scientific literature.
- Generate random samples (stochastic realisations) from prior parameter probability density functions and then use a null space projection operation to condition these realisations so that they reproduce historic site-specific observations. These projected realisations are, by definition, posterior parameter realisations since they were drawn from the prior parameter probability density functions and honour the site-specific observations used for model calibration.
- Generate stochastic realisations from the prior parameter probability density functions for parameters that are only present in the predictive model. By definition, these parameters cannot be conditioned on historic observations. The random predictive model parameter values were appended to the posterior parameter realisations to create 983 realisations of parameter sets needed to run the predictive model.
- Run the resulting realisations in the predictive model to produce 983 equiprobable predictions of Mg loading with parameters that honour the large set of historic observations.

The results Compilation tasks focused on:

- Compile predicted Mg loads within the Ranger mine area’s four ground water sheds to compute probability values for peak loads.
- Run selected predictive model realisations over 10,000 years.
- Run selected realisations in the variable density predictive model for the brine source.

- Calculate total Mg loads at 10,000 years from all sources.
- Compile peak loads and loads at 10,000 years for all other COPCs.
- Prepare input tables of COPC loads for surface water modelling through the updated groundwater surface water interaction to support KKN WS3.

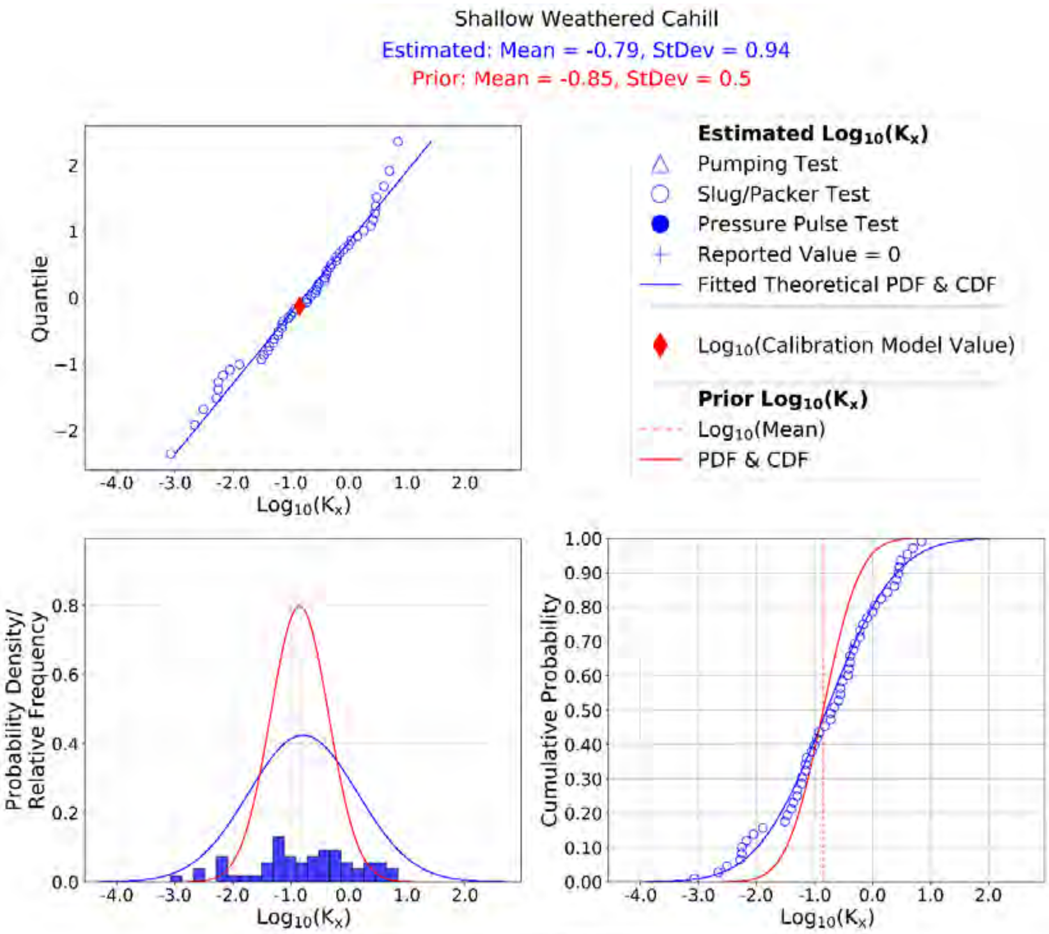
The Ranger GW UA was a comprehensive modelling study that determines groundwater loads of 20 COPCs, and their posterior predictive uncertainty, to Magela Creek and its three tributaries from all Ranger mine sources at a sitewide scale over a 10,000-year post-closure assessment period to address KKN WS2. The COPC loads are intended to inform a predictive surface model to predict COPC concentrations in receptor creeks to address KKN WS3.

The implementation tasks involved compiling all site-specific data and scientific literature information about hydraulic conductivity (K) and specific storage measurements, recharge rate estimates, and source term COPC data. This information was used to both update the calibration of the Ranger Conceptual model, described in the previous section, and used in defining prior parameter probability density functions required to support the uncertainty analysis process. Following update and re-calibration of the Ranger conceptual flow model, the predictive flow and transport model was developed and tested to simulate COPC loading from the Ranger mine sources, described previously to address KKN WS1, to surface water receptors over the 10,000 year post-closure assessment period. Groundwater flow was simulated as steady-state flow specified to represent average long-term conditions for groundwater recharge, evapotranspiration, and creek stage after he groundwater flow system has re-equilibrated with climatic stresses. These initial simulations, undertaken with the calibrated flow model were considered the base-case simulations.

A separate predictive model was constructed and tested to simulate, under variable-density conditions, the loading from the dense, viscous brine stored in the Pit 3 underfill to Magela Creek.

Following development and testing of the post closure flow models, the next set of tasks commenced to implement the uncertainty analysis. The implementation tasks started with the development of the prior probability density functions for the 135 model parameters found in both the calibration and predictive models. These model parameters include the normal hydraulic parameters as well for groundwater recharge, groundwater evapotranspiration, and anisotropy ratios. An example of a prior probability density function describing the horizontal conductivity of the shallow weathered Cahill HLU is provided in Figure 5-62.

The prior parameter probability density functions means and standard deviations were used as inputs to the PEST RANDPAR utility (Watermark Numerical Computing, 2019) to generate 1,000 prior parameter realisations, each of which contains a randomly sampled value for each of the 135 parameters. The 1,000 realisations were then subjected to the null-space projection operation for conditioning, and, where necessary, an additional PEST re-calibration optimisation iteration, to produce posterior parameter realisations that honoured the calibration data to the extent possible. Out of the 1,000 realisations, 17 produced unacceptably high posterior phi (calibration) values and were rejected, yielding 983 posterior parameter realisations, all of which had negligible water balance errors.



Prior		
Quantile	K_x (m/d)	$Log_{10}(K_x)$
0.05	2.1E-02	-1.67
0.5	1.4E-01	-0.85
0.95	9.4E-01	-0.03

Figure 5-62: Prior Kx probability density function for the shallow weathered Cahill HLU

Prior probability density functions were defined for the 70 model parameters found only in the predictive flow and transport model by examining available site-specific and literature data. This information was used to choose the mean and standard deviations for each prior probability distribution function (PDF). Predictive parameter priors were defined for the hydraulic (K and anisotropy) and transport (i.e. effective porosity) properties of HLUs found only in the predictive model (three types of Pit 3 consolidated tailings, Pit 1 consolidated tailings, and waste rock), groundwater (GW) recharge and GW ET on the landform waste rock, and COPC concentrations for the sources. Each major source was represented as a separate species in the predictive simulations to enable tracking of loads from each source to each of the four groundwater sheds.

Constructing parameter realisations for the predictive flow and transport model required two steps. First, random samples from each of the predictive parameter prior PDFs were generated with PEST's RANDPAR routine. The resulting predictive parameter realisations, each containing randomly sampled values of the 70 predictive model parameters, were combined with the posterior parameter realisations from the calibration model to create 983 realisations with the parameters needed to run the predictive model. These 983 realisations were then run in the predictive MDOFLOW-NWT (Niswonger et al. 2011) flow model and the MT3D-USGS (Bedekar et al. 2016) solute transport model.

Results from the modelling simulations were compiled for 3 physical settings, all groundwater sheds total loading, Coonjimba groundwater shed loading and Corridor creek groundwater shed loading, and for two time periods, the period during which peak loads are predicted to occur and at. 10,000 years. Peak Mg loads for each setting were calculated from the 983 equiprobable predictions by combining loads from the output files for all Mg species and determining the peak load and year of peak load for each realisation.

Examination of the total loading values for all 983 realisations over the 300-year initial simulation time revealed that all peaks occurred within the first 100 years post closure.

Probability values were computed for these peak Mg loads by compiling cumulative density functions from the 983 predictive realisations. Loads at seven probability values, called P-values, were selected to prepare loads for use in the predictive surface water model: 0.05, 0.10, 0.20, 0.50, 0.80, 0.90, and 0.95 (i.e. P05, P10, P20, P50, P80, P90, and P95). A chart showing the cumulative distribution function for Mg loads is presented in Figure 5-63.

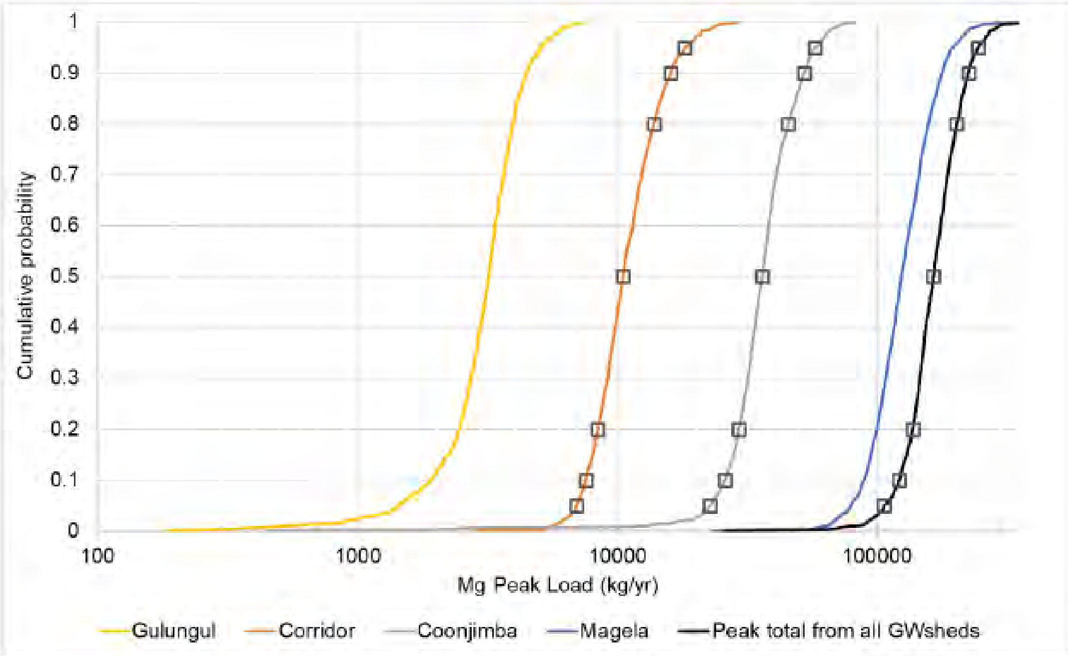


Figure 5-63: Cumulative distribution functions for peak Mg loads from the 983 predictive model runs.

Peak loads for other COPCs were calculated using a combination of scaling of Mg loads for some sources and simulations of COPC loads from plume sources. Other COPC results for the seven P-values were scaled using ratios of COPC to Mg concentrations for all but the plume sources. Loads from COPCs in the plume sources were determined from model simulations and added to the scaled loads to compute peak COPC loads.

Total loads for other COPCs at 10,000 years at the seven P-values were calculated using concentration ratios to scale Mg loads at 10,000 years from all active sources: brine, vadose zone waste rock leachate, tailings, and HDS (both in-pit disposal and consolidated sludge in the HDS out-of-pit disposal cell). SO_4 loads from vadose zone waste rock leachate were corrected to account for the exhaustion of pyrite over time.

The final compilation step was to prepare COPC loading input files for the predictive SWM. Loads at each GW shed for each setting and time period were compiled for each of the seven P-values into files for use in predicting surface water (SW) concentrations. Four of the compiled P50 simulation results were carried forward into the surface water modelling, the peak all groundwater sheds loading, the peak Coonjimba groundwater shed loading, the peak Corridor Creek groundwater shed load, and the all water sheds 10,000 year loading. Additionally, to support sensitivity analysis in the surface water modelling the P10 and P90 all groundwater sheds peak loading simulations were simulated in the surface water model. Surface water modelling is discussed later in this section to address KKN WS3.

In summary the Ranger GW UA provides robust predictions of post-closure COPC loads to creek receptors because it defined and incorporated parameter uncertainty from over 200 model parameters into its predictions of groundwater flow and transport to quantitatively estimate the predictive uncertainty.

Peak loads and total loads to creek receptors at 10,000 years for all COPCs were estimated with probability values that define the predictive uncertainty in the Ranger GW UA. These load values are derived from 983 equiprobable realisations that combine calibration-constrained posterior parameters with random samples of predictive model parameters. This means that the 983 predictions of interest were made with 983 equally well calibrated sets of parameters, many of which had values that ranged randomly across multiple orders of magnitude. The predictive parameter realisations together effectively sampled the uncertainty in model parameters and boundary conditions across a wide range of probability values, and so provide a robust estimate of predictive uncertainty that imparts increased confidence in the Ranger post closure solute transport modelling with uncertainty analysis COPC loadings results.

The uncertainty analysis also included climate variability to assess influence of climate change to the extent possible by treating groundwater recharge rates as random parameters to account for uncertainty, both with and without conditioning by historical data.

The Ranger GW UA process and numerical models were examined to determine compliance with the relevant guiding principles from the Australia groundwater modelling guidelines and uncertainty analysis (UA) guidelines. The examination demonstrated that the Ranger GW UA process fully complies with the guiding principles for planning, conceptualisation, design and construction, calibration and sensitivity analysis, prediction, uncertainty, and reporting, and provides the Ranger GW UA modelling with the highest level of confidence. Perhaps more importantly, the combination of best scientific practice for a calibration-constrained Ranger GW UA, regular review and discussion with key stakeholders, technical guidance from one of the leading scientists for GW UA, Dr John Doherty, and access to the enormous amount of data collected at Ranger provide the highest level of confidence.

5.2.5 WS3 Predicting transport of contaminants between groundwater and surface water

KKN title	Question
WS3. Predicting transport of contaminants in surface water	WS3A. *What is the nature and extent of surface water movement, now and over the long-term?*
	WS3B. *What concentrations of contaminants from the rehabilitated site will aquatic (surface and ground-water dependent) ecosystems be exposed to?*
	WS3C. *What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?*
	WS3D *Where and when does groundwater discharge to surface water?*
	WS3E *What factors are likely to be present that influence contaminant transport (including nutrients) between groundwater and surface water?*

5.2.5.1 Groundwater / Surface water interaction

Understanding and quantifying groundwater to surface water interaction forms a key component for the linking the groundwater solute transport model to the surface water model. The groundwater to surface water interactions relate to the timing, and location of groundwater flow and in turn potential for solute transport from groundwater into the receiving environments. Understanding this relationship and accurately representing it in the modelling is vital to accurately predicting the possible contamination concentrations in the receiving environment.

INTERA were engaged by ERA to develop an updated groundwater to surface water interaction conceptual model to support integration of solute load predictions from the groundwater solute transport modelling into the surface water model update, INTERA (2021a). The conceptual model of groundwater/surface water interaction was updated based on an approach considering hydraulic gradients and surface water EC data. A hydraulic gradient assessment was conducted to calculate hydraulic gradient magnitudes and directions using site-specific groundwater head data at bores along Magela Creek and Magela Creek stage data from a surface water station near the Ranger mine.

An assessment of the EC data for both Magela and Gulungul creeks was also conducted. The updated conceptual model remains consistent with the conceptualisation presented in 2018 but is improved by the new data-driven understanding that:

- The hydraulic gradient and rate of groundwater discharge to Magela Creek surface water during high creek flow are not constant but vary in time.
- Groundwater loading decreases at a rate commensurate with the decrease in creek discharge after flood events, as indicated by the EC and historical Mg concentration data in Magela and Gulungul creeks.

The data used to define the timing of the start and end of groundwater discharge to Magela Creek surface water and the time-varying rates of that discharge not only improved the conceptual model of groundwater/surface water interaction, it also increased confidence in the integration of solute loading results from the groundwater modelling as surface water model inputs. Historical EC and point-in-time groundwater head data confirmed that the updated conceptual model is appropriate historically and for all locations along the portion of Magela Creek located next to the mine.

The conceptual model was updated using continuous (2018 to 2020) and historical (late-1980s to 2020) groundwater head data at six bores, historical (late-1980s to 2020) groundwater head data at an additional three bores, continuous historical and recent creek stage data (late-1980s to 2020), and continuous EC data in Magela Creek, Georgetown Billabong, and Gulungul Creek (2017 to 2020). The data indicate that hydraulic gradients are consistently towards the creek at upslope bores whereas hydraulic gradients vary in direction between the creek and closer bores. Gradient directions and magnitudes calculated from point-in-time (dipped) groundwater head data are consistent with those calculated using recent continuous (logger) groundwater head data.

The gradient dynamics observed between Magela Creek surface water, the groundwater in bores and the surface water chemistry follow the general sequence identified in the previous conceptual model for groundwater/surface water interaction. The updated sequence comprises the follow stages:

- No groundwater discharge to surface water early in the creek flow period because groundwater heads are lower than creek stage and EC data show no indication of groundwater loading.
- Groundwater discharges to surface water at various rates during the middle of the creek flow period (with occasional, relatively brief interruptions during high creek flows).
- Groundwater discharges to surface water at a typically decreasing rate starting from the early part of the flow recession period.
- Groundwater loading to surface water decline after flood events at a rate commensurate with the decline in creek discharge.
- No groundwater discharge to surface water during late recessional flow because groundwater heads are lower than creek stage and surface water EC does not change with time.

An updated hydrograph visualising the creek flow vs groundwater loading for the 2018-2019 Magela Creek flow period is shown in Figure 5-64.

Evaluation of the similarities and differences in the hydrology and EC of Magela and Gulungul creeks was undertaken and indicated that groundwater/surface water interaction is similar for the two creeks. A pair of hydrographs is shown in Figure 5-65 demonstrating the similarities in EC and creek flow between the Magela Creek and Gulungul Creek. Therefore, the updated conceptual model is considered to be appropriate for both Magela and Gulungul creeks.

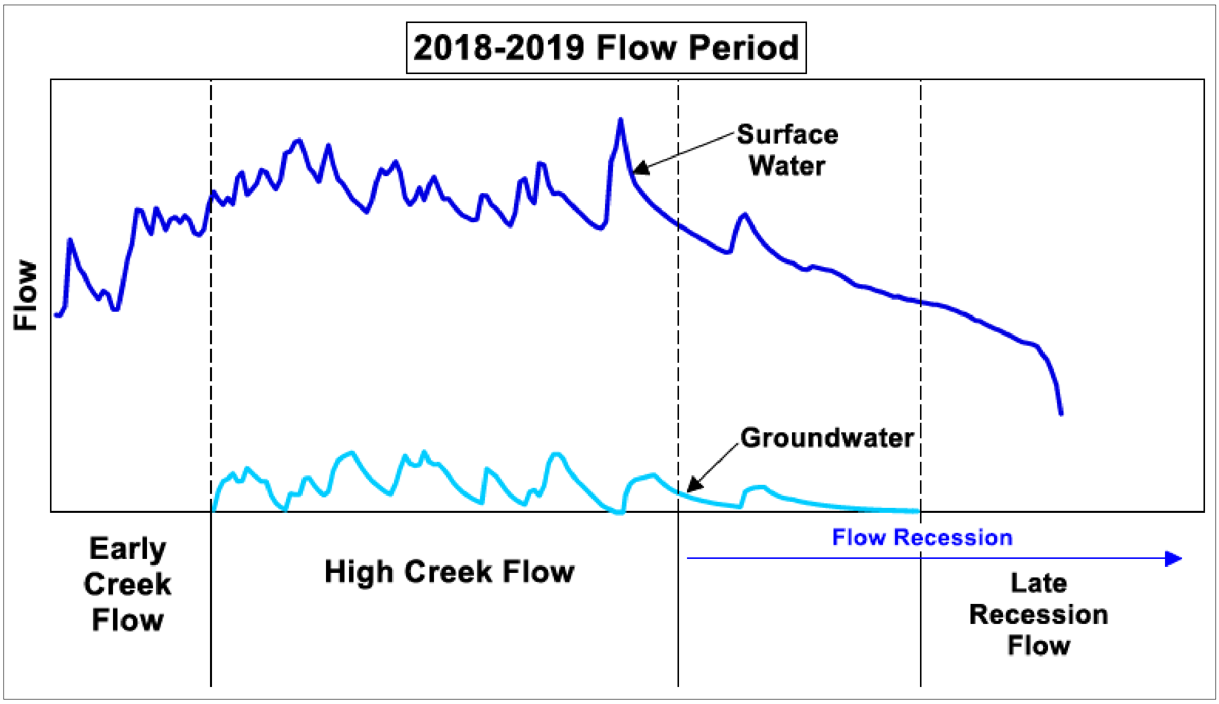


Figure 5-64: Updated conceptual model of groundwater surface water interaction

The amount of data used to develop the updated conceptual model is sufficient to provide confidence in the updated conceptualisation. Continuous groundwater head data are only available for the two recent wet seasons, but many historical point-in-time measurements corroborate the gradient findings from the recent data. In addition, the many years of continuous EC data provide historical confidence in the updated conceptual model. Monitoring of bores used in the groundwater to surface water investigation has continued and additional monitoring bores are in plan to be drilled alongside Gulungul creek to provide further confidence in the updated conceptualisation.

INTERA presented early findings of the study to the relevant ARRTC members at an out of session water and sediment focused workshop in October 2020 and the study report was provided to stakeholders for review and feedback in December 2020. Feedback on the study report was received from SSB in January and an updated report was provided to stakeholders in February. The study was endorsed by ARRTC in 2021.

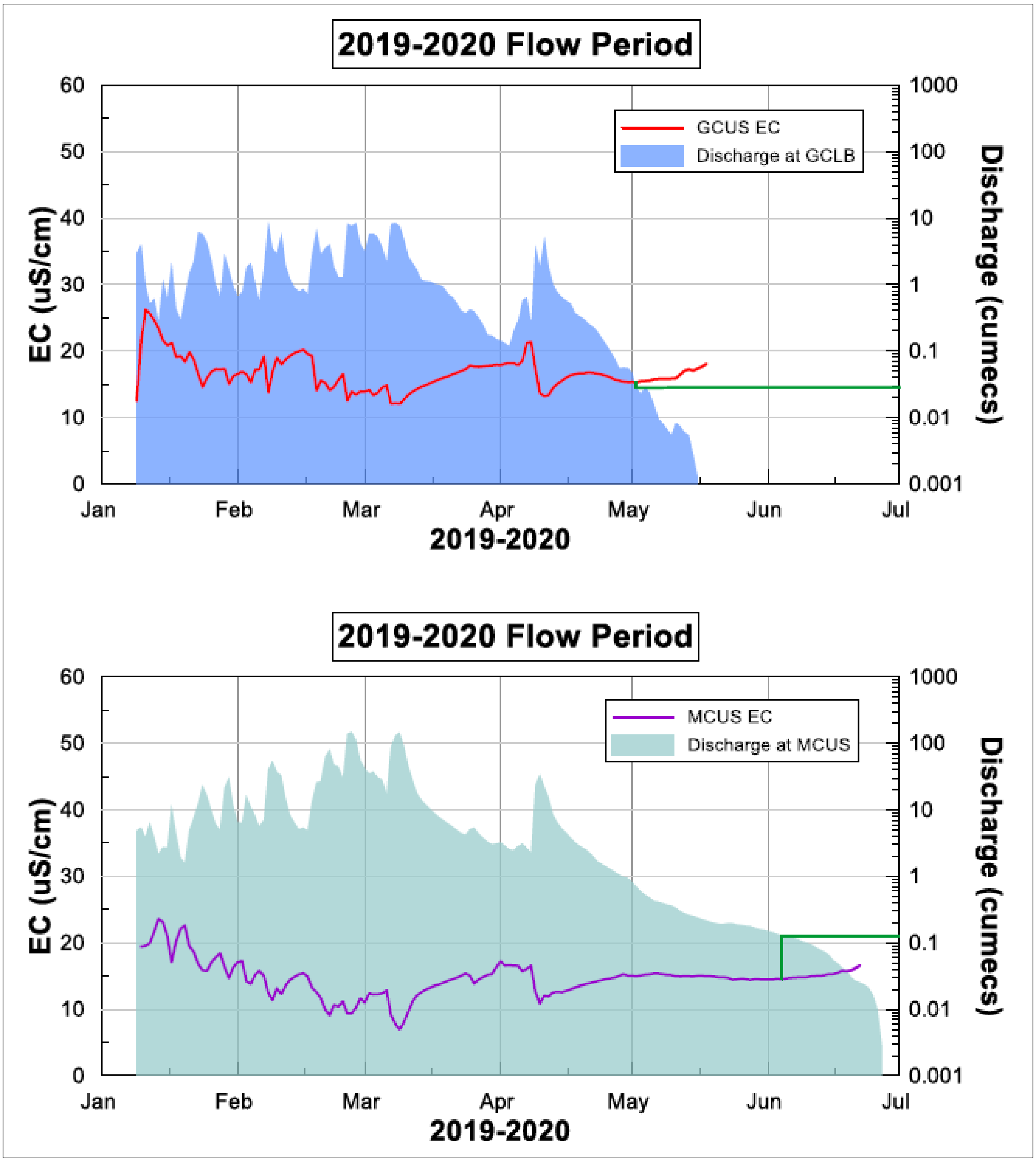


Figure 5-65: Similarity between EC increase at end of flow period and creek discharge at GCUS and MCUS for the 2019-2020 flow period.

5.2.5.2 Hydrology

Surface water management is a key focus of rehabilitation and closure, as it is one of the main pathways for COPCs to enter the environment. Understanding and modelling transport of contaminants in surface waters adjacent and down-stream of the mine site is required to address KKN WS3.

The Ranger Mine is located within the 1,600 km^2 of the Magela catchment and adjacent to Magela Creek (Figure 5-66). Two tributaries of Magela Creek are also located in close proximity to the mine: Gulungul Creek to the west and Corridor Creek to the south. Magela Creek is a seasonally flowing tributary of the East Alligator River, with a catchment originating from headwaters on the Arnhem Land Plateau.

The seasonal pulse of the wet season monsoon controls regional hydrology (Wasson 1992) with flows beginning in an average year in mid-December, after the onset of the monsoonal wet season which usually occurs in November. During the wet season, creeks become sheets of water that extend beyond the low banks. This water is reduced to a series of isolated backflow billabongs and swampy depressions in the dry season winter months. Poor drainage makes access to surrounding areas difficult, and roads and tracks are frequently cut off by flood waters for extended periods in the wet season. The sand aquifers in the channel of Magela Creek, in the middle catchment fill, with shallow groundwater and begin flowing as interflow within the creek channel, before surface flow commences in the creek. Average annual runoff for the Magela Creek system has been estimated at 420 GL (Moliere 2005, Salama & Foley 1997, Vardavas 1988).

Magela Creek and its tributaries flow north from the extensive sandstone Arnhem Plateau. In more specific terms, Magela Creek comprises four sections:

- escarpment channels that flow through deep narrow gorges, which make up around one third of the Magela catchment. These systems are fed by groundwater seeping into the fractured rock of the escarpment and can flow practically all year round. Escarpment rainforest vegetation species (dominated by Allosyncarpia ternate (a Kakadu hardwood tree species)) are found in the gullies due to year-round water supply.
- sand bed anabranching channels (Jansen & Nanson 2004) with sandy levees. Magela Creek flows through sandy soils that may be more than five metres deep along the creek channels. This is the section in which the Ranger Mine is located.
- a series of billabongs and connecting channels at Mudginberri (termed the Mudginberri Corridor)
- a 200 km2, seasonally inundated black-clay floodplain, at two to five metres above sea level, with permanent billabongs, and a single channel that discharges into the East Alligator River approximately 40 km to the north of the RPA and, ultimately, Van Diemen Gulf

Gulungul Creek, on the western boundary of the RPA, drains runoff from the catchment to the west and south of the TSF and from relatively undisturbed bushland to the west of RP1. The main stream of the Gulungul Creek has a length of around 12.5 km. The Gulungul sub-catchment has an area of approximately 98.4 km^2.

Figure 5-66: Regional extent of Magela catchment

Moliere (2005) reviewed historical stream flow data for Gulungul Creek to provide confidence in the flow and flood frequency estimations. Despite data gaps, an annual runoff of 25.5 GL at G8210012, immediately west of Ranger Mine, as shown on Figure 5-67 was determined, with a general flow period for Gulungul Creek of approximately six months between December and May. Observations from Ranger Mine operations have noted that the general flow period can, however, extend through to June or July in above average wet seasons. Stream flows are highly variable throughout the wet season and reach peak discharge during the months of February to March (Salama & Foley 1997).

Antecedent rainfall in the Gulungul sub-catchment that is required prior to overland flow in Gulungul Creek is similar to that for Magela Creek at approximately 295 mm (Moliere 2005).

Corridor Creek drains the southern side of the Ranger Mine. The natural catchment has been modified in the vicinity of the mine, with mine drainage water being redirected to water treatment areas. There is also a series of natural and artificial water bodies within the creek line that modulate the effects of storms and rainfall events. Corridor Creek runs into Georgetown Creek at Georgetown Billabong. The main water bodies in Corridor Creek include the pre-mining Georgetown Billabong and the constructed Corridor Creek wetland filter (CCWLF), the Georgetown Creek Brockman Road (GCBR) bund, Georgetown Creek Mine Bund Leveline (GCMBL) and Sleepy Cod Dam.

Prior to mining, the local hydrology included four separate sub-catchments, namely Gulungul to the west and southwest, Coonjimba in the centre west, Djalkmarra in the centre east and Corridor Creek in the east and south (Figure 5-68). Within the sub-catchments, backflow billabongs sit on the margins of Magela Creek creating complex localised hydrological relationships.

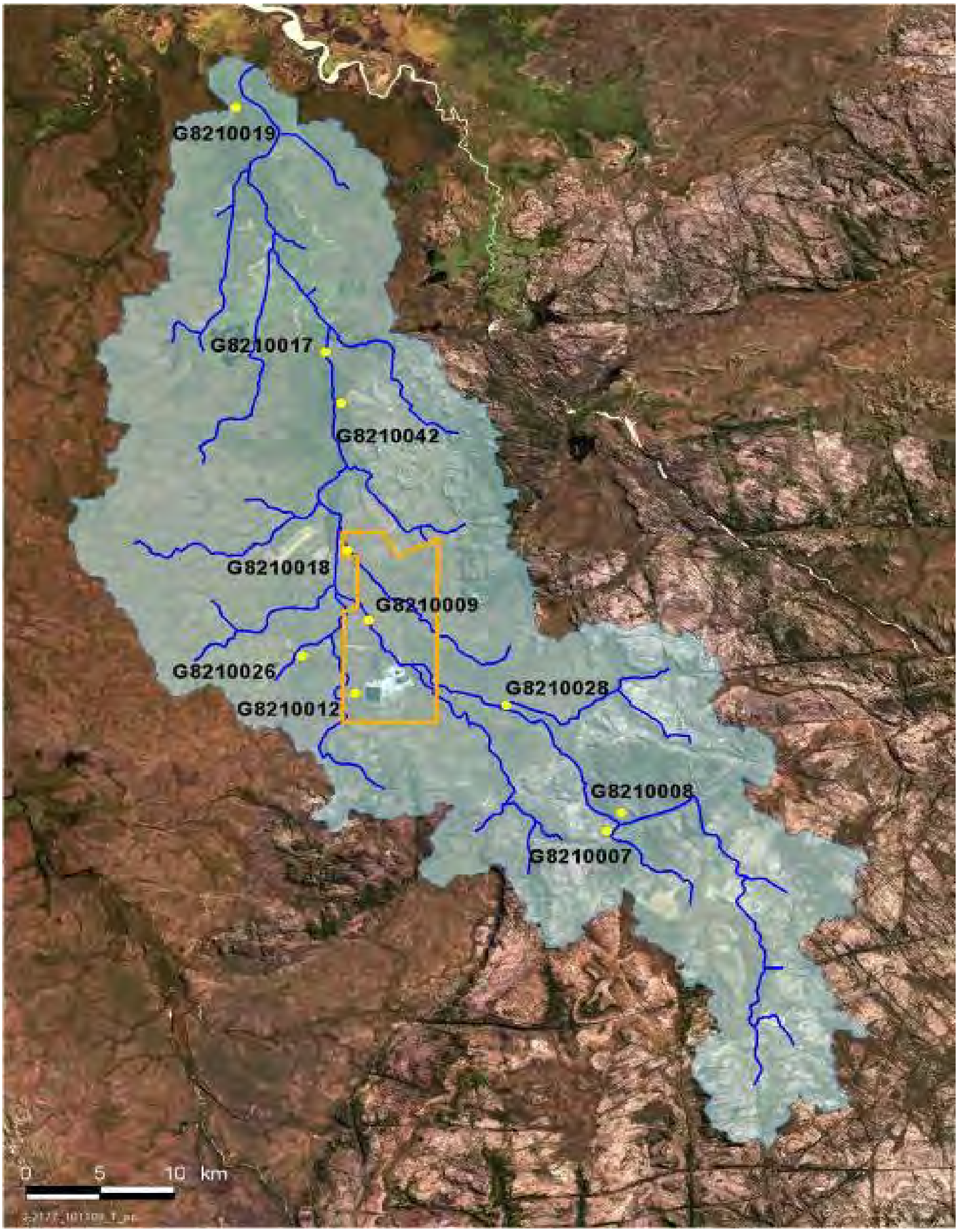


Figure 5-67: Magela catchment showing government agency gauging stations

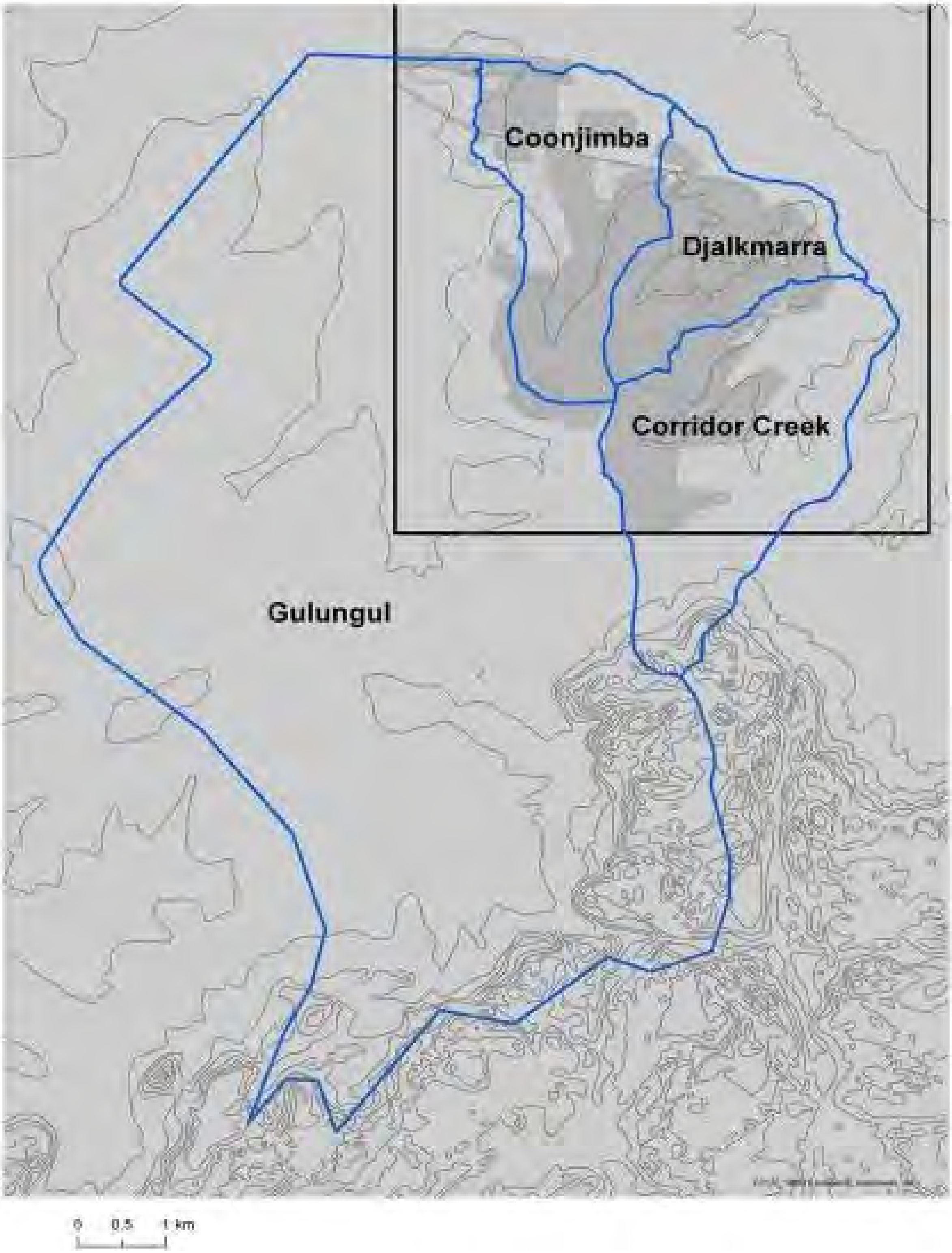


Figure 5-68: Pre-mining catchments in relation to the Ranger Mine

5.2.5.3 Surface Water Modelling

The site vegetation will mature over the decades and merge into the surrounding natural environment following the creation of the post-mine final landform. However, the solute sources related to the operation and closure of the mine site will lead to the gradual release of a range of COPCs into the environment.

To assist the planning and supporting the approval required for rehabilitation activities, Water Solutions were engaged in 2017 by ERA to develop an independent surface water model which predicts the concentrations of COPCs in receiving surface waters. The objective of the model is to providing estimates of the concentrations of nominated COPCs over a period of 10,000 years following the rehabilitation of the mine.

The model was configured, calibrated, updated and validated over the years, incorporating newly available field data and stakeholder's feedback. The final Ranger Surface Water Model (RSWM) is a composite model consisted of:

- Hydrology components:
  - Fifteen sub-catchments (Figure 5-69 and Figure 5-70) subjecting to 131 years of SILO database daily rainfall estimates and normalised evaporation
  - Creeks and billabongs projected to geometry characteristics as model nodes
  - Reach transmission losses and channel losses
  - Channel routing using WBNM
- Solute loads for 21 COPCs:
  - Calibrated natural catchment loads
  - Operational loads
  - Site solute loads derived from groundwater-surface water interaction studies.

The hydrological behaviour of the preliminary configured model was validated by undergoing flow calibration, to achieve a reasonable fit to recorded stream flow from gauging stations and billabong levels during wet season. Conceptual elements, i.e. channel loss, was configured into the model for realistic representation of the natural flow conditions under the wet-dry tropics. Billabong geometries had been reviewed and updated with new surveys and observations as a key step to calibrate the billabongs to match the behaviour during the recession flow.

The model was further calibrated for water quality under natural (no-mine) scenario to define the runoff quality from the natural landscape without the mine influence. Different conceptual model composition was applied to replicate the natural behaviour for each COPC, including Flat Concentration, First Flow, First Event, Exhaustion, Flat Load, and Flow vs Concentration correlation. It should be noted that due to the nature of available data, some of the calibrations were poor and a numerical goodness of fit was not possible for the modelled

COPCs and locations. Table 5-26 and Table 5-27 presents the final calibrated parameters for natural catchment COPC loads.

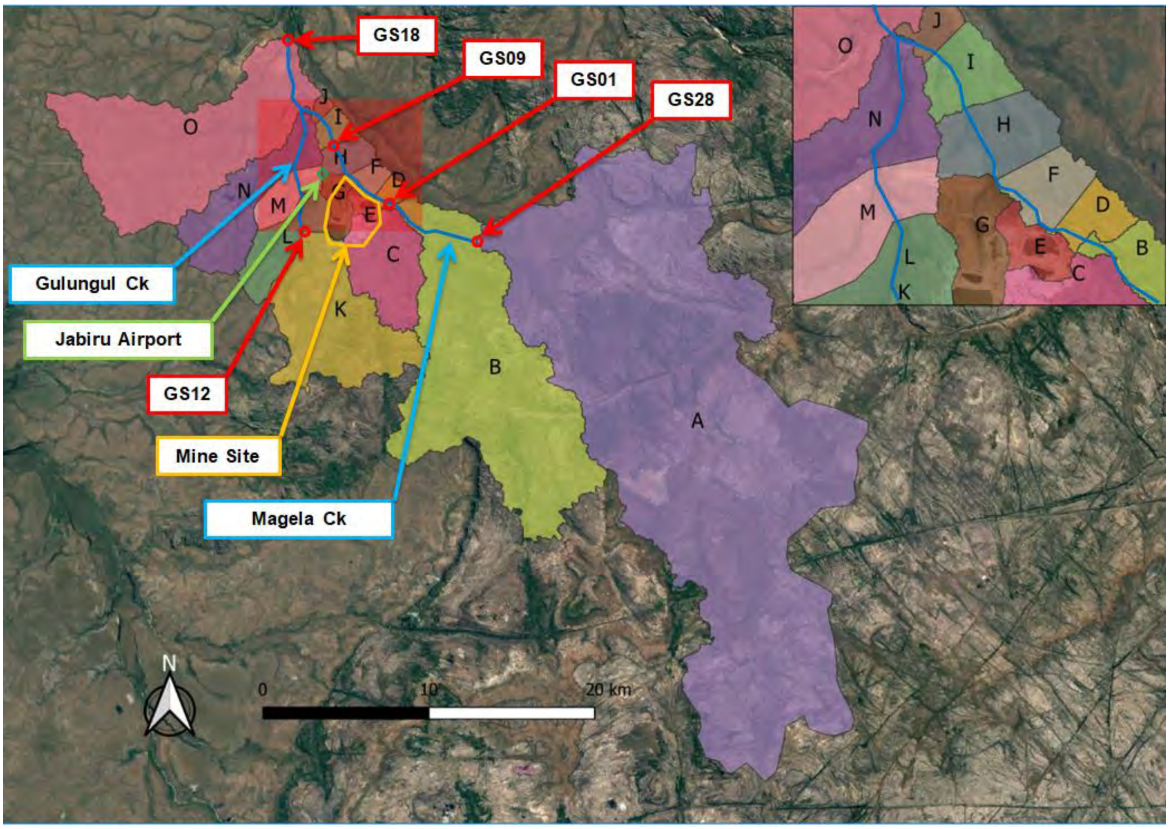


Figure 5-69: Surface water model catchment configuration and site features

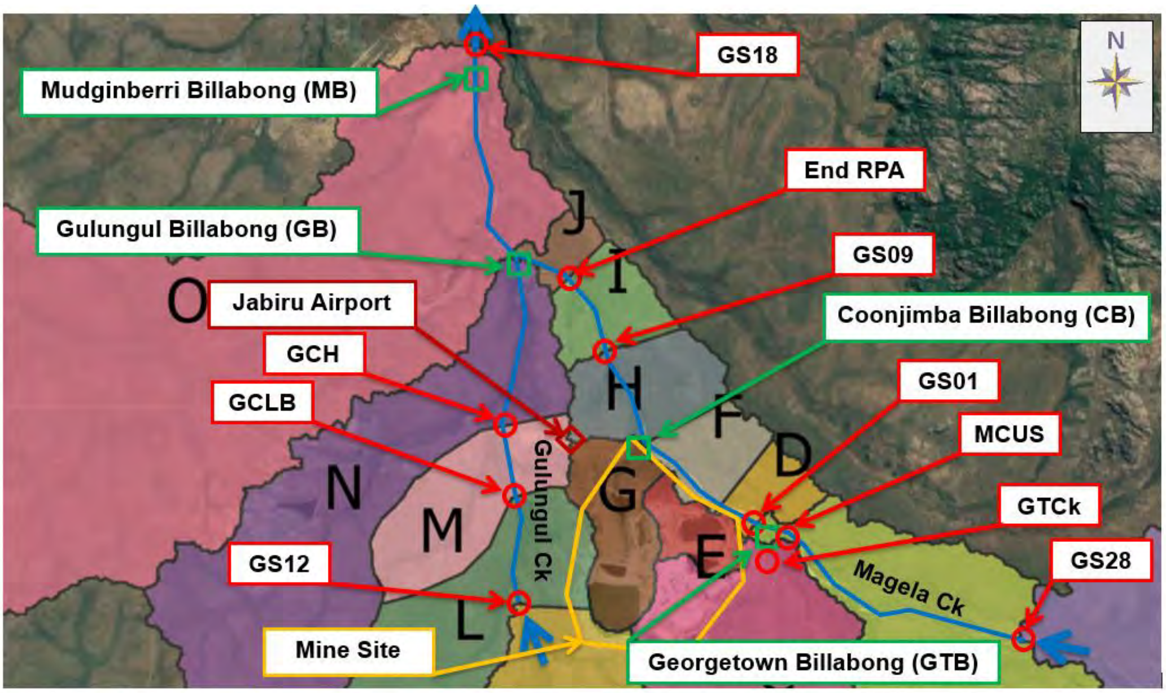


Figure 5-70: Surface water model sub catchments, billabongs, site features and key reporting nodes

Table 5-26: Natural catchment runoff water quality relationship parameters

COPC Description		Relationships Used and Parameters
Name	Symbol	
Magnesium	Mg	• Flat Concentration: 0.2 mg/L • Flat Load: 7.3 g/d/ha
Calcium	Ca	• Flat Concentration: 0.15 mg/L • Flat Load: 5.0 g/d/ha
Nitrate	NO3-N	• Flat Concentration: 3E-3 mg/L • First Flow: 0.197 mg/L
Manganese	Mn	• Flat Concentration: 4.5E-3 mg/L • Exhaustion: 0.01 mg/L, end day 167 (mid Feb)[7]
Uranium	U	• Exhaustion: 4E-5 mg/L, end day 365 (end Aug)
Ammoniacal Nitrogen	NH3-N	• Flat Concentration: 5E-3 mg/L • First Flow: 1E-3 mg/L
Orthophosphate	PO4-P	• Flat Concentration: 2.5E-3 mg/L • First Flow: 12.5E-3 mg/L
Copper	Cu	• Flat Concentration: 2E-4 mg/L
Lead	Pb	• Flat Concentration: 2.5E-5 mg/L
Cadmium	Cd	• Flat Concentration: 2.5E-5 mg/L
Iron	Fe	• Flat Concentration: 0.1 mg/L • First Flow: 0.18 mg/L
Zinc	Zn	• Flat Concentration: 4E-4 mg/L
Chromium	Cr	• Flat Concentration: 3E-4 mg/L
Vanadium	V	• Flat Concentration: 3.5E-4 mg/L • First Flow: 1E-4 mg/L
Nickel	Ni	• Flat Concentration: 1E-3 mg/L
Radium	Ra	• Flat Concentration: 60E-12 mg/L • First Event: 120E-12 mg/L
Polonium	Po	• Flat Concentration: 0.031E-12 mg/L • First Event: 0.037E-12 mg/L
Aluminium	Al	• Flat Concentration: 0.02 mg/L • Exhaustion: 0.07 mg/L, end day 242 (end Apr)
Selenium	Se	• Flat Concentration: 1E-4 mg/L • First Flow: 3E-5 mg/L
Sulfate	SO4	• Flat Concentration: 0.05 mg/L • Exhaustion: 0.85 mg/L, end date 197 (mid Mar)
Total Suspended Solids	TSS	• Exhaustion: 1.5 mg/L, end day 365 (end Aug) • Flow v Concentration, see Table 5.3.

Table 5-27: Flow vs Concentration correlation for TSS

Flow (ML/d)	TSS Concentration (mg/L)
0	0
1.0E+02	0
1.0E+03	1
1.0E+04	5
1.0E+05	35
1.0E+06	50
1.0E+07	50

Operational and closure influence quantified as site loadings were then introduced into the validated model to simulate solute concentrations in the areas of interest. Site loads during closure are configured according to the different scenarios of interest derived from the groundwater solute transport model. Four closure scenarios were modelled in the RSWM, the three peak load cases and the 10,000 year all combined watershed case using the 50% probability values (P50) for base simulations. The four arch-scenarios are modelled as:

- AWP (All watersheds peak scenario) – the peak loading case for locations downstream of the Gulungul Creek junction with Magela Creek, and also (as Gulungul Creek loads are relatively small) for sites between Coonjimba Creek Junction and Gulungul Creek Junction.
- GTP (Peak Scenario for the Corridor Creek) – the peak loading case for the Georgetown Billabong output location
- CJP (Peak Scenario for the Coonjimba and Gulungul Creek) – the peak loading case for tributary inflows to Coonjimba Billabong
- A10k (All watersheds, 10,000 year scenario) – indication of the impacts of the rehabilitated site on creek water quality at the 10,000 year time horizon

An additional Mg:Ca sub-scenario has been simulated to assist the understanding of the actual toxicity of Magnesium in relation to Calcium.

RSWM reports time-series of simulated concentration of COPCs under 131 years of climate record for each reporting node. A sample of plotted simulated results at End EPA node under all arch-scenario for Magnesium is shown in Figure 5-71. More site-specific scenarios will be configured into the RSWM to provided key reference for COPC risk as closure activity progresses.

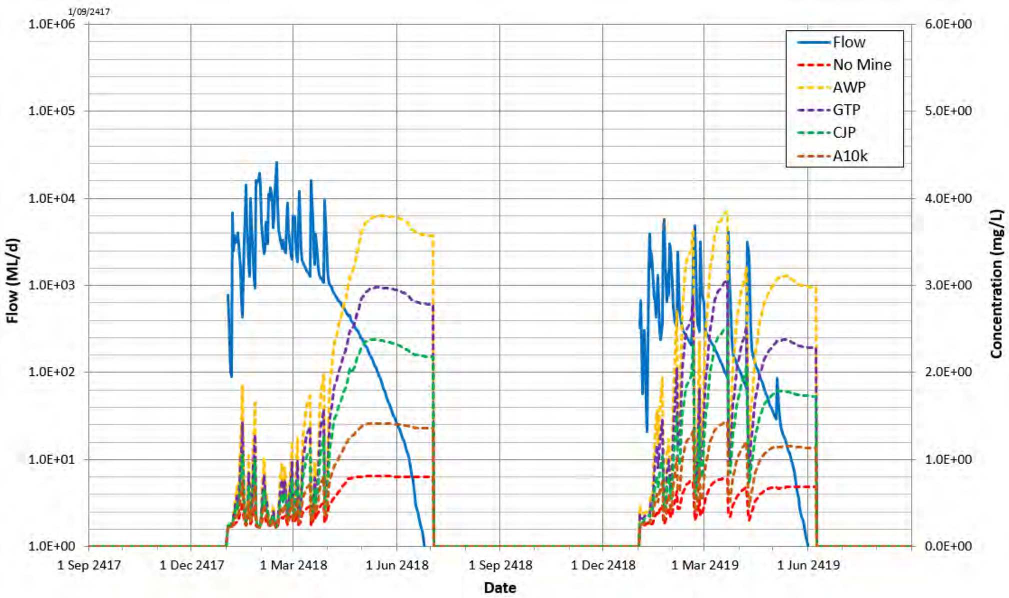


Figure 5-71: Sample of simulated model results

Additional uncertainty analysis was done on key model parameters or model mechanism (rainfall, annual groundwater site loads magnitude, daily load disaggregation method, concentration buffers) to assess the sensitivity of the model. The following sensitivity assessment has been made:

- Rainfall changes will result in more significant change of runoff particularly at downstream sites as expected, e.g. a 10% reduction of rainfall leads to 23-29% decrease in mean annul flow and a 7-19% increase of mean daily COPC concentration while a 10% increase of rainfall leads to 23-32% flow increase and a 5-13% concentration decrease. Note that more cautious needs to be taken for rainfall-related climate change assessment.
- P10 and P90 annual load was applied to compared with the P50 annual load from base case. A similar percentage change of concentration vs. annual load has shown as expected. It demonstrated that by applying various range of annual load from groundwater model output will result in a -31% to +39% difference in COPC concentrations.
- The change of End Flow for daily load disaggregation method varied to 8ML/d AND 16ML/day resulted in very limited 1% change of mean daily concentration at downstream sites.
- The removal of concentration buffering (as a conceptual component simulating stream bed sand) in the first flush storage node impacted the COPC concentration behaviour significantly throughout a wet season particularly at the further downstream sites. More studies had been recommended to assess the effect of sand bed buffering.

ARRTC has endorsed the RSWM at the May 2022 meeting. Future studies for surface water risk based on the methodology developed has been proposed. No additional KKN-related research is planned to be undertaken for the further development of the current tool. ERA will now use the tool to assess scenarios for closure planning (including climate change) and to inform future regulatory applications.

5.2.6 WS5 Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health

KKN title	Question
WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health	WS5A *Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?*

5.2.6.1 Background

Aquatic sediments at Ranger Mine and the Magela catchment have been studied since the late 1970s. This includes research projects as well as a routine monitoring to understand metal concentrations and bio-geochemical pathways, spatial distribution (vertically and within and between catchments), changes over time, and potential bioavailability.

1970 – 2001

A number of studies of sediment quality from billabongs along the Magela Floodplain were carried out in the late 1970's and early 1980's. The earlier work was done by Pancontinental in 1978 and 1979 as baseline studies, but did not include uranium data (Pancontinental, 1981).

Johnston and Milnes (2007) list a number of reports from the 1980s that assessed the fate of chemical species with respect to deposition as sediment and quantities stored in floodplain sediments and described the physico-chemical properties of sediments in billabongs. They describe the geochemical behaviour of sediments and their interactions with water and the use of sediment monitoring as a method for early detection of potential ecological effects.

Jones et al. (2001) collected sediment samples from the Magela Creek Floodplain billabongs in November and December 1997, at the end of the dry season as part of the Jabiluka baseline data collection.

Monitoring of sediments in selected billabongs on and adjoining the RPA formed part of the regulatory framework governing the authority to operate between 1981 and 2002. In 2002, the Supervising Authorities accepted a recommendation (Milnes et al. 2002) to cease the prescriptive statutory routine monitoring which they said was not a good basis for assessment of environmental protection. Instead, performance-based monitoring using a project based approach was to be undertaken.

Iles and Klessa (2010) provides a characterisation of sediments in billabongs on and off the Ranger site, based on a review of literature and a comprehensive summary of all the sediment data from Ranger wetlands and billabongs, collected by ERA from 1981 to 2002. Uranium was confirmed as the contaminant of concern. The uranium concentrations in Coonjimba, Gulungul and Mudginberri Billabongs were similar throughout this period, with an increase in concentration in Coonjimba Billabong from 1999.

2003 – 2015

Performance-based monitoring of the sediments in RP1, Georgetown Billabong (GTB) and the RP1 and CCWLF constructed wetland filters was undertaken by ERA in 2003 – 2006 to assess the current status of those sediments, in terms of spatial and temporal distribution of contaminants.

The results are reported in Iles et al. 2010 who describe the metal concentrations and relationships in surface and core sediments for different digestion methods and compares the measured concentrations in both to earlier data and to sediment quality guidelines. Based on total and bioavailable U concentrations in the surface sediments the ecological risk associated with the sediments at the onsite water bodies was ranked (from highest to lowest) as RP1 wetland filter > CCWLF > RP1 > GTB ≈ Coonjimba.

The Supervising Scientist conducted a sediment sampling and analysis program from billabongs in the Alligator Rivers Region in 2007, 2011 and 2013. The three data sets had comparable sampling and analysis methods and were designed to assess the different sampling, sediment fractions, and extraction methods. Results are reported in Parry 2016.

In 2013 an Independent Surface Water Working Group (ISWWG) was established by ERA and the Gundjeihmi Aboriginal Corporation (GAC) to review surface water management and monitoring at Ranger. Hart and Taylor (2013a) reported that the Traditional Owners were concerned that sediments were no longer routinely monitored and recommended that a sediment monitoring program be reintroduced to:

> *"…reliably evaluate possible adverse environmental impacts during the operational phase of the mine, while providing benchmark data to detect possible impacts after closure."*

2015 – 2020

To address the ISWWG recommendations, Parry (2016) reviewed past sediment studies, data and monitoring guidelines to:

- Identify, collate and document the available information.
- Design a sediment monitoring program that could identify mine related changes in sediment.
- Assess if any such changes had occurred.
- Provide a pre-closure baseline dataset.

Parry (2016) reported:

The historic dataset includes results from a variety of methods but are still useful with statistical analyses demonstrating comparable results. Analysis of the data sets showed the overall metal concentrations generally follow the order: nitric/perchloric (63 μm) > reverse aqua regia (63 μm) greater than 1 Molar HCl (63 μm) > nitric/perchloric (whole) > reverse aqua regia (whole) > 1 Molar HCl (whole).

Whilst the data sets from these variable sources could not readily be normalised, a consistent data set was identified from the ERA monitoring program and analysed using principal coordinate analysis. The principal coordinate analysis showed that for the majority of years Georgetown, Coonjimba, Gulungul and Djalkmarra billabongs (excluding radium-226) had similar compositions, with Mudginberri Billabong separated by higher concentrations of zinc and manganese, non-Ranger Mine sources. The results from this analysis demonstrated that with suitable data bases this type of statistical analysis can be used to determine any patterns of change spatially and/or temporally.

Jones et al (2001) 1997 sediment U data represents one of the best background sediment data sets, albeit based on the <63 μm fraction. It also demonstrated no change in metal concentrations in the floodplain billabongs since 1977-78.

The Supervising Scientist billabong sediment sampling in 2007, 2011 and 2013 provides a robust data set, especially for control water bodies in the Magela Creek and Nourlangie Creek catchments. The data clearly shows the distinction between on-site (within the Ranger

Project Area) water bodies and unimpacted off-site (outside the Ranger Project Area) water bodies. The 2013 Control Billabongs' data had lower concentrations than in the historic Mudginberri Billabong dataset.

Assessment of all available sediment data from 1982 to 2013 (ERA and Supervising Scientist) showed the following order of billabongs in terms of uranium concentrations: Mudginberri = Gulungul < Coonjimba ≈ Georgetown.

Sinclair (2015) showed that uranium, thorium and metal concentrations in the majority of the Ranger surface samples and sediment cores were low and comparable with concentrations at other creeks within the Alligator Rivers Region.

Lead isotope ratios showed sediments from Georgetown Billabong and the Gulungul Creek tributary in close proximity to the TSF, and to a much smaller degree the younger sections of the MCDS (Magela Creek downstream) core contain some mine derived material. This demonstrated the usefulness of the isotope method for determining the source of erosion products being transported albeit at low concentrations (equivalent to only about 1.1 mg/kg of lead at MCDS).

The Supervising Scientists biological monitoring program provides an indirect assessment of any potential sediment impacts.

Determination of uranium and radium levels in mussels from Mudginberri Billabong has shown consistently low levels with lack of any increase in concentration of U and analysis of isotope ratios in mussel tissues through time (2000 to present) indicating absence of any mining influence on the water and sediment in Mudginberri Billabong[10].

The biological monitoring results from 1988 to present across multiple sites in the Magela catchment have shown that biological communities (fish and macroinvertebrates) have not been adversely impacted as would be expected if sediments were adversely impacted.

Parry (2016) concluded that sediment concentrations in billabongs off the RPA had not increased due to mining and recommended a routine sampling and analyses program based on leading practice.

The recommendations, agreed to by a stakeholder working group, were trialled in 2015 and implemented and refined in 2016. The billabongs sampled in 2016 were Wirnmuyr, and Buba (control sites), Gulungul (exposed site), and Coonjimba and Georgetown (potentially mine affected). Corndorl (a control site) and Mudginberri Billabongs were not able to be sampled due to early rains. However, as noted above the SSB mussel monitoring program indicates the absence of any mining influence on the water and sediment in Mudginberri Billabong.

Esslemont and Iles (2017) compared the metal concentrations at these billabongs with historic data and used stable lead isotope ratios, principal component analysis, and associations with iron and aluminium to interpret the results. The updated dataset was also used to derive background concentrations for metals in sediment based the 80th, 95th and

[10] Concentrations of other metals in mussels from Mudginberri Billabong were also reported to be low and between 5 – 100 times lower than national food standards in the SSB Annual Report for 2014.

99.7th percentiles of data from un-impacted sites (control and un-impacted exposed sites, and data from potentially impacted sites prior to any identifiable change shown by time series data for each site). This follows the approach to derive background concentrations in Magela and Gulungul Creek waters (Turner et al. 2016). Regional background sediment concentrations based on this information are shown in Table 5-28.

Table 5-28: Regional background values and datasets

Element (mg/kg dry wt. <0.63mm)	Percentiles				Data sets
	50	80	95	99.7	
Copper	29	37	43	55	Metal concentration data from non mine-affected sediments were evenly represented from the billabongs, and percentiles developed from the pooled data.
Lead	21	30	40	68	
Zinc	18	27	41	73	
Manganese	84	119	174	247	
Uranium	6	9	20	25	

Based on 12 samples from Buba (2007-16), Wirnmuyurr (2007-16), Corndorl (2007-13), Coonjimba (pre 1999), Georgetown (pre 1999), Gulungul (pre 1999), and Mudginberri (pre 1999; Cu, Pb, U only)

Esslemont and Iles (2017) compared the 2016 and previous sediment-bound metal concentrations against the derived background dataset, national sediment quality guideline values or the site specific uranium guideline value derived by the SSB.

In general, sediment concentration in 2016 were generally below the sediment quality guideline values, or historical concentrations, in billabongs where sediment guidelines were lacking except for Buba Billabong.

Concentrations of metals had not increased in sediments in the offsite billabongs in the Magela catchment with concentrations within natural variation (at the low end of the range). Comparisons with historical data show that sediment concentrations of manganese were the lowest, and uranium close to the lowest, recorded for all sites except Buba Billabong.

All uranium concentrations were well below the site-specific guideline value of 94 µg/kg developed by the SSB, with the highest values for 2016 at Georgetown Billabong being less than one fifth of this and Buba Billabong being less than a tenth of this value.

Copper, lead and zinc concentrations in billabong sediments were below the national sediment quality guideline values, and with the exception of one zinc result in Buba Billabong were low relative to historical concentrations. Historical concentrations were consistently below the sediment quality guideline high values (SQG-H), and usually below the sediment quality guideline values (SQGV). As such the results show these are not metals of concern.

Elevated uranium, zinc and manganese concentrations at Buba Billabong, a control billabong not in the Magela Catchment, were not related to mining operation. However, understanding the reasons behind these elevations can help to determine if elevations that may occur at a mine exposed site in future are mining related. The associations of these metals with iron and aluminium were reviewed along with principal component and stable lead isotope analysis. These analyses showed these elevated concentrations are a result of natural accumulation of uranium with iron and aluminium oxides in alluvium, and a possible localised weathering anomaly (hydromorphic anomaly) of manganese and zinc.

Coonjimba Billabong data from the late dry season in 2015 showed some high uranium concentrations compared with historic data, in contrast with 2016 data that showed low concentrations compared with historic data. The 2015 conditions allowed aquatic sediments to be sampled from the dry central channel of the billabong which is usually submerged. In 2016 sediments were collected from the wetted edge of the billabong when the billabong still contained a substantial volume of water, and consequently samples were collected from a relatively high position up the bank and more similar to historic sampling locations. Therefore during 2015, there was a larger dataset and more spatial variation represented from across the billabong than in 2016, and the 2015 dataset identified replicate samples with concentrations above the control range as well as replicate samples with concentrations below the control range.

The 2015 dataset from Coonjimba identified that leachable (1M HCl) sediment-bound uranium concentrations within 460 meters of the RP1 release point were higher than background concentrations derived by Parry (2016), and total uranium concentrations in the billabong channel were in excess of ambient associations with bog-iron and aluminium oxides. Lead isotope ratios from 2016 and 2015 showed that uraniferous (206/207Pb) and thoriferous (208/207Pb) signatures of the sub-clay (<63 µm) sediment fraction were consistent with sediment from a uranium mineralised source. However, the thoriferous (208/207Pb) signature of the sub-sand (<2mm) sediment fraction in 2016 indicated that sand from a non-mineralised source had also contributed to the samples. As such the 2015 Coonjimba Billabong samples contained sediment from a mineralised source mixed with sediment from a non-mineralised source.

In summary the spatial variation of the sediment samples within Coonjimba Billabong are consistent with potential sources of sediment from the minesite, which had mixed with sediment from non-mineralised sources. This is expected to be observed during mine operation in a billabong located within a kilometre of the RP1 release point.

2020 onward

In collaboration with the Supervising Scientist Branch and subject matter experts, a review of historical data, best practice analytical methods and knowledge gaps culminated in the development of a memo (Iles 2020) and Sampling, Analysis and Quality Plan (SAQP) (ERA 2020) that detailed the rationale for further targeted assessments for ASS, metal(loid)s and radionuclides.

ASS exist extensively within the Magela Plain and the general lowland surrounds of the Ranger Uranium Mine (Willet 2008). As part of closure planning, consideration of environmental risks posed by naturally occurring and potentially mine-influenced ASS has led to the development of a preliminary site-wide conceptual model for ASS and risk assessment framework (ERM 2020a). The conceptual model was developed using the structure shown in Figure 5-72, with section references as in ERM 2020a. There are three key constituents that contribute to the potential formation of ASS: the potential water-logged conditions, elevated sulfate concentration (≥10 mg/L), and sufficient organic matter to establish the chemically reducing environment. Although considerable historical studies of ASS exists, a number of key knowledge gaps remained in relation to the characterisation of ASS conditions as they relate to closure.

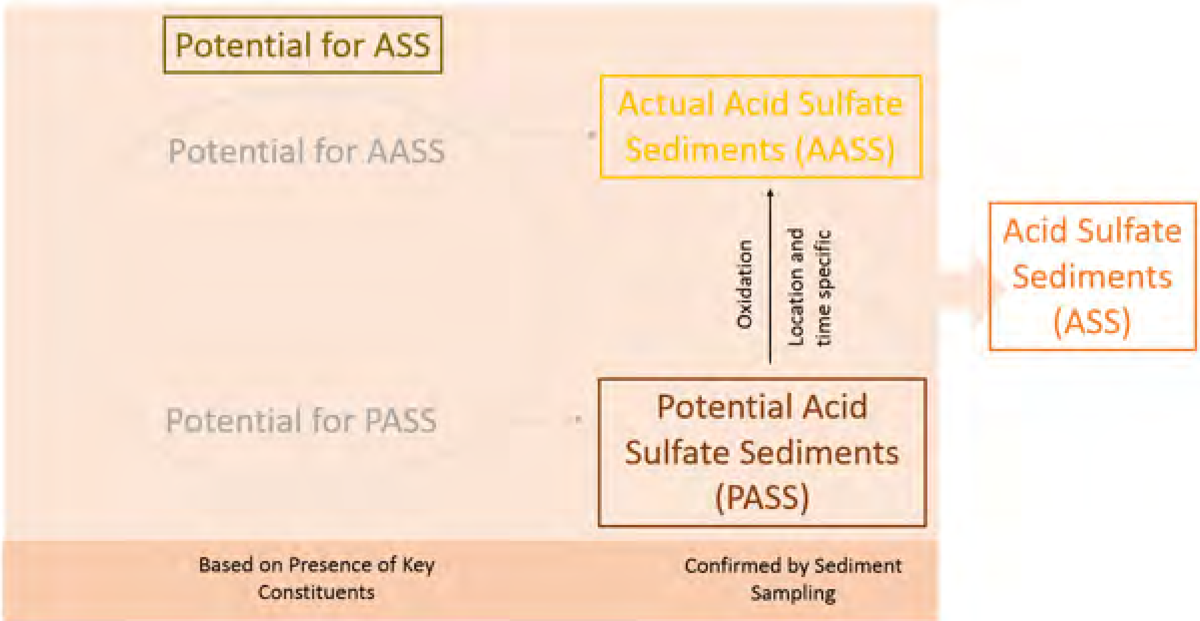


Figure 5-72: ASS terminologies (Source: ERM 2020a)

A total of sixty-three sediment samples were collected and analysed from nine sites within and downstream of the RPA; Indium Billabong, GCMBL, Sleepy Cod, Djalkmarra Release Point (DJKRP), Gulungul Billabong, Georgetown Creek Tributary 2 (GCT2), RP1, Mudginberri Billabong and GTB. Sampling was conducted over two campaigns; the first in the dry season (9-13 November 2020) and the second in the wet season (2-5 February 2021).

Samples were selectively analysed for ASS, metal(loid)s and radionuclides. The sample design and analytical methods were informed by specialist and stakeholder input and review and agreed to by the SSB. ARRTC was provided with the SAQP (ERA 2020) in November 2020.

ASS was confirmed in at least one or more samples at all sites assessed for ASS, totalling fifty positive samples. Monosulfidic Black Ooze (MBO) was identified in four of eleven samples within RP1 and one sample within GTB.

Metal and radionuclide concentrations were investigated at all sites except GCT2, with a total of 48 samples collected. This analysis builds on the previous investigations into metals in sediments that was conducted by Esslemont and Iles (2017) and others prior.

Due to laboratory error, all samples collected were initially analysed for metals on the < 63 µm sediment fraction using a weak aqua regia (WAR) digest, rather than the nitric/perchloric digest as was proposed in the SAQP (ERA, 2020) and was used to develop the regional background values (Esslemont & Iles, 2017). This error was identified at the end of the program, however where remaining sample was available, samples were re-analysed using the nitric/perchloric digest on the < 63 µm fraction to enable a comparison to historical trends and the RBVs.

The results and interpretation of this target investigation program is currently under stakeholder review and will be detailed in future iterations of the MCP.

Based on the results of the conceptual model and field assessments, a risk assessment of domains across the minesite is completed in the form of a water pathways risk assessment to understand the future ASS occurrences/persistence in the billabongs (Section 5.2.2) This will also inform the requirement of location-specific conceptual site models which will in turn inform the closure management plan. If the risk assessment indicates sulfate in water needs to be reduced or ASS sediments treated, trial mitigations and remediation options will be investigated.

5.2.7 WS6 Determining the impact of nutrients in surface water on biodiversity and ecosystem health

KKN title	Question
WS6. Determining the impact of nutrients in surface water on biodiversity and ecosystem health	WS6B *Can Annual Additional Load Limits (AALL) be used to inform ammonia closure criteria?*
	WS6C *Will the total load of nutrients (N and P) to surface waters cause eutrophication?*

There are three major sources of trace metals and nutrients to the Magela Creek system: natural (rainwater and pristine catchment), the Ranger uranium mining operation, and the Jabiru township (Hart *et al* 1986b).

The sources of nutrients at Ranger to the water management system are from; waste rock, ammonia and phosphate (in lime) added to the mill process circuit, residual nitrates from blast residue in waste rock, and fertiliser application. These sources result in the following different water quality profiles for nutrients:

- ammonia is high in process water but not pond or release water
- nitrate levels are negligible, moderate and lo in process, pond and release waters respectively
- phosphate is low in all waters

Currently ERA must comply with Annual Additional Load Limits (AALL) for the discharge of NO_3-N (4.4 t/a) and PO_4-P (2.8 t/a) to Magela Creek and with NH_3-N concentration limits in Magela Creek. The load limits were set in the 1980s (Brown *et al*. 1985). No load limit was set for ammonia; only a concentration limit was set as it was considered to pose a toxicological, rather than an eutrophication risk.

The risk from nutrients has been low during the operational phase as waters are segregated and treated before directing to the release water circuit. Following closure the nutrient profile and the potential to reach the surface waters on and downstream of the mine are different to that during the operational phase.

- In relation to nitrogen forms, *ammonia* will be present in high concentrations in tailings and concentrated brine contained in the mine pit voids. Ammonia may be mobilised under certain conditions and leach from the buried tailings and brine, entering surrounding surface water through groundwater egress. Waste rock is known to be a major source for *nitrate* due to N in blast residues on the waste rock. Although this is expected to wash out in a short time, it may also reach receiving waters through direct wet season runoff or through groundwater egress associated with rainfall infiltration of the waste rock landform cover and leaching.
- Waste rock is also known to be a source for *phosphate-P*. It may also reach receiving waters at mine closure through the same mechanisms as for nitrate above.

Concentrations of ammonia, nitrate and phosphate entering the surface water environment after closure are being predicted through solute transport modelling. The risk of eutrophication after closure needs to be assessed by comparing predicted post closure concentrations of nutrients to relevant thresholds. Default guideline values for northern Australia (ANZG 2018) are not appropriate as they are lower than the concentrations that occur locally. Load limits for nitrate and phosphate were developed for the Ranger mine in the mid 1980s but not for ammonia.

KKN WS6B focussed on reviewing the current load limits for nutrients and WS6C focusses on identifying concentrations of nutrients that cause eutrophication in the Magela system.

KKN WS6b asks two questions regarding nutrients:

- Are the current AALLs for nutrients still relevant?
- Can ammonia loads be considered in the same context?

A literature review by ERA found that between 1984 and 1986, the Supervising Scientist, through the Alligator Rivers Region Research Institute, developed water quality standards for release of water from Ranger mine to protect the broad downstream receiving environment (i.e. Mudginberri corridor and Magela floodplains) and people who sourced food from these environments (Brown *et al.* 1985). AALL and allowable concentrations were derived for a number of stressors including AALL and concentration limits for nitrate and phosphate, and concentration limits only for ammonia.

The standards are reported in Brown *et al.* (1985) together with a brief summary of the derivation process. More detail on the derivation and basis of the standards is available in Office of the Supervising Scientist (2002). The basis for the nitrogen-N and phosphorus-P AALL was listed in these reports as “ecological” (Table 5-29). The discussion of risks reveals the aim of the AALLs was to prevent eutrophication. For ammonia, a concentration limit was set to protect against toxicity, but it was not considered a stressor for eutrophication and so no AALL was set.

Table 5-29: Nutrient limits (concentrations or loads) from Brown et al. (1985)

Constituent	unit	Magela Creek mean (or limit)	Basis
Concentrations			
Molecular NH3 (as -N)	mg/L	(0.02)	Toxicological
Nitrate/nitrite (as -N)	mg/L	10	Drinking water
Phosphate (as -P04)	mg/L	0.01	Statistical
Additional Load			
Phosphate (as -P)	t/a	2.8	Ecological
Nitrate (as -N)	t/a	4.4	Ecological

Neither Brown *et al*. (1985) nor Office of the Supervising Scientist (2002) provide further detail on how the N and P AALL were derived except to refer to it being the subject of another study. Personal communications with Dr. Arthur Johnston (former Supervising Scientist) and Professor Barry Hart (former consultant to the Supervising Scientist) indicated the basis was the natural loads measured in Magela Creek in the mid-1980s (published values in Hart *et al.* (1986a, 1987a)).

A review of the literature shows the AALL are approximately the same as the natural loads in Magela Creek passing the Ranger minesite in the 1982-83 wet season, as reported in Hart *et al.* (1986a, 1987a) (Table 5-30). Allowing the same amount to be added to the creeks is effectively doubling the natural loads.

The "ecological" basis identified for loads (Brown *et al.* 1985) appears to be a misnomer with the limit based on change to natural loads rather than biological-effects information. Prevention of biological effects is the preferred approach to deriving water quality criteria for ecosystem protection (ANZG 2018). Even as reference-based limits, the data used to calculate AALLs were based on just one wet season which is not a robust statistical basis for guideline derivations (ANZG 2018).

In addition, the loads in Magela Creek passing the minesite and reporting to the downstream environment are not relevant to protecting Gulungul Billabong which the stakeholder water and sediment working group identified as the highest post-closure risk receptor.

Table 5-30: AALL for nitrate and phosphate compared to loads added to the Magela Creek in rainwater and transported to the flood plain by Magela Creek; load and (error)

Parameter	Rain water	Creek water	AALL	Relationship between 1982/83 loads and AALL
NO3–N (t/a)	60a 36 (51)b	5.1 a 5.1 (3.9) b	4.4 Nitrate as N	AALL is similar to natural load, effectively allowing a doubling of natural loads to the creek system.
Total-P (t/a)	30a 14 (32)b	0.91a 1.0 (1.2)b	2.8 Phosphate	0.91 t P = 2.8 t of PO4. Doubling of natural load allowed.

a – Hart *et al.* 1986a
b – Hart *et al.* 1987a

In summary:

- The current AALLs for nitrate and phosphate are based on a limited reference dataset and have limited relevance as a guideline for preventing eutrophication, particularly in Gulungul Billabong.
- An ammonia AALL should not be derived using the same approach used for the existing nitrate and phosphate limits.
- Biological effects information, which is more relevant to understanding eutrophication risks, is addressed in a separate KKN (WS6c).
- Stakeholders and the ARRTC agreed that the current AALL are not suitable for closure criteria, and that KKN WS6b can be closed because biological effects-based approaches for deriving water quality criteria have superseded the AALL philosophy and methods, and work is underway under KKN WS 6C to derive nutrient thresholds based on local biological effects.

KKN WS6C addresses a key step in assessing eutrophication risks by determining thresholds of nutrient concentrations that define different trophic states (or levels of enrichment) of primary producers in Ranger receiving waterbodies. SSB, with input from ERA, is undertaking a study to determine threshold concentrations, the approaches have the following focus:

- Consideration of all potential ecosystem receptors, i.e. sand creek channels, backflow billabongs (e.g. Gulungul) and channel billabongs (e.g. Mudginberri).
- Inclusion of all potential primary producers (ecological receptors), i.e. phytoplankton, attached algae and larger aquatic plants (or ‘macrophytes’), and the contribution of nutrients in sediments as sources of internal loading.

- Application of a site-specific, biological-effects based, approach – consistent with ANZG (2018) – to derive nutrient thresholds associated with change in trophic status of the different primary producer groups
- Identification of suitable nutrients and associated biological response data to derive biological-effects thresholds.

This study is in an advanced stage. Progress reports have been provided to ARRTC and a report detailing the findings is in preparation. The report will undergo peer review and is expected to be provided to ARRTC ahead of the November 2021 meeting. In lieu of finalised and agreed threshold values, interim values were provided to ERA to use in the water pathways risk assessment project.

5.3 Radiation theme

5.3.1 Background

5.3.1.1 Terrestrial baseline radiation

The pre-mining radiological conditions for the Ranger Mine have been investigated and reported by the Supervising Scientist (Bollhöfer *et al*. 2014). The study was based on pre-mining aerial surveys, with extensive ground measurements to provide calibration of the final external gamma radiation dose rates. Ground measurements taken for soil radon concentrations and radon exhalation rates were then correlated to the airborne gamma results to obtain averages for the area. The summary of results from this study is provided in Table 5-31.

Table 5-31: Pre-mining radiological baseline determined by the Supervising Scientist (Bollhöfer et al., 2014)

Location	Average gamma dose rate (μGy h^{-1}) *	Average radium concentration (Bq kg^{-1}) *	Average radon exhalation (Bq m^{-2} s^{-1}) *
Pit 1	0.87 ± 0.18	1,880 ± 430	2.7 ± 0.8
Pit 3	0.44 ± 0.09	880 ± 200	1.3 ± 0.4
Djalkmarra land application area	0.20 ± 0.03	310 ± 70	0.46 ± 0.14
Corridor Creek land application area	0.14 ± 0.02	170 ± 40	0.25 ± 0.08
TSF	0.11 ± 0.01	110 ± 30	0.16 ± 0.05
Magela land application area	0.12 ± 0.01	110 ± 30	0.17 ± 0.05
RP1	0.11 ± 0.01	90 ± 20	0.14 ± 0.04
RP1 land application area	0.11 ± 0.01	90 ± 20	0.13 ± 0.04
Jabiru East land	0.10 ± 0.01	90 ± 20	0.13 ± 0.04

Location	Average gamma dose rate ($\mu Gy\ h^{-1}$) *	Average radium concentration ($Bq\ kg^{-1}$) *	Average radon exhalation ($Bq\ m^{-2}\ s^{-1}$) *
application area			
Jabiru	0.11 ± 0.01	90 ± 20	0.14 ± 0.04
Ranger Project Area	0.11 ± 0.01	110 ± 20	0.15 ± 0.05
* ± 95% confidence			

The results show that the average external gamma dose rate in areas removed from uranium mineralisation ranges between 0.10 and 0.20 microgray per hour, with the overall average for the RPA being 0.11 microgray per hour. Dose rates above the orebodies were, as expected, much higher, reaching an average of 0.87 microgray per hour above Pit 1.

Similar patterns to the gamma dose rates were observed for both average soil radium concentrations and average radon exhalation. Average radium concentrations over the orebodies (880 – 1,800 Becquerels (Bq)/kg) were much higher than for the surrounding area (110 Bq/kg), as were the average radon flux densities over the orebodies (1.3 -2.7 Bq/kg per square metre per second) relative to the surrounding area (0.15 Bq per square metre per second).

5.3.1.2 Aquatic baseline radiation

The RPA contains three distinct regional HLU zones which are described in KKN WS2. The derivation of the background threshold values for uranium and radium is discussed in KKN WS1. The results for uranium and radium groundwater background threshold values (discussed in KKN WS1) are presented in Table 5-32.

Table 5-32: Calculated BTVs for HLUs and Analytes in the Background Evaluation where data sufficiency requirements were met, ERM (2020)

Analyte	Unit	Shallow Bedrock Cahill	Deep Weathered Cahill	Shallow Weathered Cahill	Shallow Bedrock Nanambu	Deep Weathered Nanambu	Shallow Weathered Nanambu	MBL Zone (UMS subunit)
Radium	mBq/L	130	50	27.3[a]	130[a]	90	30	37.3[a]
Uranium	ug/L	7.74	21.9	3.03	5.76	5.7	3.37	1.92

[a] Although Radium is a primary COPC, the background evaluation did not indicate this was the case for the Shallow Weathered Cahill, Shallow Bedrock Nanambu and MBL Zone.

Notes:

Greyed out BTVs are for analytes that are not COPCs in that HLU.

Radionuclide concentrations in Magela Creek, upstream of the Ranger Mine, are routinely monitored throughout the wet season by both ERA and the SSB. Water quality at this location is considered to be unaffected by mining and therefore representative of baseline conditions. The statistical results of Magela Creek upstream monitoring conducted by ERA for the 2010 to 2014 wet seasons are presented in Table 5-33.

Table 5-33: Magela Creek upstream radionuclide concentrations (2010 – 2014 average)

Magela Creek upstream	Total radium-226 (mBq/L)	Total uranium (mBq/L)
Average	2.1	0.70
Minimum	1.2	0.16
Maximum	4.0	2.6
Standard deviation	0.9	0.48

5.3.1.3 Bushfood baseline radiation

Radiation work to date has focused on radiation exposure of people living a traditional lifestyle in the area, and downstream of the RPA, along with radiation exposure of plants and animals inside and downstream of the RPA. This work has included extensive monitoring to determine pre-mining, area-wide radiological conditions, as a first step to assessing post-mining changes and the success of rehabilitation from a radiological perspective (e.g. Bollhöfer et al. 2014, Bollhöfer et al. 2011, Esparon et al. 2009)

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

A model diet for local Aboriginal people was obtained from the following sources:

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

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 mSv/year. This radiation dose is irrespective of the mining activity and reflects the natural state for Aboriginal people living in Kakadu NP.

ERISS has compiled this data, along with more recently collected information, into a database (Doering 2013). The database can be used to determine bush food concentration ratios, from which the ingestion dose from various parameter inputs and a variety of situations can be calculated (Ryan et al. 2011). The database contains more than 1,500 individual records of radionuclide activity concentrations in various plants, animal tissues and environmental media. All information in the database has associated geospatial information to allow for spatial analysis. ERISS has also developed a bush foods geospatial information system called the "bushtucker database" (Walden 2011). This contains 30 years of data on radionuclide concentrations in traditional bush foods and is available to the public.

A summary of radionuclide concentrations published by ERISS for key flora and fauna of the Alligator Rivers Region is provided in Table 5-34 (Bollhöfer et al. 2011, Martin & Ryan 2004, Ryan et al. 2009, Ryan et al. 2005). Since completion of the baseline data assessment ERISS have since published updated radionuclide activity concentrations (Doering and Bollhöfer, 2016b, Doering et al., 2017). This data will be used in any further radiation dose assessments.

Table 5-34: Radionuclide concentrations in local bush foods

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

Notes:

[1] Mussels from Mudginberri Billabong, data provided are dry weights; [2] Source (Ryan *et al*. 2009);

[3] Source (Martin & Ryan 2004); [4] Source (Bollhöfer *et al*. 2011); [5] Source (Ryan *et al*. 2005)

5.3.2 RAD1A, RAD2A, RAD6E, RAD7A, RAD7B, RAD8A, RAD9A, RAD9C, RAD9D

KKN title	Question
RAD1. Radionuclides in the rehabilitated site	RAD1A. *What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and land application areas?*
RAD2. Radionuclides in aquatic ecosystems	RAD2A. *What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?*
RAD6. Radiation dose to wildlife	RAD6E. *What is the sensitivity of model parameters on the assessed radiation doses to wildlife?*
RAD7. Radiation dose to the public	RAD7A. *What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?*
	RAD7B. *What is the sensitivity of model parameters on the assessed doses to the public?*
RAD8. Impacts of contaminants on wildlife	RAD8A. *Will contaminant concentrations in surface water (including creeks, billabongs and seeps) pose a risk of chronic or acute impacts to terrestrial wildlife?*
RAD9. Impacts of contaminants on human health	RAD9A *What are the contaminants of potential concern to human health from the rehabilitated site?*
	RAD9C. *What are the concentrations of contaminants in drinking water sources?*

KKN title	Question
	RAD9D. *What is the dietary exposure of, and toxicity risk to, a member of the public associated with all contaminant sources, and is this within relevant Australian and/or international guidelines?*

The Ranger radiological impact assessment, required to assess the radiological impact to members of public and terrestrial and aquatic wildlife is in progress with information on the methodology followed in the section below. This impact assessment will address all the above mentioned KKNs under the reposnsibility of ERA.

5.3.2.1 Atmospheric dispersion modelling

All concentrations considered were above naturally occurring background levels. These incremental post closure levels were determined via source modelling as outlined below.

Atmospheric dispersion modelling of radon and particulate matter for post-closure conditions was completed in 2018 (SLR 2018a). This modelling included:

- meteorological modelling using the weather research and forecast model, and CALMET models to compile a three-dimensional meteorological dataset for the study domain
- emission estimation of radon from waste rock covered areas and the LAAs, based on radon flux rate information provided by ERA, with estimation of particulate emissions performed using published emission factors for wind erosion (DSEWPC 2012)
- dispersion modelling of the downwind dispersion of estimated emissions of particulate matter and radon using the CALPUFF dispersion model

For this study the meteorological data inputs have been compiled using the Weather Research and Forecast (WRF) and CALMET meteorological models. The meteorological dataset used in the modelling (based on the calendar year 2016) was validated by comparing key variables with the available measured data recorded at the nearest meteorological station, located at Jabiru Airport.

Radon and particulate emissions from the LAAs and waste rock area were modelled as ground level area sources based on the following emission rates:

- the radon emission rate provided by ERA for use in the modelling study was 0.5 $Bq/m^2/s$ for both the Ranger Mine footprint (waste rock areas) and the LAAs
- the total suspended particulates (TSP) emissions from the waste rock area and LAAs were modelled based on an uncontrolled emission rate of 0.4 kg/ha/hour and the following control factors to account for the reduction in dust emissions that may be expected from increasing ground cover (trees, grasses, leaf litter etc) in the years following closure of the Ranger Mine:
    - scenario 1 – immediately post-closure

- scenario 2 – 100 years post-closure.

In addition to control factors accounting for vegetation growth, the modelling also investigated the sensitivity of the modelling results to the effects of rainfall, which will act to suppress dust emissions. This was done by assuming that no emissions occurred on days with greater than 5 mm rain, based on data recorded at Jabiru Airport during 2016 (i.e. during the same meteorological year used in the modelling).

A concentration of 630 Bq/kg for radionuclides in the U-238 decay chain, contained within deposited dust was used in the terrestrial assessment. This concentration was not expected to change significantly over time.

5.3.2.2 Radiological Impact Assessment

ERA has engaged JRHC Enterprises Pty Ltd to complete an impact assessment of the radiation related impacts to the public and non-human biota following the closure of the ERA Ranger Uranium Mine.

The following radiation exposure pathways were considered to determine the radiological impacts of the closure of the Ranger Mine on human and non-human biota:

- incremental radon concentrations
- gamma radiation levels
- radionuclide concentrations in dust
- environmental radionuclide concentrations

The method for assessing potential impacts varies depending on the exposure pathways. Table 5-355 provides an overview of the human exposure assessment methods for the different exposure pathways.

Table 5-35 Exposure estimation methods *(JRHC in draft)*

Exposure Pathway	Assessment Method
Gamma radiation	From first principles and based on changes in the substrate natural radionuclide concentrations.
Inhalation of radionuclides in dust	From air quality modelling results (section 5.3.2.1) based on predicted dust emission rates post closure.
Inhalation of radon decay products (also known as RnDP)	From air quality modelling results (section 5.3.2.1) based on predicted radon emission rates post closure.
Ingestion of radionuclides	Based on deposition of radionuclides into the environment from air quality modelling and estimates of water solute transfer.

The predicted concentrations of radionuclides above natural background levels will be considered for Mudginberri, Coonjimba, Georgetown and Gulungul billabongs for the peak surface water concentration timeframes. Future occupancy intentions and the bushfood diet discussed in Section 8 and Paulka (2016) plays an integral role in the calculation of the predicted radiation doses post closure.

For non-human biota, the ERICA assessment software tool (http://www.erica-tool.com/) is utilised. The impact to specific terrestrial and aquatic species is based on changes in radionuclide concentrations of the media within which the species resides. The impacts to biota will be assessed using these incremental concentration changes and the ERICA assessment software tool (http://www.erica-tool.com/).

Post-closure guidance values have been developed to provide radiological protection to terrestrial and freshwater aquatic species (Doering & Bollhöfer 2016, Doering *et al*. 2019). The guidance values will be compared to the predicted changes in media concentrations for above background concentrations of Ra-226. An update to the surface water modelling is underway (WS3) and the new predicted changes will be updated in the radiological impact assessment.

Progress on the radiological impact assessment is currently halted due to the update to the surface water modelling currently underway (WS3) as the concentrations inform the assessment.

5.4 Ecosystem rehabilitation theme

5.4.1 ESR1. Determining the requirements and characteristics of terrestrial vegetation in natural ecosystems adjacent to the minesite, including Kakadu National Park

KKN title	Question
ESR1. Determining the requirements and characteristics of terrestrial vegetation in natural ecosystems adjacent to the minesite, including Kakadu National Park.	ESR1A. *What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally inundated savanna) in natural ecosystems adjacent to the mine site, how do they vary spatially and temporally, and what are the factors that contribute to this variation?*

5.4.1.1 Background

Bioregions for the Australian continent have been created as part of a national classification of ecosystems. There are currently 89 bioregions and 419 sub-regions in Australia. Each region is based on similarities in climate, geology, landform, native vegetation and species information. Most of the RPA lies within the northeast section of the 28,520 km2 Pine Creek Bioregion. Features of the Pine Creek Bioregion include:

- a landscape broadly consisting of hilly to rugged ridges with undulating plains;
- vegetation communities that include eucalypt woodland, with patches of monsoon forest;

- major land uses that include conservation, pastoralism, intensive rural freehold blocks, horticulture, mining and indigenous freehold; and
- major population centres at Batchelor, Adelaide River, Pine Creek and Jabiru.

The Pine Creek Bioregion, in the Top End of the NT, comprises hilly ridges with undulating plains within the foothills of the Arnhem Land Massif (ERA 2014b, DNREA 2005). Typical vegetation types consist broadly of tall eucalypt woodlands, dominated by Darwin woollybutt (*Eucalyptus miniata*) and Darwin stringybark (*E. tetrodonta*) with patches of monsoon forests, riparian vegetation and tussock grasslands (DNREA 2005). The bioregion supports a high diversity of flora and fauna, with 279 bird species, 100 reptile species and approximately 2,300 plant taxa recorded in 2005. During the wet season (November to March) approximately 90 % of annual rainfall occurs in this tropical monsoonal bioregion (DEE 2005).

The RPA is surrounded by, but separate from, Kakadu NP, where approximately 1,600 terrestrial and aquatic flora species have been recorded, including 15 species considered rare or threatened (Director of National Parks 2016). No terrestrial or aquatic flora species of conservation significance listed under the *Territory Parks and Wildlife Conservation Act 1978* (NT) (*TPWC Act*) or the *EPBC Act* have been recorded in the RPA.

There are distinct vegetation communities that occur across the RPA. Schodde *et al*. (1987) described four vegetation types, dominated by eucalypt open forest and/or woodland (Figure 5-73 and Figure 5-74). Similarly, Firth (2012) described the main vegetation / habitats on the RPA as comprising of woodland and open forest, mostly co-dominated by *E. tetrodonta* and/or *E miniata*. The RPA is surrounded for the most part by vast unbroken and undeveloped tracts of the same eucalypt woodlands and open forest savannas that cover at least 180,000 km^2 in the NT alone (Woinarski *et al*. 2005). The topography of the RPA is relatively simple and as with vegetation, mirrors that of the region as a whole. The different vegetation types are described below and the area and proportion of each vegetation type on the RPA and in Kakadu NP are given in Table 5-36.

Habitat 1: Myrtle-Pandanus Savanna/Paperbark Forest/Coastal Deciduous Rainforest

Paperbark forests line freshwater creek systems and the edges of billabongs and are dominated by *Melaleuca* spp. The canopy can be 15 to 20 m in height and can vary greatly from open to almost closed. The shrub layer varies from sparse to dense and comprises *Acacia* spp., *Ficus* spp. on marginal areas and the ubiquitous freshwater mangrove *Barringtonia acutangula*. *Pandanus aquaticus* and *B. acutangula* line streams and channels. In zones edging woodland (which is often the case in the RPA), the trees are wider spaced and often form an ecotone with myrtle-pandanus savanna. In this ecotone area eucalypts, bloodwoods and other savanna trees co-dominate with the paperbarks. Coastal deciduous rainforest habitat is not present in the RPA according to the description of Schodde *et al*. (1987).

Habitat 2: Myrtle-Pandanus Savanna

Consists of grassland with small open pockets of woodland, mixed shrubland and rainforest trees, interspersed with strips of Pandanus (*Pandanus spiralis*) along the edges of floodplains and with paperbarks (*Melaleuca* spp.) along creeks and streams. Tall trees from genera such as *Corymbia* and *Eucalyptus* are sparingly present. A very patchy shrub layer of *Melaleuca viridiflora*, *M. nervosa* and *P. spiralis* occur. Common grasses include annuals from genera such as *Digitaria*, *Ectrosia*, *Panicum*, *Schizachyrium* and *Sorghum* and perennial grasses including those from genera such as *Eriachne* and *Themeda*. Sedges (Cyperaceae) are also a common component of the ground cover.

Habitat 3: Open Forest

Tall (12 to 20 m) open forest dominated by *E. miniata* and *E. tetrodonta* and with other species of eucalypts present in the canopy. The only frequent non-eucalypt that occurs in the canopy is Ironwood *Erythrophleum chlorostachys*. The shrub layer consists of *Acacia* spp., *Calytrix exstipulata*, *Gardenia* spp., *Livistona humilis*, *Petalostigma quadriloculare*, *Planchonia careya*, *Terminalia* spp. and *Xanthostemon paradoxus*. Ground cover is usually sparse, inconspicuous and comprises mostly annual grasses of *Sorghum* spp. and other herbaceous plants.

Habitat 4: Woodland

This habitat typically lacks a distinct canopy and is more stunted (usually less than 12 m) than open forest, being dominated by bloodwoods (*Corymbia* spp.), but also contains eucalypts such as *E. miniata*, *E. tetrodonta* and *E. tectifica*. However, it is quite variable in structure and can be tall on slopes to the point where it grades into open forest. The shrub layer is the same as in open forest but much sparser. The palm *L. humilis* is common and pockets of *P. spiralis* may also be present. The ground cover is much denser than in open forest, containing mainly annual grasses, e.g. *Sorghum* spp. In stunted woodlands perennial grasses *Heteropogon triticeus* and *Sehima* sp. dominate.

Table 5-36: Area and proportion of vegetation communities on the RPA and Kakadu NP

Community (Schodde *et al.* 1987)	RPA[1] (ha)	RPA[1] (%)	Kakadu NP (ha)	Kakadu NP (%)	RPA community as a percentage of equivalent habitat in Kakadu NP (by area)
Myrtle-pandanus savanna/ paperbark/coastal rainforest	434	6	39,487	4	1.1
Myrtle-pandanus savanna	1,863	26	170,802	16	1.1
Open forest	3,018	42	336,269	32	0.9
Woodland	1,870	26	508,000	48	0.4

Note 1 – undisturbed (non-mine) sections only

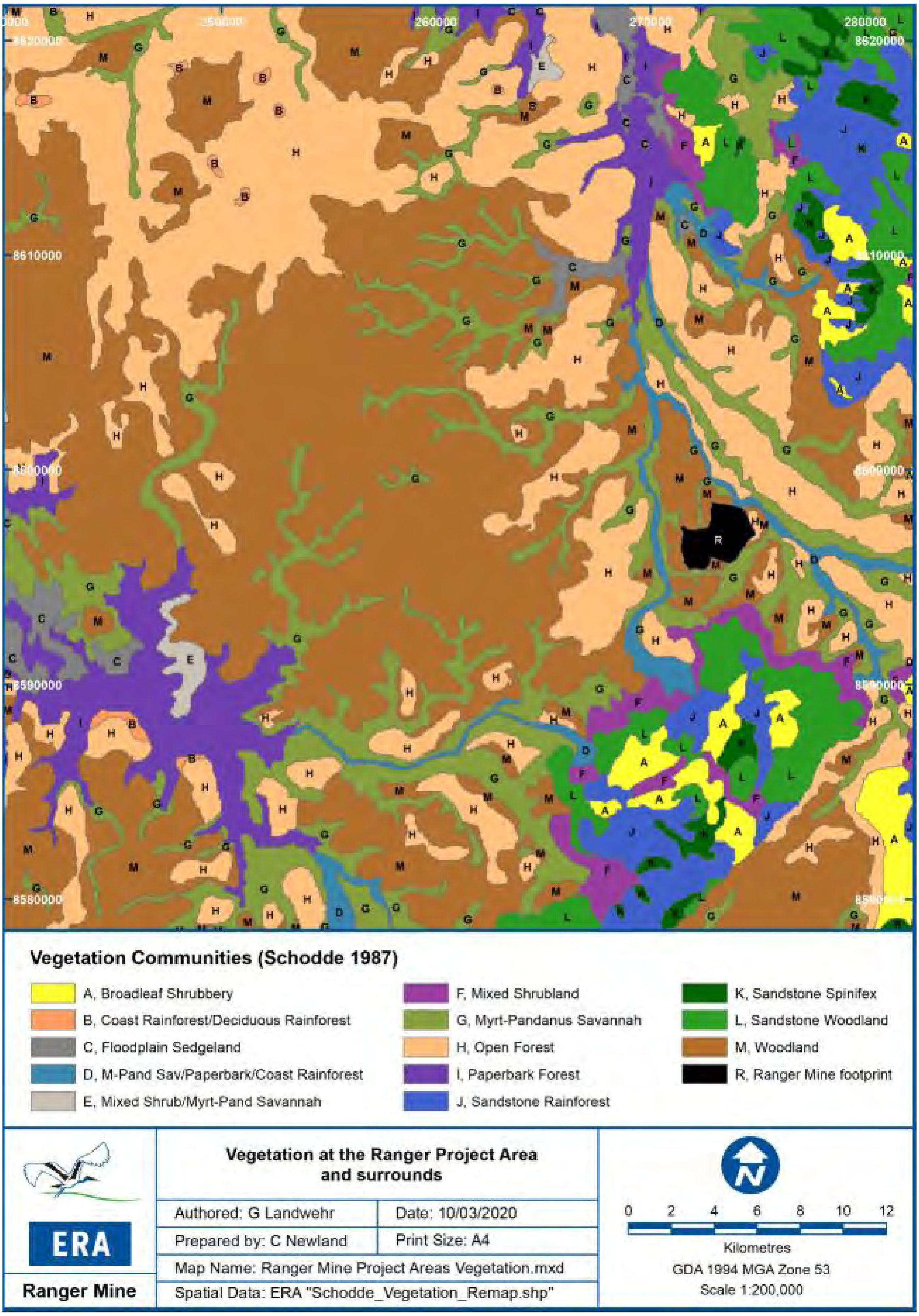


Figure 5-73: Vegetation of the RPA and surrounding Kakadu NP (Schodde *et al*. 1987)

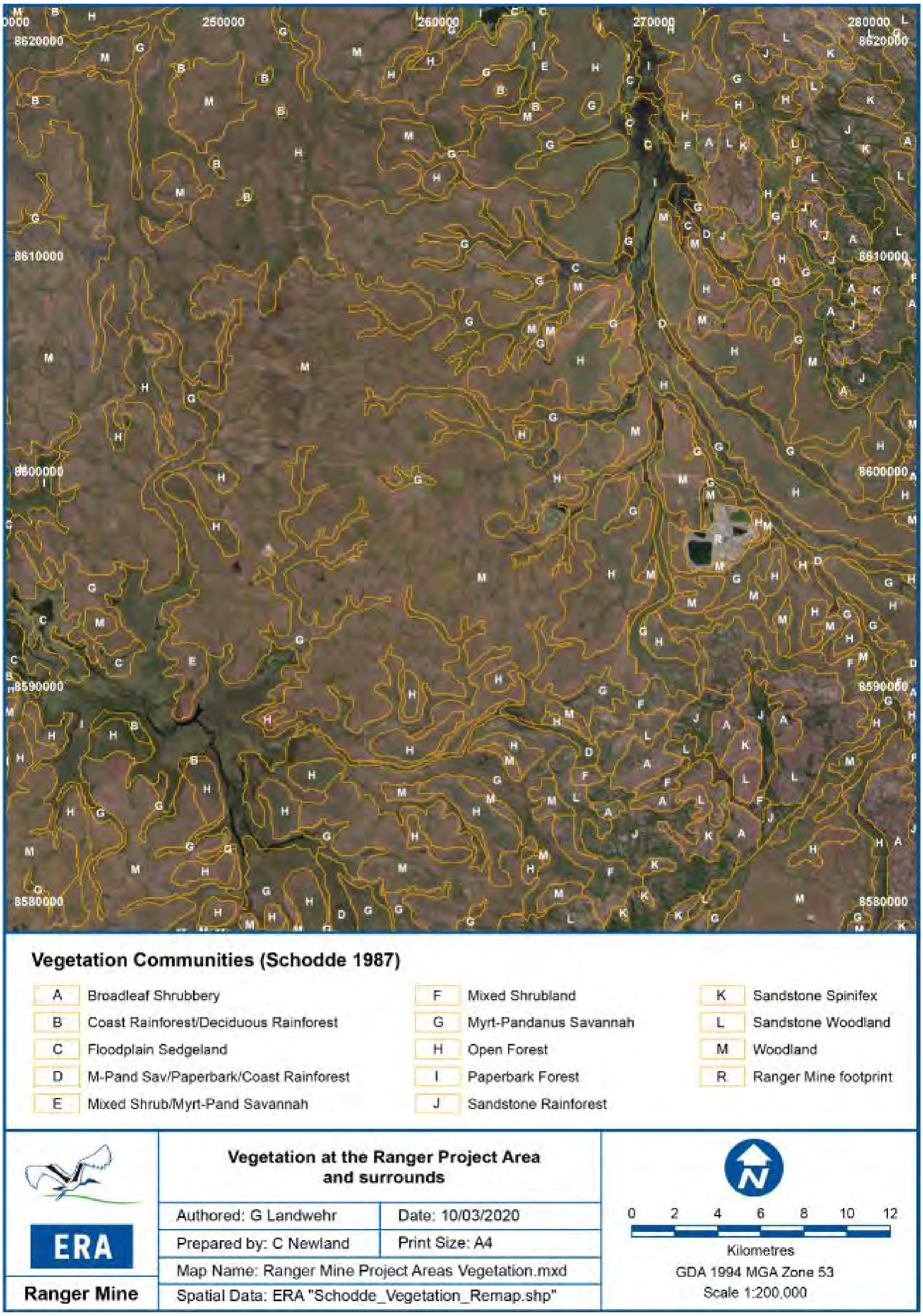


Figure 5-74: Vegetation types over aerial of the RPA and surrounding Kakadu NP

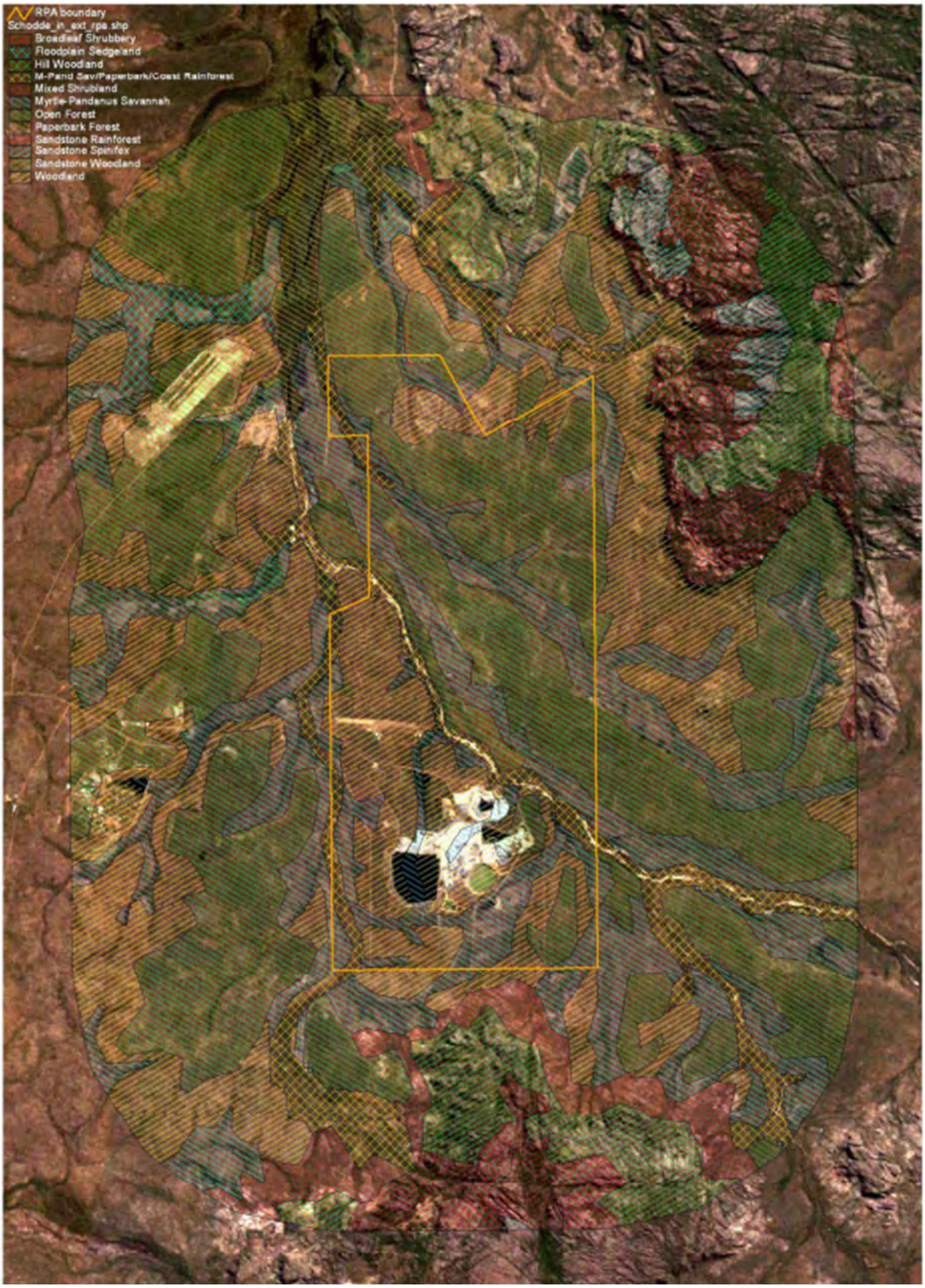


Figure 5-75: Vegetation habitat map (Schodde et al 1987) of the RPA

At the broad scale, the distribution of the more dominant native forest and woodland communities near Ranger in the wet-dry tropics of northern Australia is controlled predominantly by three factors:

- The underlying geomorphology (which influences site hydrological features and soil fertility);
- The seasonality and predictability (inter-annual variability) of climate; and
- The frequency and intensity of fire.

These factors govern the structural complexity (e.g. height, biomass, number of strata, size class distributions, root depth and distribution patterns), species compositions and the functioning of the vegetation (e.g. water use, nutritional uptake, regeneration strategies, and phenology). These are the environmental factors that have moulded (and constrained) the native vegetation, and its responses to disturbances. Within areas with similar climate and fire regime, geomorphology plays the major role in determining vegetation communities. This is reflected in distinctive catenary sequences of forest and woodland vegetation that are found throughout the lowland parts of Kakadu NP (Bowman *et al*. 1988) and is the basis of 'land system' and other mapping that has been undertaken in the region (Story *et al*. 1969). However, the way in which individual plant communities have been delineated and classified in these surveys has depended on factors such as the scale of the mapping (1:20,000 to 1:1,000,000) and the particular purpose for which the survey was conducted (e.g. broadscale vegetation description, fire risk management, fauna habitat mapping or mine environmental impact statement).

5.4.1.2 Ecosystem rehabilitation and influence of post-mining conditions

As prescribed in the ERs (Section 8), ERA must establish an environment using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu NP. This will be no mean feat considering the extreme level of disturbance from mining and the dramatically different characteristics of the final landform waste rock substrate compared to natural soils (see KKN ESR7).

Although ERA has demonstrated that the final landform material can support development of a native woodland ecosystem on the Trial Landform (TLF) and other trials (see KKN ESR3), there will likely be a degree of difference in these revegetated ecosystems to those that were there previously. In 2020, ERA produced a technical brief of potential physical and chemical constraints that may influence vegetation suitability (as evidenced by their ability to establish and develop into a sustainable ecosystem), particularly on the waste rock final landform. This brief was reviewed with key stakeholders (May 2020 Ecosystem Restoration Working Group, comprising ERA, SSB, NLC and select ARRTC representatives) and it was agreed that most constraints warranted further consideration as ERA continues to refine the agreed reference ecosystems and related criteria. These potential constraints are summarised below (and discussed in detail in Section ESR7), including:

- material type and relationships to plant water availability, rooting depth and so on;

- surface hydrology and subsurface hydrogeology, including seasonal variations;
- substrate chemical status, including nutrients and contaminants of potential concern; and
- slopes and aspect.

Material type

The key aspects of waste rock impacting vegetation establishment relate to plant water availability (PAW) and rooting depth. The studies relating to PAW are discussed under ESR7.

Waste rock PAW depends on the proportion of fines (<2mm) in the material as well as the total depth available for plant root establishment. For example, Section 1A of the TLF was constructed of material with an average of 33% fines and has been able to successfully establish a range of native overstorey and midstorey species (discussed in Section ESR3 and ESR5). Monitoring of the TLF and WAVES modelling has indicated that a minimum of 15% fines is sufficient to sustain a native woodland ecosystem (Lu et al. 2019). It is understood that material with higher fines will have a greater PAW, act more like a natural 'soil' and be able to support the local, natural woodland ecosystems with fewer adjustments.

Particle size distribution (PSD) analysis of waste rock in stockpiles indicates that the waste rock ranges between 10% - 60% fines. Mine planning and bulk earthworks processes have been developed to ensure that the material to be placed in the surface growth layers (e.g. up to 6 m depth) of the final landform is not below 15% fines and, wherever possible has more fines to optimise PAW.

Except for the backfilled pits and the upper reaches of the final landform, 62% of the final landform has less than 6 m of waste rock overlying natural soils (Table 5-37and Figure 5-76). This means that plants in these areas, particularly larger plants with greater rooting depths, may be able to access any PAW in these soil and possibly have improved plant-water relations in the late dry season when seasonal stresses are greatest. Plants on the other 38% of the final landform will have at least 6m of waste rock rooting depth available which has been modelled as sufficient to sustain a native woodland ecosystem dependent on the fines proportion (eg. minimum 15% fines) (Lu *et al*. 2019).

Surface hydrology and subsurface hydrogeology

The main impact of surface hydrology is in the distribution of basins and drainage features across the integrated final landform (Figure 5-77). A range of suitable vegetation will be required to colonise and stabilise these features, from the drier upper reaches down towards where drainage lines develop into riparian creeks.

Due to differences in hydraulic conductivity of the waste rock of the final landform and the underlying natural soils, modelling indicates that areas around the final landform perimeter may experience extended periods of saturated soils. Although relatively small in areal extent, this scenario would largely preclude the establishment of vegetation of the common regional woodlands which are used to a prolonged dry season each year. Similarly, the nature of the subsurface hydrogeology in the area of the TSF will likely be an influence on what vegetation can establish.

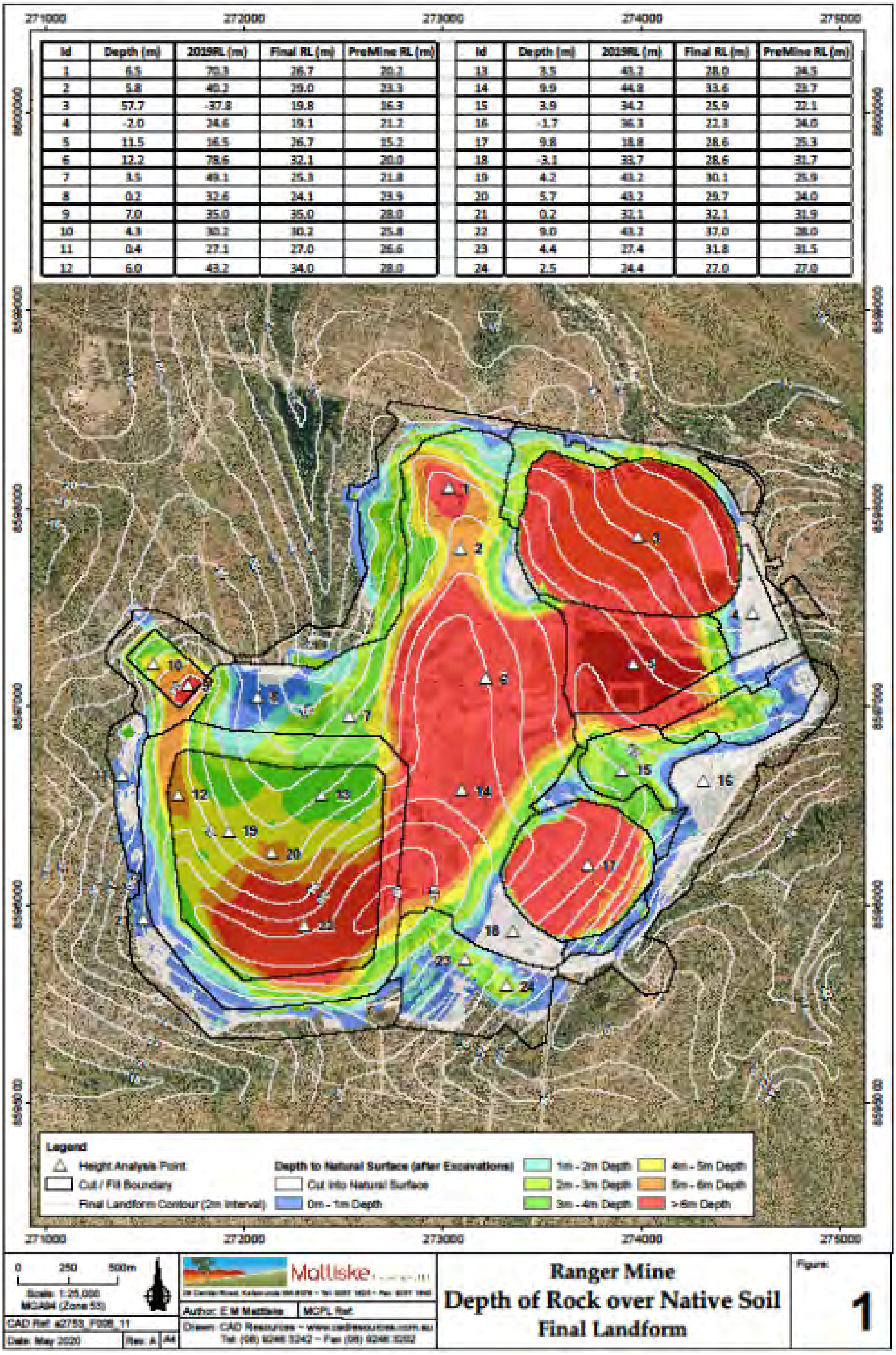
Table 5-37: Approximate depth of waste rock over natural soils (based on 2020 BMM plan)

Depth	Area (ha)
Cut into Natural Surface	65
0 m – 1 m	73
1 m – 2 m	52
2 m – 3 m	59
3 m – 4 m	86
4 m – 5 m	72
5 m – 6 m	57
> 6 m	283
Total	747

Substrate chemical status, including nutrients and contaminants of potential concern

As discussed in the 2018 *Cumulative ecological risk assessment for the rehabilitation and closure of Ranger uranium mine* (Bayliss 2018), chemicals in substrates can play a critical role in revegetation success, including: a limiting nutrient; a toxicant above a threshold effects level; a modifier or facilitator of other chemical processes/interactions; or a combination. Overall, the waste rock material at Ranger Mine differs from natural soils by having higher pH, EC, CEC, Mg, total P and SO4 concentrations, and having lower levels of organic carbon and nitrogen. The ecological risk assessment found that risks to terrestrial revegetation from mine-derived chemicals is assumed zero (Bayliss 2018).

As part of the technical constraints review, it was identified that areas of potential acid sulfate soils (PASS) may be present, particularly in areas requiring future 'riparian' revegetation. Studies into this are ongoing and a specific revegetation strategy, including suitable reference ecosystems, shall be developed if necessary.



Id	Depth (m)	2019RL (m)	Final RL (m)	PreMine RL (m)
1	6.5	70.3	26.7	20.2
2	5.8	40.2	29.0	23.3
3	57.7	-37.8	19.8	16.3
4	-2.0	24.6	19.1	21.2
5	11.5	16.5	26.7	15.2
6	12.2	78.6	32.1	20.0
7	3.5	49.1	25.3	21.8
8	0.2	32.6	24.1	23.9
9	7.0	35.0	35.0	28.0
10	4.3	30.2	30.2	25.8
11	0.4	27.1	27.0	26.6
12	6.0	43.2	34.0	28.0
13	3.5	43.2	28.0	24.5
14	9.9	44.8	33.6	23.7
15	3.9	34.2	25.9	22.1
16	-1.7	36.3	22.3	24.0
17	9.8	18.8	28.6	25.3
18	-3.1	33.7	28.6	31.7
19	4.2	43.2	30.1	25.9
20	5.7	43.2	29.7	24.0
21	0.2	32.1	32.1	31.9
22	9.0	43.2	37.0	28.0
23	4.4	27.4	31.8	31.5
24	2.5	24.4	27.0	27.0

Figure 5-76: Depth of rock over natural soil

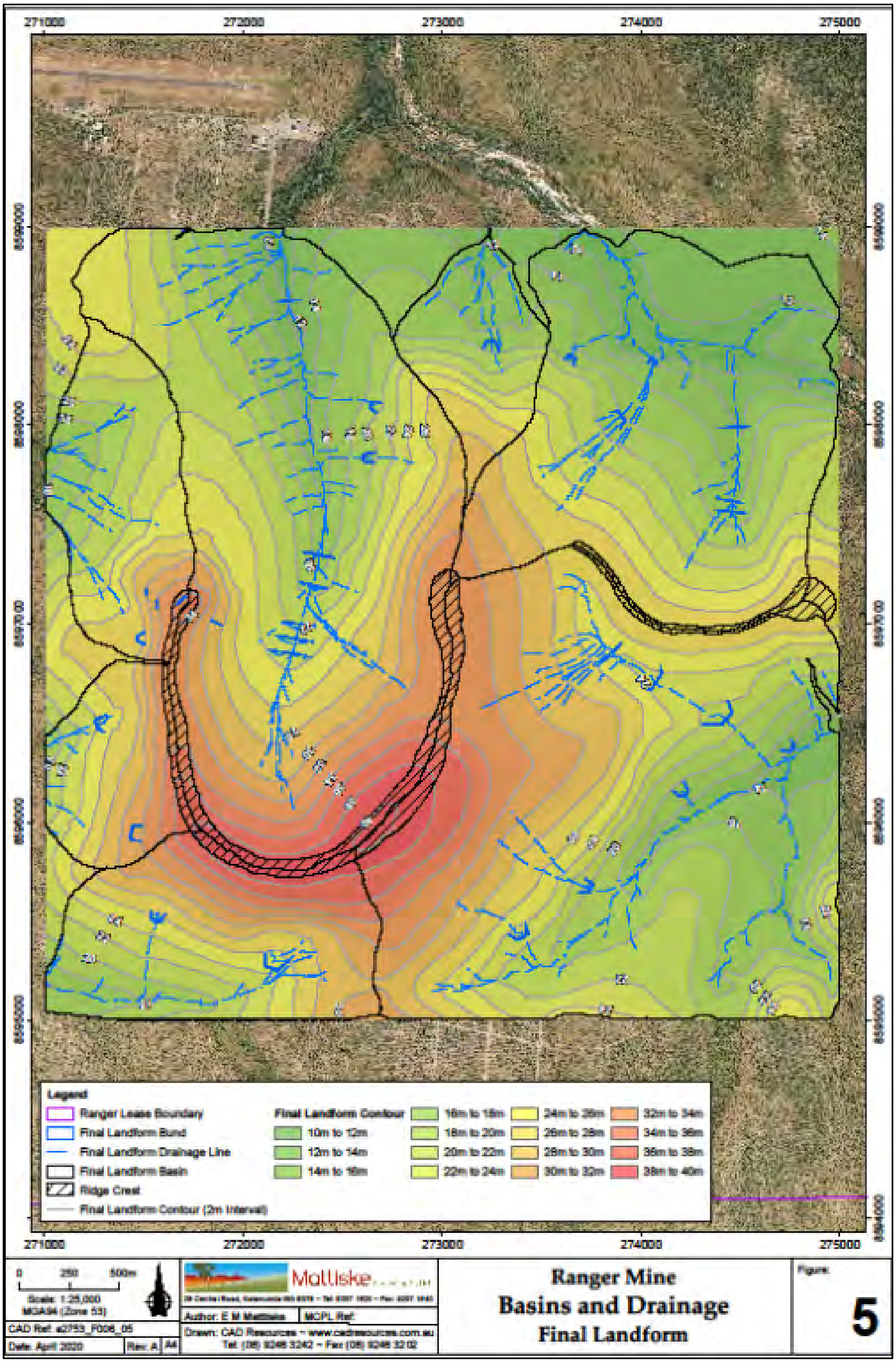


Figure 5-77: Basins and drainage features of the final landform.

Slope and aspect

Whilst slopes and aspects can be significant influences in some mine rehabilitation scenarios, at Ranger Mine almost all slopes are less than 5° and do not require any particularly drastic revegetation treatment. Surface ripping of areas with steeper slopes is allowed for, which should mitigate against any potential erosion risks.

5.4.1.3 RPA and surrounding environment survey history

Part of the Ranger Ecosystem Establishment Strategy has been to identify and describe vegetation types that are ecologically, culturally and technically realistic target endpoints, for different facets of the final landform, based on the likely physical and chemical environments that will be created (Appendix 5.4). The final landform is being designed to resemble, and behave in a manner similar to, landforms of the surrounding area, while still providing for the long-term protection of the environment (refer landform section above). Based on the likely low-rocky rise features of this landform, most research to date has focussed on identifying and characterising natural ecosystems occurring in comparable landscape locations, for use as appropriate reference ecosystems. There is a range of vegetation community types in areas outside the mine footprint that represent the spectrum of environments likely to be found across the rehabilitated final landform and RPA. By understanding the environmental features that are associated with the normal range of native vegetation community types, the conditions required to support these communities and/or the community types that best suit particular environmental conditions of the Ranger Mine final landform, can be identified (Humphrey *et al.* 2009).

There has been substantial surveying and monitoring of the terrestrial flora across the RPA and surrounding Kakadu NP over the past few decades. These were performed to obtain quantitative data on the surrounding environment to inform revegetation planning and management, as well as performance objectives and assessment methods (in terms of closure criteria) (e.g. Hollingsworth and Meek 2003, Brennan 2005, Hollingsworth et al. 2007b, Humphrey 2013, Humphrey & Fox 2010, Humphrey et al. 2009, Humphrey et al. 2011, Humphrey et al. 2008, Humphrey et al. 2012; Table 5-38).

Table 5-38: Vegetation survey data collected in the Alligator Rivers Region (adapted from Erskine *et al.* 2019)

Reference	Sites	Date	Design	Plot size and methods	Plots within 10 km radius of Ranger
Conservation Commission (White *et al.* 1985)	77	1979-1981	Unknown	Vegetation present within 50 m radius of soil sampling site. Understorey not collected	36%
Brennan (2005)	20	1991-1993	Stratified Random	Two assessments based on height >1.5m = Ten 20m x 20m randomly placed in 1ha (4000m^2); <1.5m = 20 x 5m x	35%

Reference	Sites	Date	Design	Plot size and methods	Plots within 10 km radius of Ranger
				5m quadrats (400m²) 25 understorey (0.71m x 0.71m (12.5m²)	
EWLS (Hollingsworth & Meek 2003)	20	2002	Stratified Systematic	For trees and shrubs >2m; 320m x 20m plots (total of 1200m²) at each site stratified by ecosystem types. 10 understorey x 1m x 1m (10m²)	100%
Cyclone Monica (Saynor *et al.* 2009)	31	2006	Stratified Random	For trees & shrubs >2m 30m x 30m plots (900m²) Understorey not collected	67%
Hollingsworth *et al*. (2007a)	38	2007	Stratified & mixture of random and systematic	Data from Hollingsworth and Meek (2003) and Brennan (2005)	100%
2010 Survey (Humphrey *et al*. 2012)	54	2010	Stratified Random	For trees & shrubs >2m 20m x 20m plots (400m²) plots except site A53 (25m x 20m) Understorey not collected	100%
2019-2020 (Supervising Scientist 2019b)	12	2019-2020	Stratified and Random	For Trees and Shrubs: >1.5m , <1.5m on Transects in 1ha. Density of Stems and % Cover Understorey presence absence and cover. SSB S1 to SSB S10 from within 10km radius of the Ranger mine and SSB G1 and SSB G2 from part of the Georgetown area south-east of RPA.	100%

5.4.1.4 Potential substrate factors influencing vegetation community variability

Early work by the Supervising Scientist (Needham *et al*. 1973) and NT Land Conservation Unit (Uren 1992) identified a number of locations in the Alligator Rivers Region as being weathered hills composed of Cahill formation schists – likely to be natural sites where both topography and rock type were similar to that expected on the Ranger final landform. Referencing this work, a later Supervising Scientist study by Brennan (2005) compared vegetation found at areas adjacent to the Ranger site and those further afield (but within Kakadu NP). As Brennan (2005) states:

The concept of site revegetation based on the characteristics of adjacent or pre-existing plant communities has much popular appeal a clear statement of intent to restore disturbed sites to their previous undisturbed state. However, there is a potential problem in applying this concept to guide revegetation on the Ranger Waste Rock Dump (WRD) ... The basis of the problem is that the landform and substrate of the WRD are not related to the pre-existing landforms, or to substrates adjacent to it. The WRD is composed of metamorphic, Cahill-formation schists whereas adjacent substrates belong to a geologically unrelated entity known as the Koolpinyah- surface (Needham et al. 1973, Wells 1979). Given these striking geotopographic differences it seemed reasonable to suggest that native vegetation communities immediately adjacent to the WRD might not contain the most appropriate species for revegetating this area.

There has been a lot of research on what drives community types in the region. A key finding from Brennan (2005) was that floristic heterogeneity (among the hill sites) was due to the dissimilarity of their substrates or parent-rock types. A later study by Humphrey, Fox and Lu (2008) looked at previously surveyed vegetation communities and soil factors associated with sites, including soil chemistry, PSD, soil water retention properties, soil morphology, surface drainage classes and soil permeability. Generally, no relationship was found between underlying soil properties and community composition and structure based on statistical analyses performed (Humphrey et al. 2008). It may be that these contrasting conclusions resulted from difference in scales at which the studies were undertaken.

A review of the drivers of vegetation structure in northern Australian savannas concluded that water availability, particularly during the dry season was the major determinant of tree structure (Cook et al. 2020; Murphy et al. 2015). As part of the long-term Kapalga experiment in Kakadu NP, it was found that soil depth, most likely through the mechanism of water availability during the dry season, is a major driver of tree stand structure, and that evergreen trees increased in basal area as soil depth increased, but deciduous trees showed no significant variation with soil depth (Figure 5-78) (Cook 2021).

Key drivers of vegetation structure in woodland and forest savanna ecosystems are summarised by Cook (2021):

Both fire and water limitations expressed through seasonal water deficits lead to tree death, and this leads to the development of multi-age and multi-size tree stands in the savannas (Cook et al. 2020; Cook et al. 2016). Mortality rates from both causes are greater in woodlands (2.7% per year) than open forests (2.15% per year) (Cook et al. 2020). Larger trees in these systems may be several centuries old. The open forests dominate on deeper loam to sandy loam soils while woodlands dominate on shallower soils with greater water limitations. Fire in these systems has a secondary role compared to that of soil and landscape position. In riparian zones, high water availability can favour fire sensitive species, but frequent fire can greatly reduce the number of woody species along ephemeral streams in the region (Douglas et al. 2003). Further, the density of riparian vegetation is reduced with frequent fires.

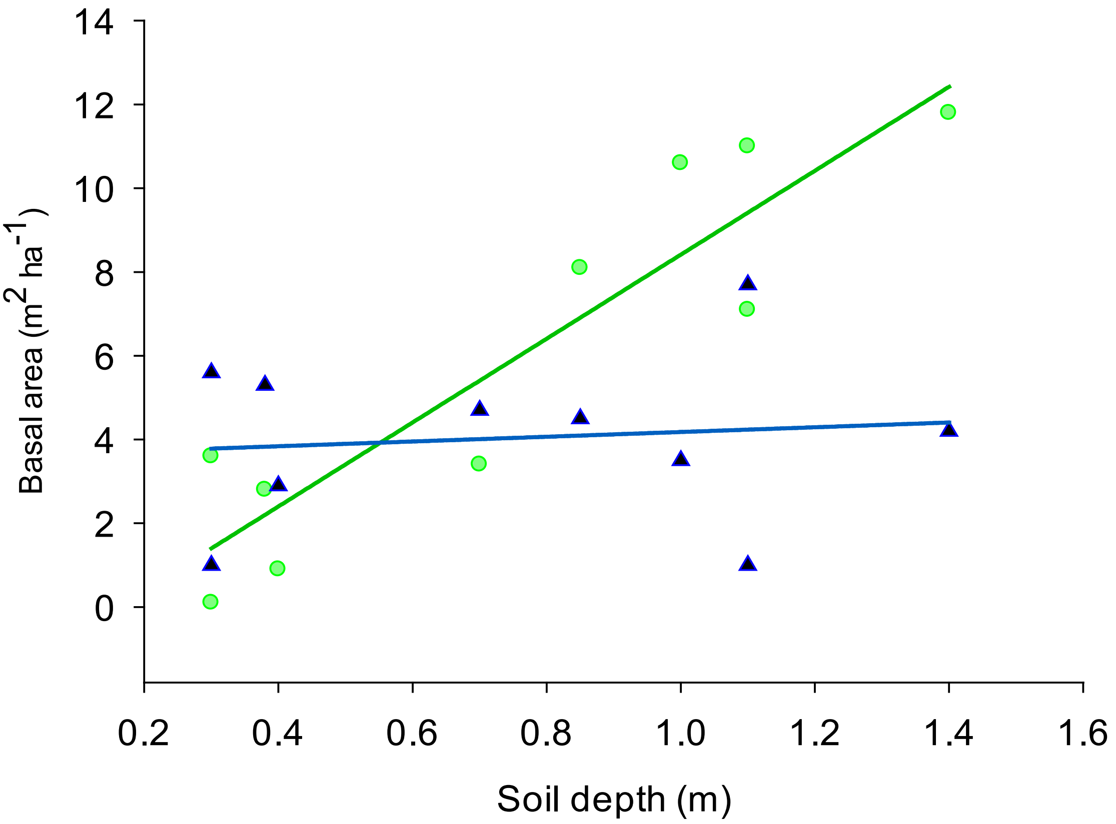


Figure 5-78: Variation in the basal area of evergreen trees (●) and deciduous trees (▲) in relation to soil depth along downslope catenary sequences at Kapalga in Kakadu National Park (Cook *et al* 2020).

5.4.1.5 Identifying suitable natural reference sites for Ranger rehabilitation

An area of particular focus on the RPA has been the 'The Georgetown Creek Reference Area' (hereon referred to as Georgetown Area, the hexagon in Figure 5-79), chosen because it is representative of nearby Kakadu NP habitats that are considered appropriate for a rocky final landform (Hollingsworth et al. 2003a). Early work focussed on describing the detailed geomorphic and pedological characteristics of different units that were present and on relating these to compositional and structural features of their vegetation cover (Hollingsworth et al. 2003a, Hollingsworth & Meek 2003).

Extensive surveys of the Georgetown Area have been completed, including a 400 ha grid survey (at 200 m spacing) that has shown graphically the natural variability of the vegetation types across the analogue area (Hollingsworth & Meek, 2003; Figure 5-80). Monitoring plots in Figure 5-80 are coloured according to vegetation type:

- Pink: Tall *Eucalyptus tetrodonta* open forest
- Yellow: Tall *Corymbia bleeseri* and *E. tetrodonta* mixed open woodland

- Blue: Mid-high *Melaleuca viridiflora* open woodland
- Green: Tall *E. tetrodonta*, *E. miniata* and *E. tectifica* open woodland
- White: Tall *E. tetrodonta, E. miniata*, *C. dunlopiana*, and *C. porrecta* open forest
- Brown: Tall *C. foelscheana*, *E. tetrodonta* and *C. disjuncta* mixed open woodland
- Red: Mid-high *C. disjuncta*, *E. tectifica* and *C. foelscheana* open woodland

The soils in the Georgetown Area vary in their drainage status and are typically gravelly and less than one metre deep to parent rock. The variation in the plant communities is typical of the lowland regional surface (Russell-Smith 1995) and there is a strong response to drainage and water supply (Williams et al. 1996). The structure and composition of the Georgetown Area vegetation is likely to be governed principally by water availability and plant available nutrients, typical of northern Australian savanna (Williams et al. 1996). Key geomorphic features (including parent material, slope, effective soil depth etc.) may also be important. However, more subtle variations in the vegetation composition and structure are likely to be the result of interplay between historic factors, proximity and context (i.e. the surrounding vegetation types) and discrete, often localised, disturbance events.

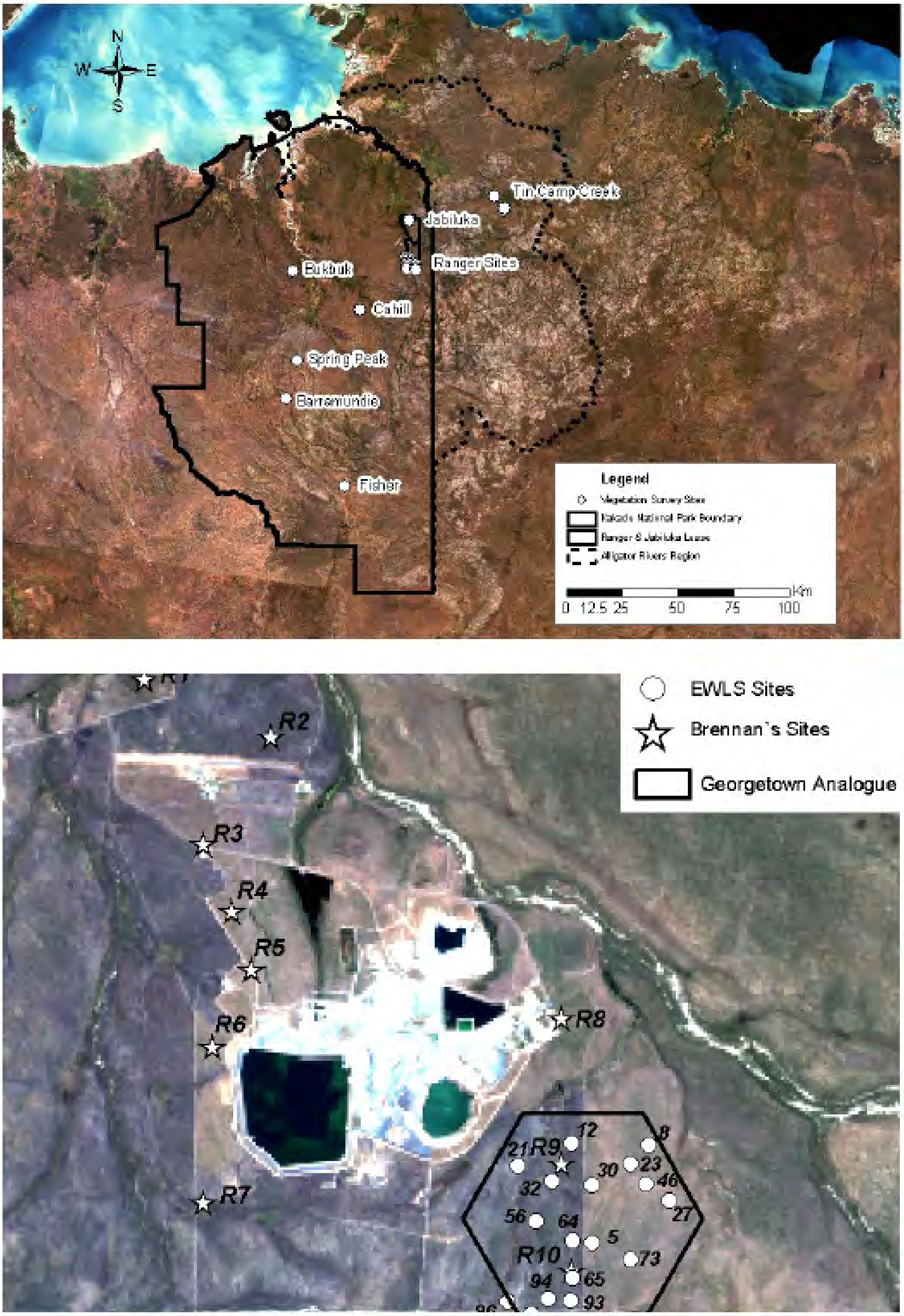


Figure 5-79: Maps of plant analogue sites surveyed by Brennan (2005) (top and bottom) and (Hollingsworth *et al.* 2003a) (bottom)

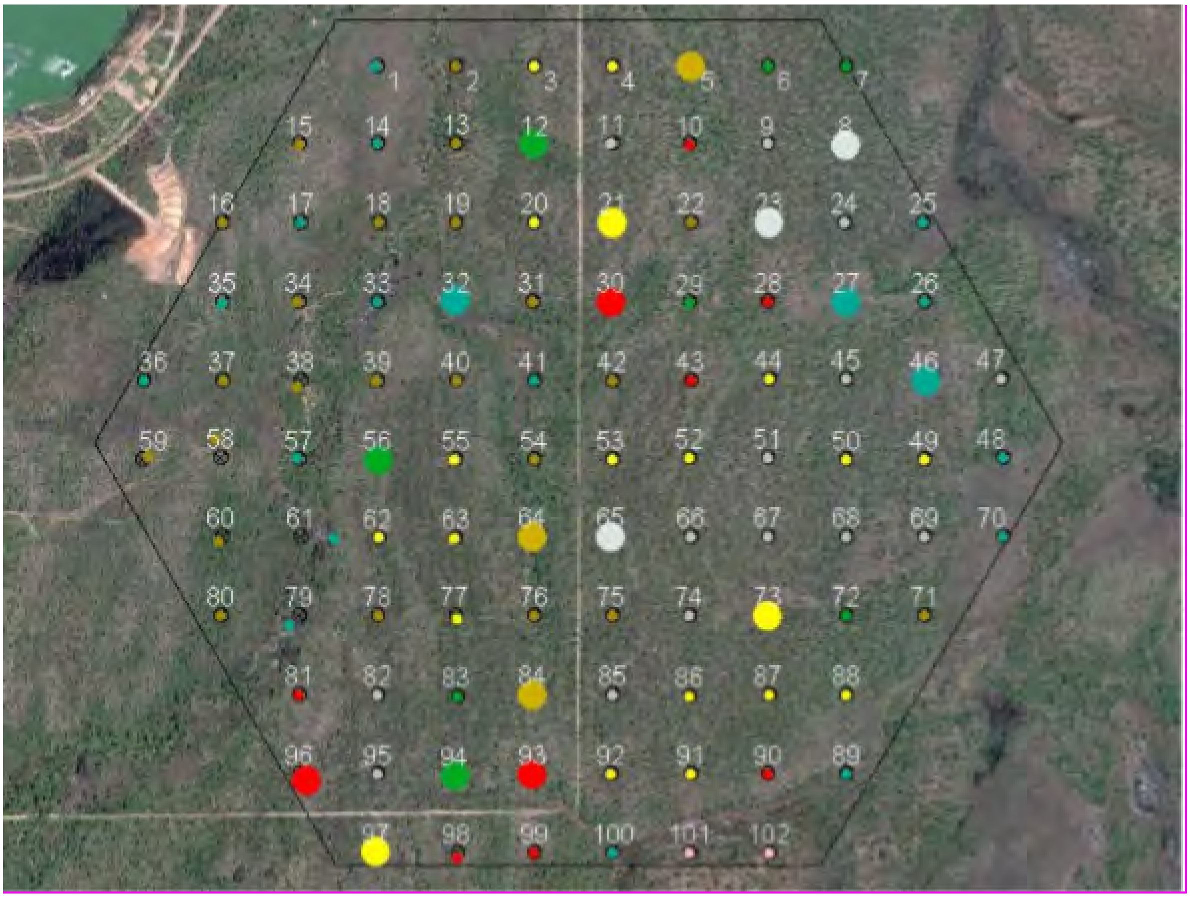


Figure 5-80: Georgetown Creek Reference Area vegetation type variation across monitoring sites

From 2018 - 2019, SSB surveyed 12 one-hectare vegetation reference plots (including two sites within the Georgetown Area) from within a 10 km radius of the mine site. In 2021, a further two one-hectare sites were surveyed in the Georgetown Area.

Four intermittently flooding savanna ecosystems were also surveyed by SSB in 2019 and 2020, in recognition that some areas of the Ranger final landform may have impacted surface hydrology and subsurface hydrogeology, including impeded drainage, seasonal flooding etc. The data from these sites are considered preliminary, and stakeholder discussion on seasonally inundated sites is ongoing. Future iterations of the RMCP will include updates on this work as it progresses.

5.4.1.6 Proposed conceptual reference ecosystems for ERA Ranger Mine

Due to the permanent and irreversible changes to the site, particularly in terms of topography, hydrology and substrate of the final landform, ecological conditions will be different to the pre-mining environment and no real analogue exists in the natural surroundings. In the absence of a natural reference ecosystem with a similar substrate, a nearby natural reference ecosystem can be adopted but adjusted to accommodate changed or predicted environmental conditions (SRG SERA 2021). The target ecosystem(s) in the case of Ranger Mine will be a conceptual ecological model, also referred to as a conceptual reference ecosystem (CRE). The CREs will be synthesised from numerous appropriate reference sites, revegetation trials, cultural values and historical and predictive records (e.g. potential modifications for predicted climate change or substrate limitations, Prober et al. 2015).

ERA is collaborating with key stakeholders to define appropriate CRE(s), and develop agreed closure criteria (Section 8), for the rehabilitation of Ranger Mine. As work on this has progressed, a clearer pathway towards development of an agreed CRE model for Ranger Mine revegetation has appeared, as outlined below:

- ensure a shared understanding of clear and specific objectives;
- understand the ideal environmental conditions for the target post-mine land use and, as far as practicable, consider these in the design and execution of the rehabilitated landform; and
- understand any constraints (and opportunities) to vegetation establishment imposed by the post-mining conditions.

In late 2019, ERA commissioned Dr Libby Mattiske, a renowned expert in the field of mine site rehabilitation, monitoring and assessment, to review the available vegetation data for Ranger Mine, compare these to benchmarked approaches from other operations and jurisdictions, and recommend an updated method to develop CREs for ERA. This work built on many years of research efforts with an emphasis on the current local and regional values that may influence the selection of appropriate species and communities for the rehabilitation areas predicted on the Ranger site. It also placed such information into the context of the constraints to the values on the post-mining site conditions with regard for current industry practices for rehabilitation management and objective setting.

The data sets from the various studies to date were integrated and a series of analyses undertaken on the representative subsets of data to clarify a potential way forward to maximise the use of the datasets (Mattiske & Meek 2020). Surveys analysed included ten of the SSB 2018/19 surveyed woodland sites, as well as the data sets from Humphrey et al. (2012), Saynor et al. (2009), and Hollingsworth and Meek (2003). The survey data was integrated with a reliance particularly on stem numbers of the overstorey and midstorey species due to the greater consistency between researchers and the need to concentrate on these species for the initial revegetation works on the Ranger Mine. This initial focus also avoided the constraints of variations in seasonal conditions at the time of samplings and the complexity of different lifeforms (Mattiske & Meek 2020).

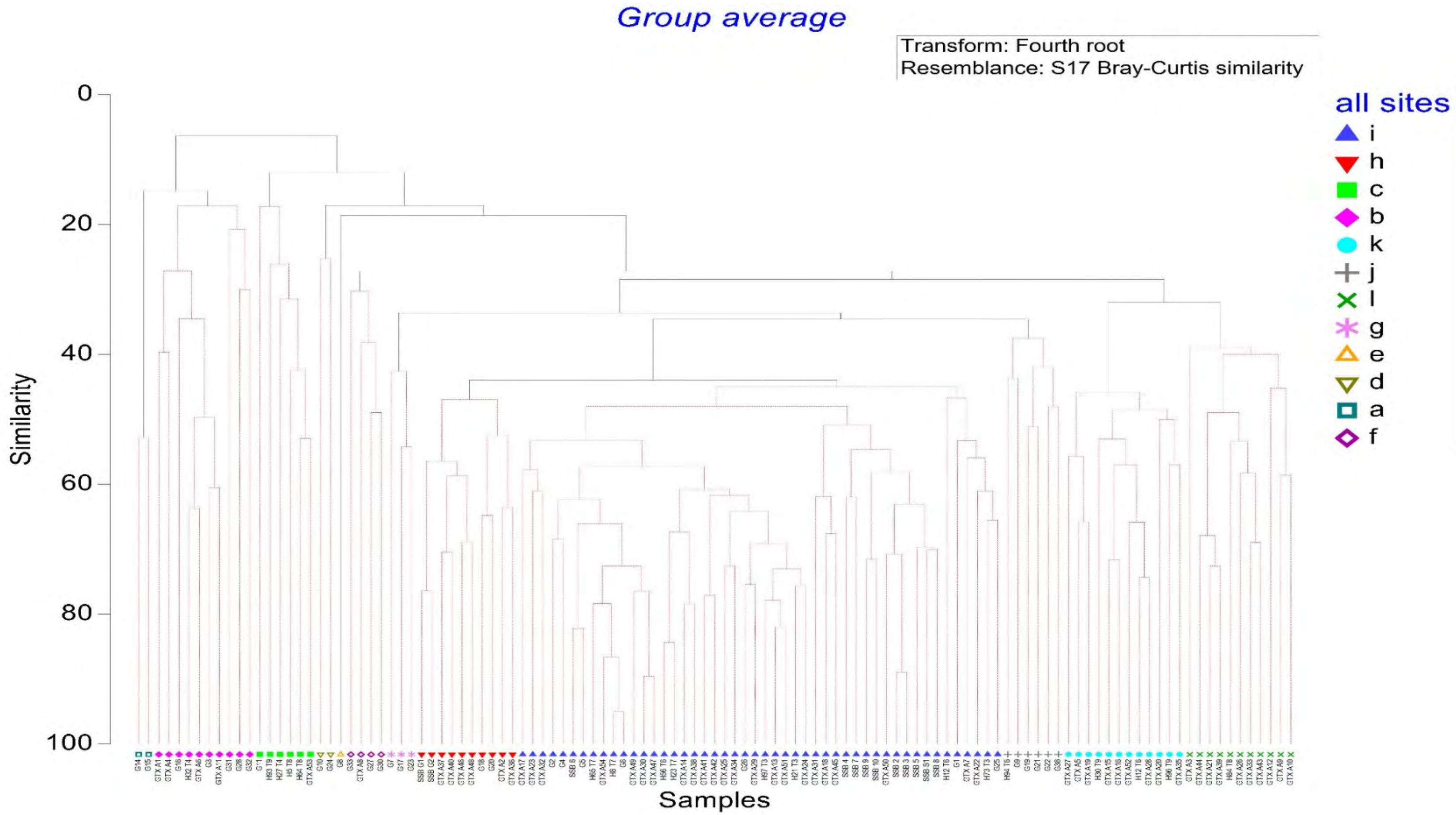


Figure 5-81: Dendrogram illustrating similarity of SSB sites near Ranger (2019/2020 data) and all of Saynor et al. (2009) and Georgetown (Hollingsworth & Meek 2003, Humphry et al (2012) using stems/ha overstorey/midstorey species (Mattiske & Meek 2020).

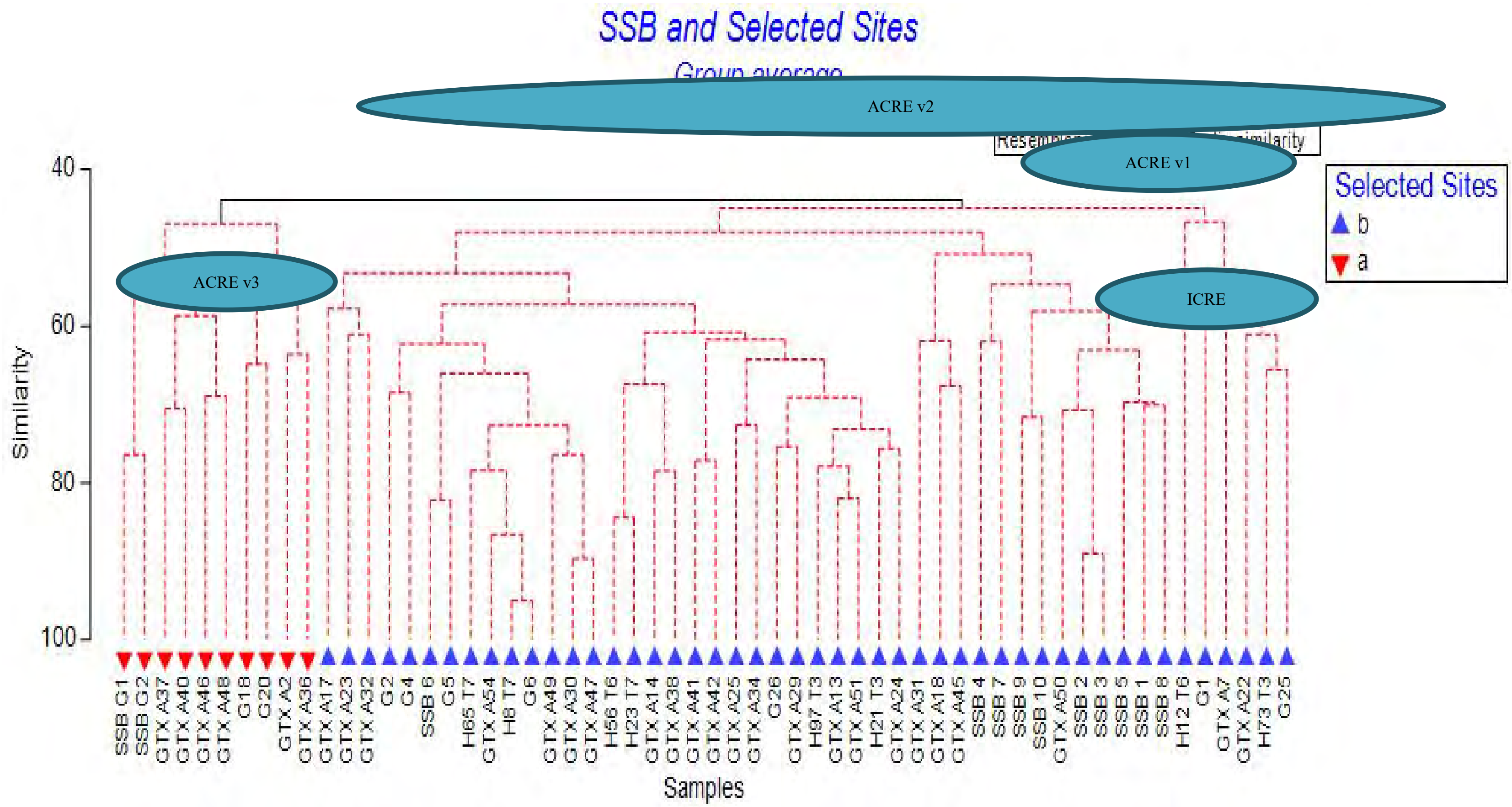


Figure 5-82: Dendrogram illustrating similarity of a subset of SSB sites near Ranger (2019/2020 data), Saynor et al. (2009) and Georgetown (Hollingsworth & Meek 2003, Humphry et al (2012) using stems/ha of overstorey/midstorey species (Mattiske & Meek 2020).

The data was analysed using Clarke and Gorley (2015) Primer version 7.0.13 using Bray – Curtis similarity. As indicated in the dendrogram (Figure 5-81) the data from some Georgetown woodland sites align with the SSB Eucalypt woodlands. Consequently, it was seen that the results supported a combination of the SSB sites with other selected sites from within and near the RPA, to broaden the coverage of natural variations within the local woodland. The report proposed that the ten SSB 2018/19 sites represent an 'Initial Conceptual Reference Ecosystem' (ICRE), and that three versions of potential alternative CREs (ACREs) in Table 5-82) be considered based on a combination of SSB 2018/19 data and the other surveys. These included ACREv1 as a slightly modified ICRE, ACREv2 which included species and communities wider in representation, and ACREv3 which allowed for the inclusion of what was considered 'drier site tolerant species'.

There was general agreement from stakeholders that the proposed alternative CREv2 formed a suitable basis for a CRE. In particular, the inclusion of a number of Georgetown survey sites (20x20 m quadrats) expanding the overstorey species array for *E. tetrodonta / E. miniata* dominated savanna than that which was contained in SSB one-ha 2018/2019 reference plots. However, two key issues where raised for consideration:

- the disturbance history of reference sites / plots, and whether 'impacted' sites should be included in developing the CRE; and
- given the mix of scales, different survey methods and disproportionate (over)representation of Georgetown survey sites, implications for (i) use of the alternative CREv2 site data in deriving a species and stem density list for ecosystem establishment, (ii) demonstration and scenario testing, and (iii) future monitoring of the reference ecosystem going forward.

Following from this assessment, it was agreed that two of the SSB sites surveyed in 2018 not be included in the CRE due to their recent disturbance histories, and that two additional one-hectare surveys be performed in the Georgetown Area. The selection of the two new Georgetown sites was done with consultation between ERA, SSB, NLC and Traditional Owners. The two survey plots were established in *E. tetrodonta / E. miniata* dominated savanna that had a greater representation of overstorey species present, including *E. tectifica.* The CRE as of early 2022 consists of ten one-hectare sites (Figure 5-83);

- S1, S2, S3, S6, S7 and S8 – surveyed in March and April 2018;
- S9 and S10 – surveyed in March 2019; and
- S11 and S12 (expanded from previously surveyed 20x20m Georgetown quadrats) – surveyed in March 2021.

The sites are highly variable in regards to species richness, stem densities (total and species-specific), and cover % (Figure 5-84 and Figure 5-85). This supports the degree of local variation in the sites and communities near the Ranger operations that have been apparent in previous studies.

There are however concerns that the dominance of certain species is potentially driven by undesirable and inappropriate fire regimes, in particular annual *Sorghum* and *Acacia mimula.* This prompted discussions on the functional role collective groups of species' play, rather than individual species, particularly with understorey which can be very ephemeral and variable within the same woodland on a year-to-year basis. It was decided that a 'functional understorey approach' be considered for the CREs. A dedicated workshop was held to develop this approach on the 24th of June 2021, which involved relevant ERA, SSB, NLC personnel, as well as experts from Charles Darwin University and Kakadu Native Plants Pty Ltd (draft report Bellairs, 2021). This functional group approach has also been adopted for the understorey composition closure criterion (*Section 8*).

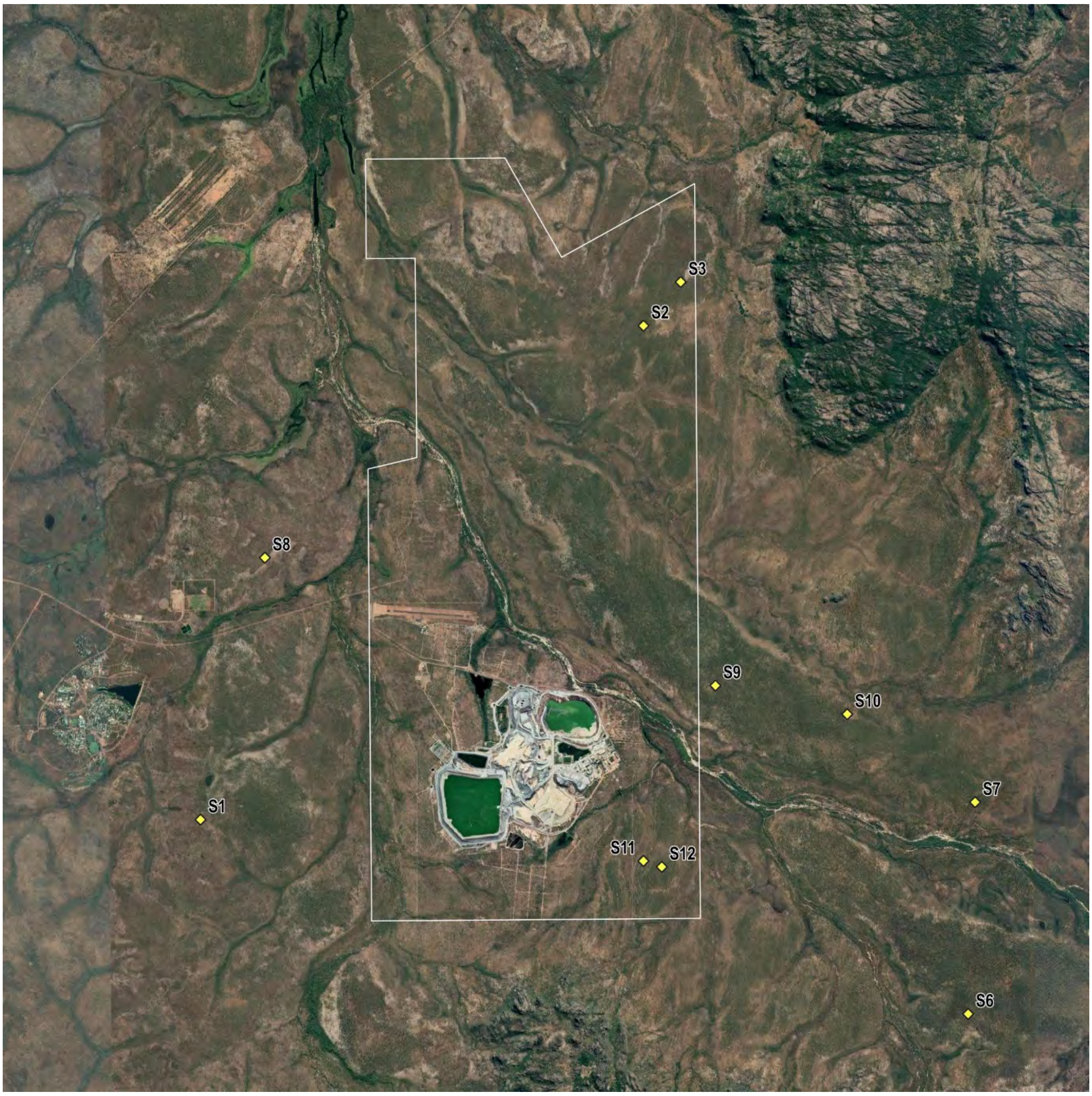


Figure 5-83: Location of conceptual reference ecosystem sites in relation to the Ranger Project Area

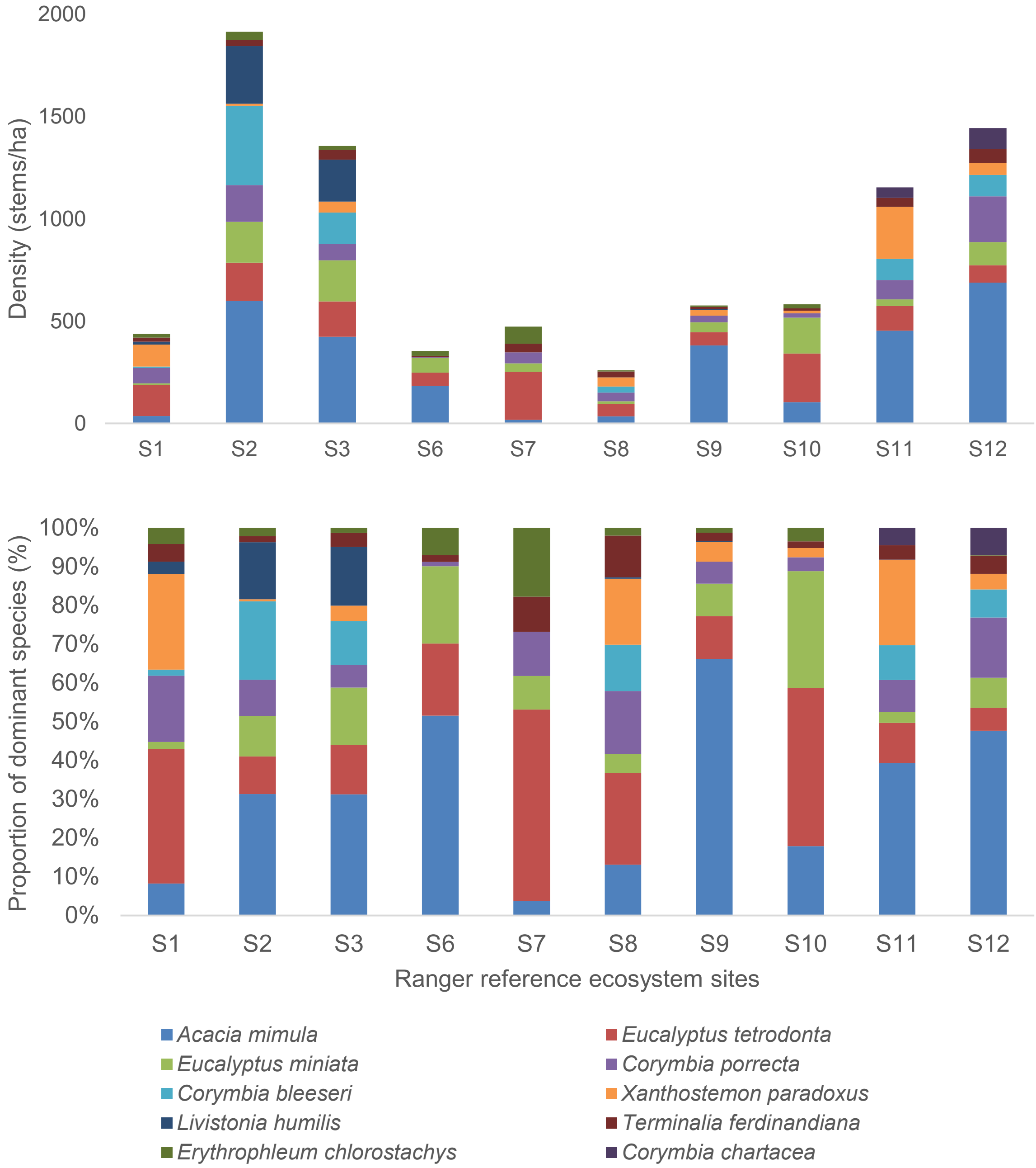


Figure 5-84: Stem density and species composition of the dominant ten shrub and tree species present in the CRE sites

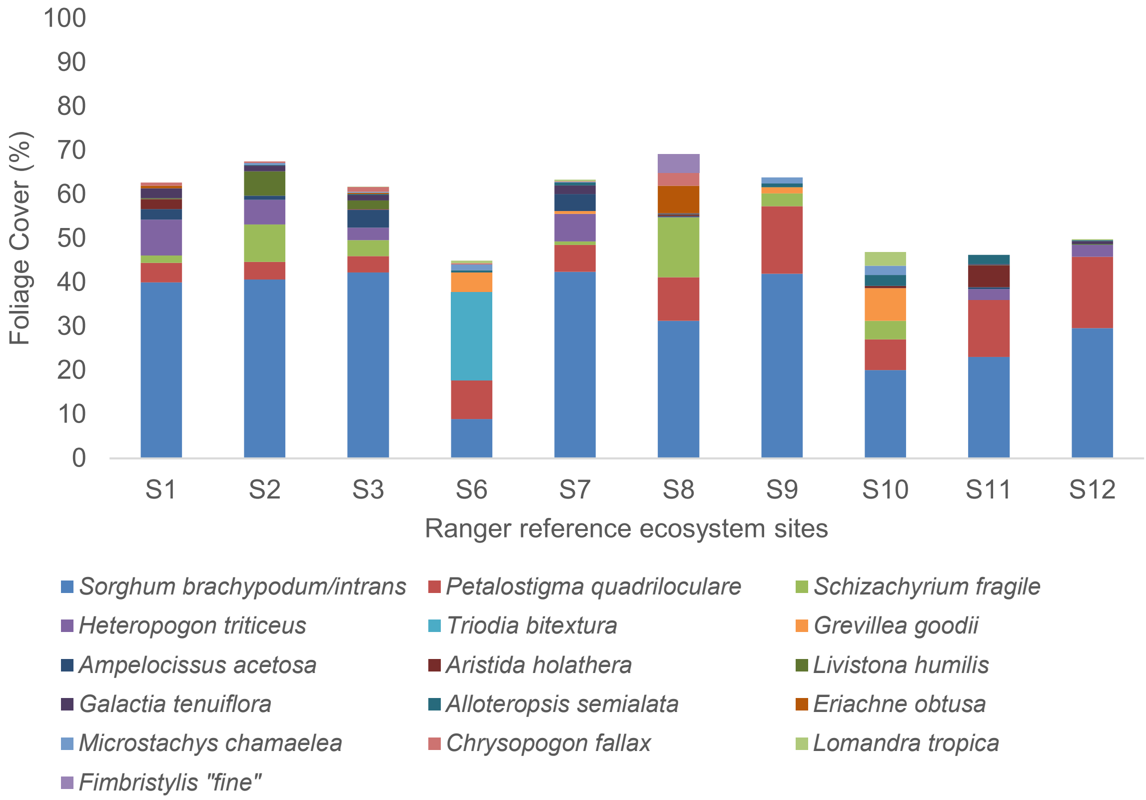


Figure 5-85: Dominant understorey species (> 0.4% average) vegetation cover in the CRE sites

5.4.1.7 Future work on the conceptual reference ecosystem(s)

The CRE project has significantly progressed in 2021 and 2022 and is nearing finalisation. Topics identified for continued work/discussion include:

- Continued consultation with the Cultural Reconnection Working Group on FLF features. For example, potentially increasing densities of desired species along long-term tracks and roads, or creating localised habitat/cultural features (rocky sites, drainage-lines, groves etc.).
- Further stakeholder discussion on particular species' dominances, whether they are appropriate for the CRE (eg. Acacia mimula dominance being potentially driven by undesirable fire regimes), and how some species' may be considered at a genus level, or other grouping, instead.
- Further stakeholder discussion to clarify different scale options for the CRE and for monitoring the ecosystem closure criteria (Section 8 and Section 10). For example, it is acknowledged that canopy cover should be considered at a landscape-scale rather than a per hectare scale.
- Continued development of an ecosystem rehabilitation plan for seasonally inundated / drainage areas on the RPA, driven by stakeholder consultation.

5.4.2 ESR7 Understanding the effect of waste rock properties on ecosystem establishment and sustainability

KKN title	Question
ESR7. Understanding the effect of waste rock properties of ecosystem establishment and sustainability	ESR7A *What is the potential for plant available nutrients (e.g. nitrogen and phosphorus) to be a limiting factor for sustainable nutrient cycling in waste rock?*
	ESR7B *Will sufficient plant available water be available in the final landform to support a mature vegetation community?*
	ESR7C *Will ecological processes required for vegetation sustainability (e.g. soil formation) occur on the rehabilitated landform and if not, what are the mitigation responses?*

5.4.2.1 Final landform material properties

Weathering and soil development

Developing waste rock 'soil' to a level able to sustain native vegetation is a result of complex interactions between the waste rock, plant roots, leaf litter, a range of microbial organisms and other environmental and climatic factors. Production of rock fines through weathering forms an important component of this process, as does generation and infiltration (illuviation) of organic matter (Tony Milnes, pers. comm. 2019).

Weathering of the waste rock over time increases both the proportion of fines in the soil profile as well as water holding capacity. General observations indicate the Run-of-Mine (ROM) waste rock on the TLF have been breaking down since its initial placement as a consequence of physical, chemical and biological weathering processes, vegetation establishment and litter accumulation, and decomposition by microbial activity in the substrate. The increased proportion of fines will provide a suitable substrate to support understorey development. Natural establishment of understorey species in the waste-rock-only section of the TLF began considerably increasing approximately10 years after revegetation, supporting the theory.

Johnston and Milnes (2007) reviewed various Commonwealth Scientific and Industrial Research Organisation (CSIRO) investigations of waste rock 'soil' formation to inform the Ranger revegetation strategy. Some of these early studies identified rapid weathering of exposed Pit 1 waste rock on the surface of the stockpiles; however it has since been recognised that this is more isolated and associated with certain rock types. Fitzpatrick *et al* (1989) recognised colour mottling from increased hydromorphy, variations in soil texture due to water erosion of fines material, structure development, decreasing pH from pyrite oxidation and sulfate weathering occurred within two years of waste rock stockpile construction.

- A number of distinct 'minesoil' types were recognised on the waste rock stockpiles. (Fitzpatrick 1986). Fitzpatrick noted that K and S released during weathering of waste rock were 'sufficient' for plant growth in minesoils, and 'sufficient' P was available to support deep-rooted vegetation. However, the very high ratios of Mg to Ca in the minesoil solution could affect the nutrition of some plants.

Table 5-39 and Table 5-40 show the edaphic properties measured for the rehabilitated waste rock landform and the analogue natural landform (Hollingsworth 2010).

Table 5-39: Rehabilitated waste rock landform properties

Depth	Rock content	Soil texture	Dry bulk density	Infiltration rate	Saturated hydraulic conductivity	Plant available water content	Soil penetration resistance
	%		$kg.m^{-3}$	$mm.hr^{-1}$	$mm.hr^{-1}$	$mm.m^{-1}$	MPa
Soil							
0 – 0.5 m	>60	Sand	1.4 – 2.3	1 - 10	1,000	10	>3
0.5 < 1.5 m	50 < 60	Sandy loam	>1.6		1 - 10	50	
>1.5 m					>1,000	10	
Landform	**Recharge rate**	**Runoff coeff.**	**Relief**	**Catchment area**	**Slope**		
	10 – 25% of rainfall	>50%	<5 m	11 ha	0 – 3%		

Table 5-40: Analogue landscape properties

Soil depth	Gravel content %	Soil texture	Dry bulk density $kg.m^{-3}$	Infiltration rate $mm.hr^{-1}$	Saturated hydraulic conductivity $mm.hr^{-1}$	Plant available water content $mm.m^{-1}$	Soil penetration resistance MPa
0 – 0.5 m	>60	Sand to sandy loam	1.1 – 1.7	300 – 4,800	1,000	10	>3
0.5 < 1.5 m	50 < 60	Sandy loam – sandy clay loam	>1.6		60 – 4,500	50	
1.5 – 2.0 m	>60	Sandy loam	>1.8		0.4	50 – 100	
2.0 – 3.0 m					0.08	50 – 100	
Landform	**Recharge rate**	**Runoff coeff.**	**Relief**	**Catchment area**	**Slope**	**Leaf area index**	
	5 – 10% of rainfall	>20%	<30 m	1,500 – 5,000 m^2	1 – 5%	0.8 – 1.6	

Waste rock particle size distribution

A key parameter to assess water holding capacity of the growth media (waste rock), is the percentage (%) of the fines smaller or equal to 2 mm (≤2 mm) in size. Typically, only this portion of the material is considered able to store water for plant use.

Waste rock particle size is also an important parameter in landform evolution modelling. Studies and data on PSD related to landform are provided under KKN LAN3.

As discussed under KKN LAN3, during the TLF construction in 2009 PSD sampling was conducted. One pit in each of the 1A and 1B TLF subsections were constructed from waste rock material only. Samples were taken in triplicate from the surface and at depths of one, two, three and four metres (m) from these pits. The samples were sieved to determine weight of the fraction of material greater than 2 mm (>2 mm) and less than 2 mm (<2 mm). Sub-samples of the fine earth fraction (i.e. <2 mm) were provided to the University of Melbourne for particle size analysis using the Bekham Coulter LP13320 laser sizer. Particle sizes were grouped into sand, silt and clay fractions according to United States Department of Agriculture (USDA) size classes. It should be noted that this early sampling work did not follow the Australian Standard for PSD measurement.

PSD results from the TLF section 1A profile are presented in Table 5-41. Note the sand, silt and clay fractions make up 100 % of the fine earth fraction (i.e. particles <2 mm), termed '*fines*'. The rock content (i.e. particles >2 mm) range from 61 to 73 % averaging 67 % consistent with SSB observed 70 % rock content (Mike Saynor, *pers. comm.*).

A breakdown of the fines content is shown in Table 5-41, with similar values published by Saynor & Houghton (2011) and provided under KKN LAN3; describing the determination of the particle size statistics of the surface material from different areas of the TLF.

Table 5-41: Particle size distribution data from TLF 1A section at construction in 2009

Depth (cm)	Total volume of material (rock and fines)		Classification and breakdown of fines portion (particles <2 mm)		
	Rock %v/v	Fines %v/v	Sand %	Silt %	Clay %
0	66.2	33.8	83.8 ± 1.4	14.9 ± 1.3	1.3 ± 0.2
100	68.0	32.0	82.8 ± 2.5	15.8 ± 2.4	1.3 ± 0.2
200	63.8	36.2	82.9 ± 1.2	15.7 ± 1.1	1.4 ± 0.1
300	73.0	27.0	83.6 ± 0.3	15.0 ± 0.2	1.4 ± 0.1
400	61.6	38.4	82.9 ± 2.1	15.7 ± 1.9	1.3 ± 0.2

Hollingsworth (2010) measured PSD, water content and water potential from 24 core samples from the northern Ranger Mine experimental waste rock cover comprised of the Pit 3 materials. The substrate contained 36% of fines (<2 mm) and 64% of gravels/rocks (>2mm).

A CSIRO study (Emerson and Hignett, 1986) on revegetated waste rock dumps at Ranger, identified rock fractions (> 2 mm) of samples taken from the trenches in three rock piles of Pit 1 materials were 'surprisingly' uniform with means of 61 %, 54 % and 57 %, respectively (Emerson & Hignett, 1986). These rock contents are lower than but comparable to the TLF finding of 67 %. These findings also suggest that Pit 3 stockpile materials in the TLF, combined with the Hollingsworth (2010) findings and the Pit 1 (Emerson & Hignett 1986) and Pit 3 waste rock materials are similar in terms of their fines content.

In 2013 the University of Queensland and Charles Darwin University (CDU) conducted a small-scale excavation of section 1A of the TLF at Ranger mine. Particle size analysis was conducted to assess particle size distribution. A slight increase in fines was observed and compared to measured proportions taken during initial construction of the TLF in 2009 (Figure 5-86, Figure 5-87).

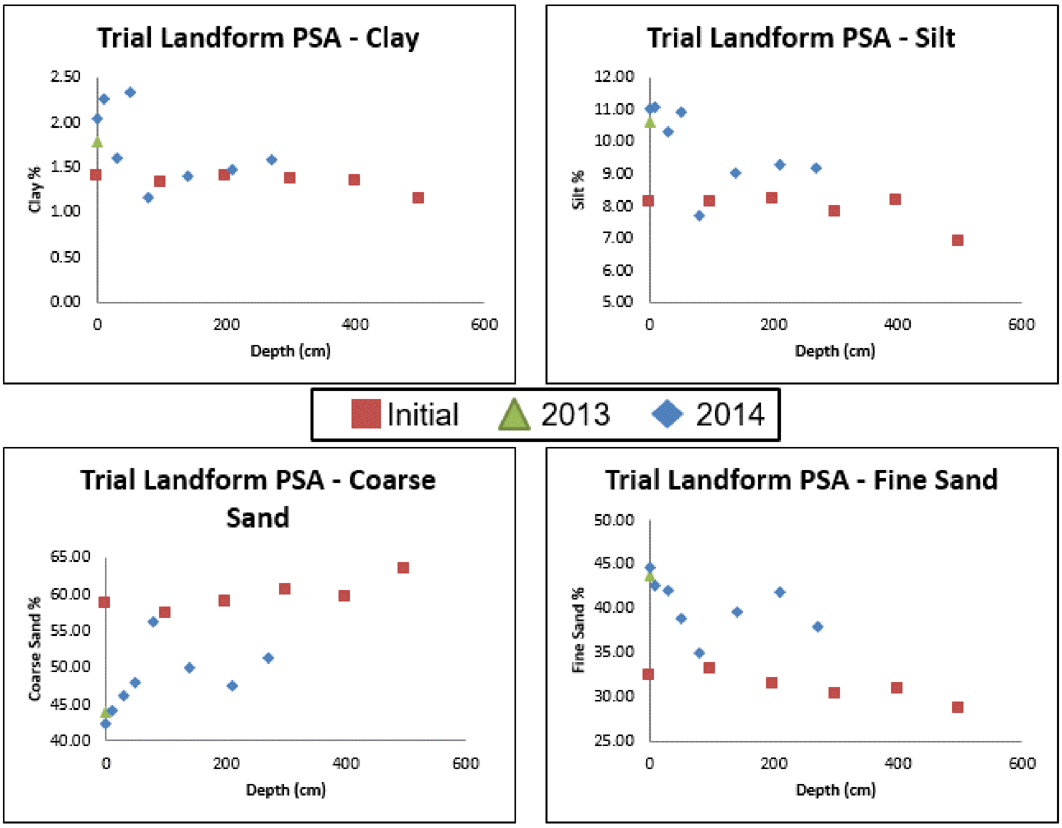


Figure 5-86: Changes in PSD on TLF from 2009 to 2014 inclusive

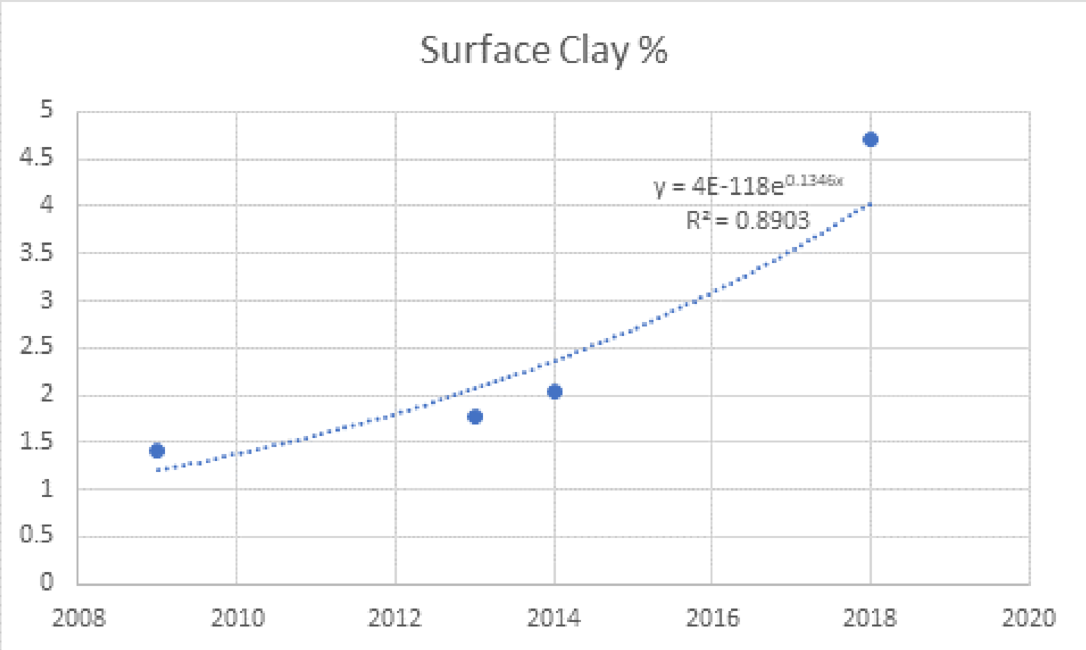


Figure 5-87: Changes in PSD on TLF1A (including 2018 surface soil samples) at 5 cm depth

During the construction of the Pit 1 final landform layer (top 6m, described in Section 9) ERA engaged Douglas Partners Geotechnical & Environmental Consultants to develop an appropriate PSD sampling method based on the Australian Standard and conduct monitoring across the pit as it was being constructed. A total of 82 samples were collected across the two final landform construction layers; the upper layer (U; 1.5 m) and lower layer (L; 1.5 m to 6 m). An average and a median PSD curve for both the upper layer material and lower layer material were calculated using all the sample results (Figure 5-88). There is an approximate ten percent difference between the average and median value of the fine fraction for the lower layer, indicating material characteristics of the lower layer potentially present a more heterogeneous form in the fine size fractions compared to that in the upper layer materials.

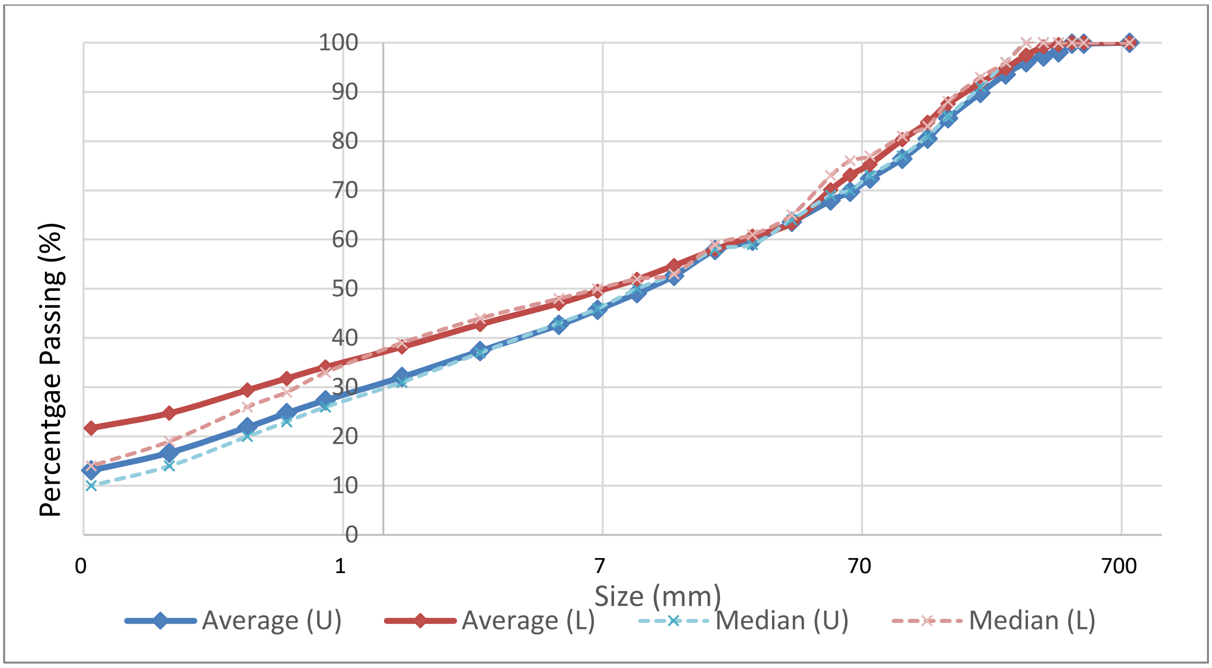


Figure 5-88: PSD result average and median for upper and lower layer

5.4.2.2 Plant available water studies

Ranger Mine is located in the seasonally wet-dry tropics of northern Australia, where approximately 95 % of rainfall occurs between November and April. The most important factors shaping the landscape which determines savanna ecosystem type are soil water availability and vegetation survival during the dry season. This also presents the most critical challenge for Ranger Mine site revegetation post-mining, with soils often lacking structure or containing large amounts of rock fragments that reduces water holding capacity.

To address the critical question of whether the waste rock substrate of the Ranger Mine final landform can supply sufficient plant available water (PAW) to sustain a range of sustainable vegetation communities similar to those in Kakadu National Park, ERA has undertaken extensive research over the past three decades, particularly the two decades (Hollingsworth 2010, Lu 2017, Lu *et al*. 2019). These studies are summarised in this section and include long-term ecohydrological studies in the Georgetown Creek Reference Ecosystem area since 2008 and extensive soil water dynamics and vegetation performance studies on the Ranger Mine TLF since 2009.

PAW Modelling

From 2011, ERA engaged CDU to undertake a modelling approach to understand the TLF water balance. The hydrologic characteristics of the waste rock substrate combined with results from the ecohydrological studies informed the CSIRO Water, Vegetation, Energy and Solute (WAVES) model (Zhang & Dawes 1998). The model focussed on estimating required PAW in the waste rock surface layer to meet the predicted demand to sustain the rehabilitated ecosystem (ERA 2019).

PAW is the amount of available water that can be stored in soil within the rooting zone available for growing plants. The Ranger waste rock growth media often lacks structure or may contain large amounts of rock fragments and macropores which reduces water holding capacity compared to natural soils.

In 2021, ERA engaged Okane Consultants Pty Ltd (Okane), a world leader in water balance studies of waste rock cover, to undertake further modelling, using updated input data, to re-evaluate PAW for the Pit 1 final landform. Okane completed modelling in two phases using Geostudio Flow Model Software and the WAVES Model to evaluate PAW for several modelling scenarios. Phase 1 work was completed to validate the WAVES model using the Geostudio Flow 2021 software suite. Phase 2 modelling involved the application of WAVES and Geostudio modelling to evaluate three Scenarios.

- Scenario 1 – Assessment using material properties and vegetation inputs within the previous WAVES modelling (TLF) coupled with new climate data acquired since the previous modelling.
- Scenario 2 – Assessment using Pit 1 final landform material testing results completed in 2019/2020 and the same climate sequence and vegetation inputs as Scenario 1.
- Scenario 3 - Assessment using Pit 1 final landform material testing results completed in 2019/2020 and the same vegetation inputs as modelling Scenario 1 and 2 using a 'dry' rainfall climate.

A summary of the work completed to date is provided below. Once completed final reports will be issues to stakeholders for review and updates will continue to be provided in this MCP.

Phase 1 Modelling

Phase 1 involved a validation exercise for the WAVES model using 1D Geostudio Flow 2021 software suite (GeoSlope, 2021). Previous model inputs (material properties, vegetation and climate) developed in the WAVES calibration modelling program were used in the Geostudio soil-plant-atmosphere (SPA) and WAVES. The results of the 1D models provided validation that the WAVES software used for previous assessments performs similarly to the globally recognised and accepted Geostudio software. Geostudio SPA modelling resulted in similar predictions of water balance parameters to that of the WAVES model.

Phase 2 Modelling

Scenario 1 - Trial Landform Modelling

Scenario 1 modelling was completed to compare estimated PAW results to those discussed in the previuos modelling (ERA 2019). Okane completed 1D SPA modelling using Geostudio Flow Models and WAVES Models. Results obtained by the Geostudio Models were similar to those of the WAVES Model thus validated the use of this method to evaluate PAW.

Similar to previous modelling, PAW was evaluated for various waste rock thicknesses and varying material fines content. Okane used their proprietary Inverse SPA Model to estimate material properties for the waste rock materials using field measured volumetric water content data. Material properties representative of 10-20%, 20-30%, and 30-40% range of fines content were developed based on material characterisation data from the waste rock and soil-moisture measurements from the TLF.

Results of the Scenario 1 modelling indicated a similar trend to those discussed in ERA (2019). Increased coarse content of the material requires a thicker waste rock layer to maintain a lower net negative PAW balance. To maintain a net negative PAW balance of less than 5% under high (Georgetown reference Site 21) evapotranspirative demands a minimum waste rock thickness of 5 m is required with a fines content greater than 33%. However, if the waste rock thickness is increased to 6 m, a fines content of 25% or greater would be sufficient. This result is similar to those in ERA (2019).

Scenario 2 – Final Landform Modelling and Sensitivity Analysis

Scenario 2 modelling was completed for the final landform based on Pit 1 material investigations completed between 2019 and 2020 (Miller, 2020a, 2020b; Okane, 2021). A range of material properties were evaluated for the low (less than 20%) and high (greater than 40%) fines materials. As expected, material with lower fines stored less water when compared to the higher fines material. However, the lower fines material was still capable of maintaining a net negative PAW balance of no more than 5% under high (Site 21) evapotranspirative demands and a waste rock depth of only 5 m. The influence of waste rock thickness on PAW was the same as Scenario 1 in that PAW increases with increasing waste rock thickness. The higher fines material was able to maintain a 0% net negative PAW balance regardless of waste rock thickness (>= 5 m) or evapotranspirative demands.

Scenario 3 – Final Landform Modelling with 'Dry Climate'

Modelling completed for Scenario 3 replicated that of Scenario 2 with the exception of the rainfall model input. The 100-year climate database used to evaluate Scenario 3 was provided by SSB and is considered to be representative of a 'dry climate'.

Net negative PAW balance was evaluated for a 5 m thick waste rock layer for both the lower and higher fines material. The higher fines materials resulted in a 0 % net negative PAW balance for both evapotranspiration demand regimes. However, the lower fines material resulted in a 5 % and 7 % net negative PAW balance for Site 30 (lower evapotranspirative demand) and Site 21 (higher evapotranspirative demand), respectively.

Ecohydrology of natural tropical savanna ecosystems

As discussed previously, a particularly strong influence on vegetation survival in the wet-dry topics is water availability. Plant adaptations have evolved to survive in their particular environment including physiological responses to cope with a broad natural range of scenarios. In the seasonally wet-dry tropics, survival strategies range from extremes of inundation or 'drought' to more-nuanced variations such as length of dry season, or timing of the wet season onset. In the dry season, plant survival is dependent on water balance especially towards the end of the dry season when the soil water stress is highest. Strategies to survive these periods of low water availability include stomatal closure, loss of leaves, and development of a progressively deeper root system.

A key strategy to avoid catastrophic cavitation of the water-conducting xylem system is to balance canopy water loss with root absorption. As soil moisture reduces, trees minimise their water loss initially by stomatal closure, followed by sacrificing non-vital, peripheral organs (i.e. leaves, twigs, branches and above ground stems). These adaptations slow down water loss and soil water depletion increasing chance of survival in times of drought (Tyree and Sperry 1988). Most plants, including evergreen trees notably *Eucalyptus miniata* and *Eucalyptus tetrodonta*, shed their leaves to reduce transpiration (water loss from tree canopy). This maintains a balance between root water uptake and canopy water loss (Thomas and Eamus, 1999). These adaptations assist plant survival when soil PAW is very low.

Another key strategy to reduce water stress as the dry season progresses is to develop roots that can access PAW as it retreats down the soil profile. Root soil water extraction is energy driven; water is pulled by a tension gradient created between the leaf surface to the root tips. Roots first extract the soil water from nearer the soil surface where water is mostly readily available (water potential is high or less negative) thereafter accessing water progressively deeper in the ground as the upper soil profile dries out. Plants will not generally establish roots to a depth below a layer that has already provided sufficient soil-water. That is, if soil-water is available in the top four or five metres of the soil profile, plants will typically not require roots deeper than this. If water is more readily available below this depth, i.e. the plant can spend less energy accessing water at depth than from the upper dryer soil layer, the plant will extend its root system into the deeper layer providing the level of hydraulic tension within the plant xylem vessels does not reach a catastrophic level that will kill the plant (runaway of xylem embolism, Tyree and Sperry 1988). In this way plants have evolved to maintain the balance of water demand and supply to avoid this catastrophic result (Tyree and Sperry 1988).

The trees of the savanna woodlands typical of Kakadu NP and the revegetation target at Ranger, typically have the majority of their root system in the upper one metre of the substrate to access water during the wet season when growth rates are at a maximum (Janos *et al*. 2008; Hutley 2008). This is partly due to the ferricrete layer (duricrust) that occurs approximately 1 to 1.5 m below the soil surface throughout the region (Figure 5-89). This layer limits root development further down but enables penetration by deeper-tapping roots through macropores (Werner and Murphy 2001; Hutley 2008; Hutley *et al*. 2000). Many important top end savanna species can root to depths up to five or six metres (Hutley *et al*. 2000; Kelley *et al*. 2002; Kelley *et al*. 2007)

Hutley (2008) summarised the key features of savanna vegetation water use and carbon allocation strategies for vegetation adaptations to Top-End monsoonal seasons (Figure 5-90). During the wet season, trees maximise their growth and water uptake from the nutrient rich shallow soils. During the dry season the shallow soil water is quickly depleted, and trees cease growing, instead accessing water from deeper in the soil to maintain photosynthesis and, under more severe conditions, maintain the viability of vital organs. For plants, water uptake (use) from deeper in the soil is very low and the nutrients are very limited, where sub-soil water storage is critical to survival.

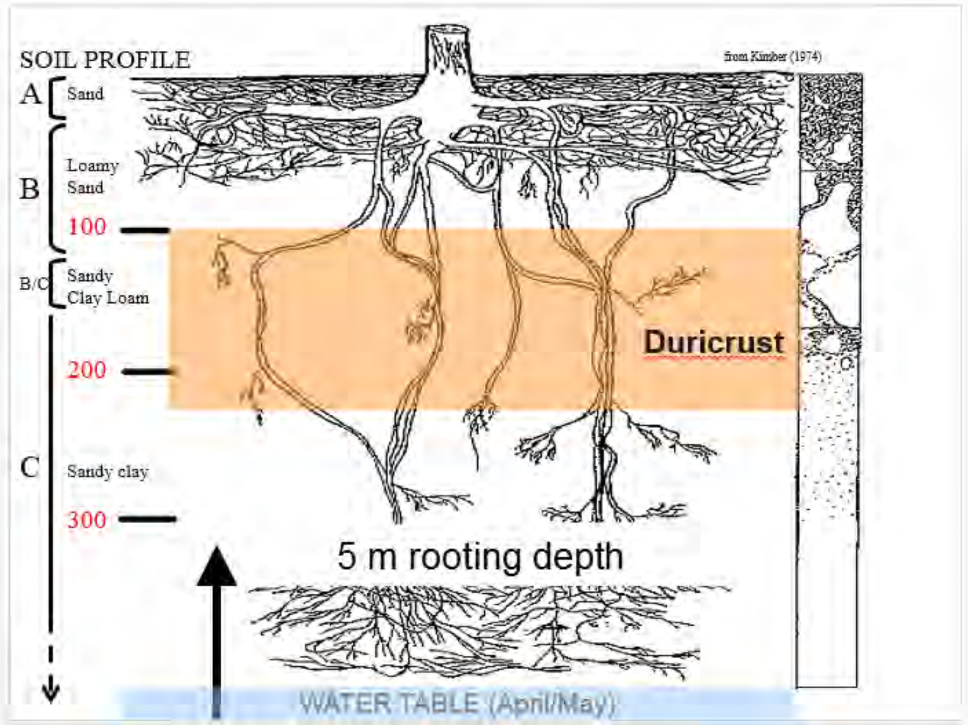


Figure 5-89: Rooting pattern of the savanna woodland trees in the Top-End (Source: Hutley 2008)

Features of savanna water use carbon allocation

- Dual root systems – maximise carbon and water uptake in seasonal climate
- Wet season, 0-1 m depth
    - Surface fine roots – water and nutrient uptake
    - Stem increment possible
- Dry season, 2-5 m depth
    - No surface soil moisture, limited nutrient availability, no stem growth possible
    - Account for dry season ET using soil water balance
    - **Trees using up to 5 m of soil for dry season water requirements**
    - Sub-soil water storage critical
    - Photosynthesis maintained
    - Carbon partitioned into maintenance of deep roots, storage in lignotuber and reproduction
- Partitioning of soil water usage
    - grasses: 0 - 0.5 m (wet)
    - trees: 0 - 5 m (wet and dry)
  - competition with grasses limited or avoided

Figure 5-90: Key features of savanna vegetation water-use and carbon allocation strategies adapted to the Top-End seasonality (Source: Hutley 2008)

Plant growth rate and water demand decline as the wet season ends and the dry season progresses. The fine root mass diminishes with the receding soil-water reserve, where the cost to the plant of maintaining these fine roots during the dry season with little or no return is too great. (Janos *et al*. 2008). Any residual water demand must be met by the ability of plants to use deeper roots to access the remaining soil-water reserve.

Soil moisture extraction patterns at the Ranger's Georgetown Creek Reference Area (Site 21) demonstrates soil water is extracted from between 5.5 to 5.8 m below the surface in the late dry season. (See *Groundwater table and soil water dynamics* section under this KKN)

Canopy cover dynamics

Long-term canopy cover measured by Leaf Area Index (LAI) of woodlands monitored at four ecohydrological study sites have shown significant seasonal variability (refer to Figure 5-91). The LAI is highest during the wet season and lowest during the dry season. The seasonal reduction is approximately 50%, but is higher in some dry years (Lu *et al* 2019).

Site 21 has the densest canopy (highest LAI) and the highest seasonal variation of all sites. The LAI reduced by about 70% over the extended dry period leading into the late 2015-16 wet season. Whole-tree sap flow measurement demonstrated that Site 21 has the highest annual transpiration. Site 21 has a species composition dominated by the overstorey species *E. tetrodonta* and *E. miniata* and basal area of 8 m^2 ha^{-1} similar to tropical savannas across northern Australia (Hutley *et al*. 2000).

Plants will shed more leaves earlier during the driest part of a dry season if water is beyond reach of the roots, observed at reference sites 21 and 30. Site 30 is a drier site regarding substrate-type, where plants shed more leaves earlier and more rapidly than species at Site 21 reflected in the seasonal dynamics of the LAI (Figure 5-92). In the worst-case scenario, if PAW is less than the target, trees that survive the dry season regrow during the wet season.

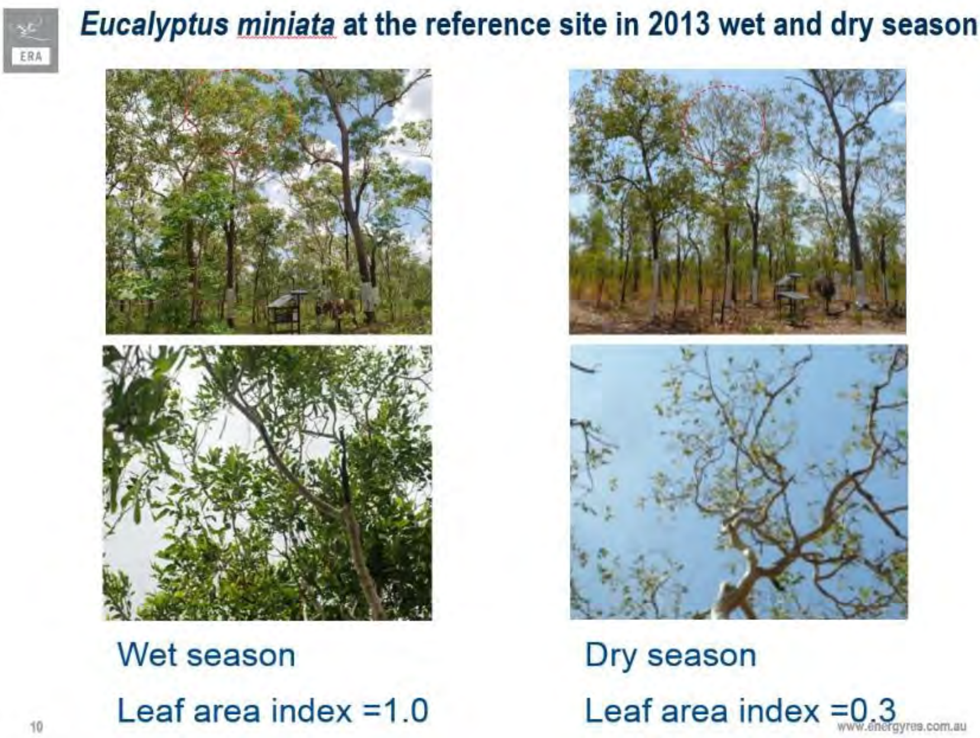


Figure 5-91: Seasonal change in leaf area index at the Georgetown Creek Reference Area (Source: Lu *et al*. 2018)

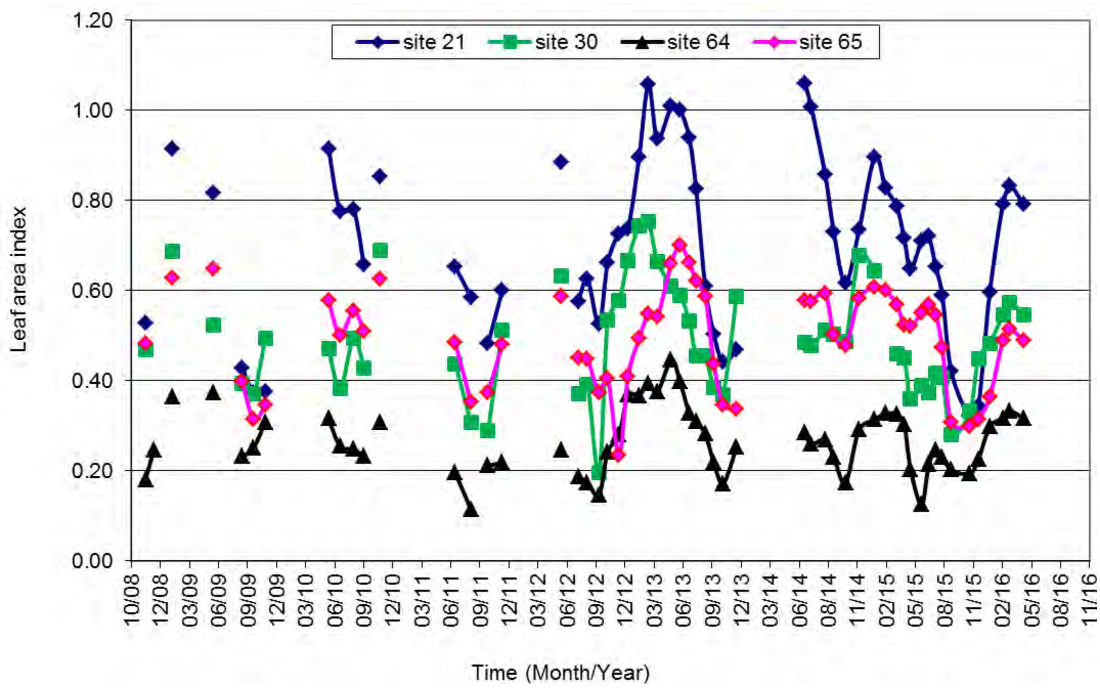


Figure 5-92: LAI dynamics at the four ecohydrological study sites (missing data during the wet season due to site inaccessibility)

Total water requirements of the vegetation during dry season

Total water requirement for vegetation is typically measured by evapotranspiration (ET), the sum of overstorey transpiration, understorey transpiration, and soil evaporation (Figure 5-93). Other closely related processes shown in Figure 5-93 are runoff and groundwater recharge.

In the Top End of Northern Australia, during the dry season, woodland vegetation water use is dominated by the overstorey and midstorey vegetation. The understorey dries rapidly at the beginning of each dry season where its contribution to ET is negligible compared to tree and shrub water use (Hutley 2008, Hutley *et al*. 2000).

Stand transpiration measured from the woodland near Ranger site was estimated based on tree stem xylem sap flow measurements at Site 21 (Figure 5-94, Figure 5-95). Lu *et al* (2019) details measurements of sap flow and stand transpiration. Tree water use peaks towards the end of wet season and/or the beginning of the dry season (April to June) when the soil water availability is high, days are sunny, the air is dry, evaporative demand and LAI are high (Figure 5-92). Transpiration decreases during the dry season as the soil dries out and LAI decreases (Figure 5-92). It reaches its minimum at the end of the dry season right before a significant rainfall event. In the early wet-season transpiration increases as the soil water availability and canopy LAI increase, but has not reached it maximum rate due to rainfall.

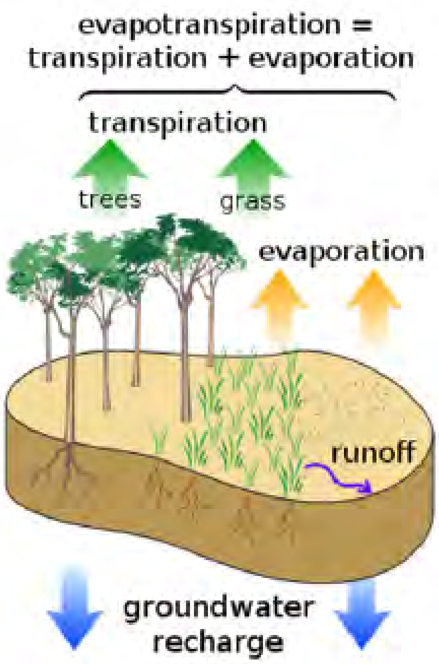


Figure 5-93: Evapotranspiration and its components

Figure 5-94: General view of an instrumented study site

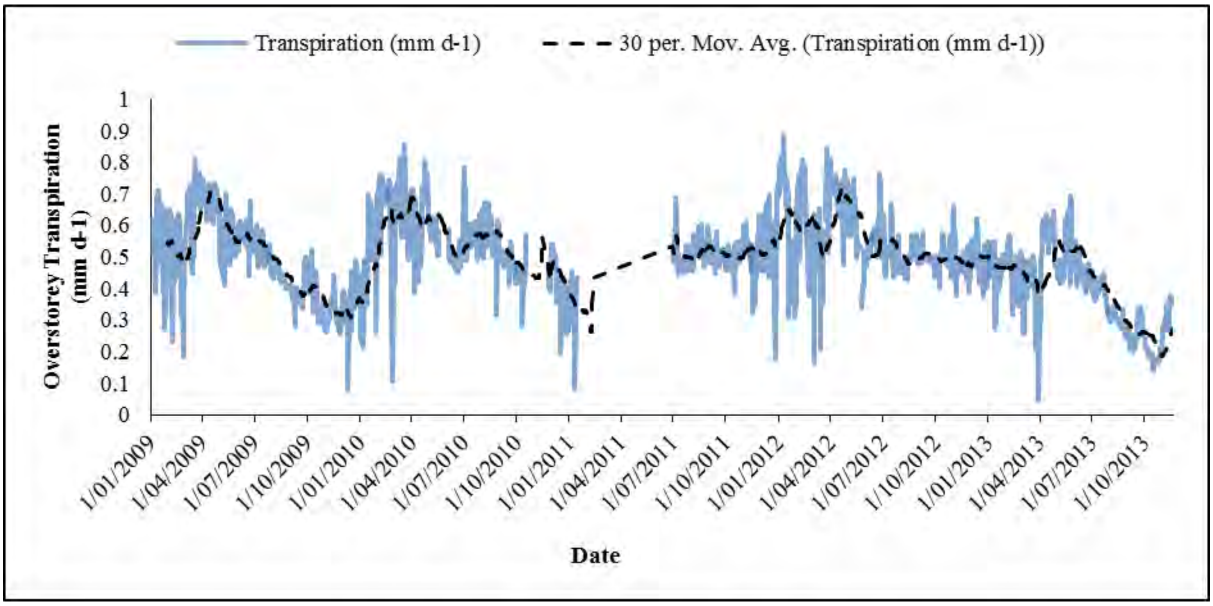


Figure 5-95: Annual dynamics of over storey tree transpiration at Site 21

Canopy cover (LAI) is directly and highly correlated with vegetation water use (Baumgartl *et al*. 2018). Site 21, which has the highest LAI and therefore the highest vegetation water use, is the reference site for modelling. Comparison of dry season natural vegetation water requirement with PAW supply in the final waste rock landform at this site presents a conservative target for the vegetation water requirement (Baumgartl *et al*. 2018) with an upper envelop of the average dry season transpiration of 0.5 mm○day^{-1} adopted for the WAVES modelling.

Groundwater table and soil water dynamics

At Site 21, the groundwater table level is dynamic (Figure 5-96). The shallow groundwater system is very transient during the wet season, where water levels reached within 0.5 m of the soil surface and peaks, then subsiding rapidly after heavy rainfall ceases. During the dry season the groundwater table drops 10 m below the soil surface. These characteristics are typical of a groundwater system with a low hill topography comprised of porous shallow ground material.

Note that the bore hole depth is slightly deeper than 10 m and the cable length of the hydrostatic pressure transducer was set to 10 m. When the water level drops below 10 m the transducer (logged) gives a maximal 10 m depth afterwhich a manual dipper can provide a reading until the bottom of the borehole is dry. Groundwater and soil moisture measurement details can be found in Lu *et al* 2019.

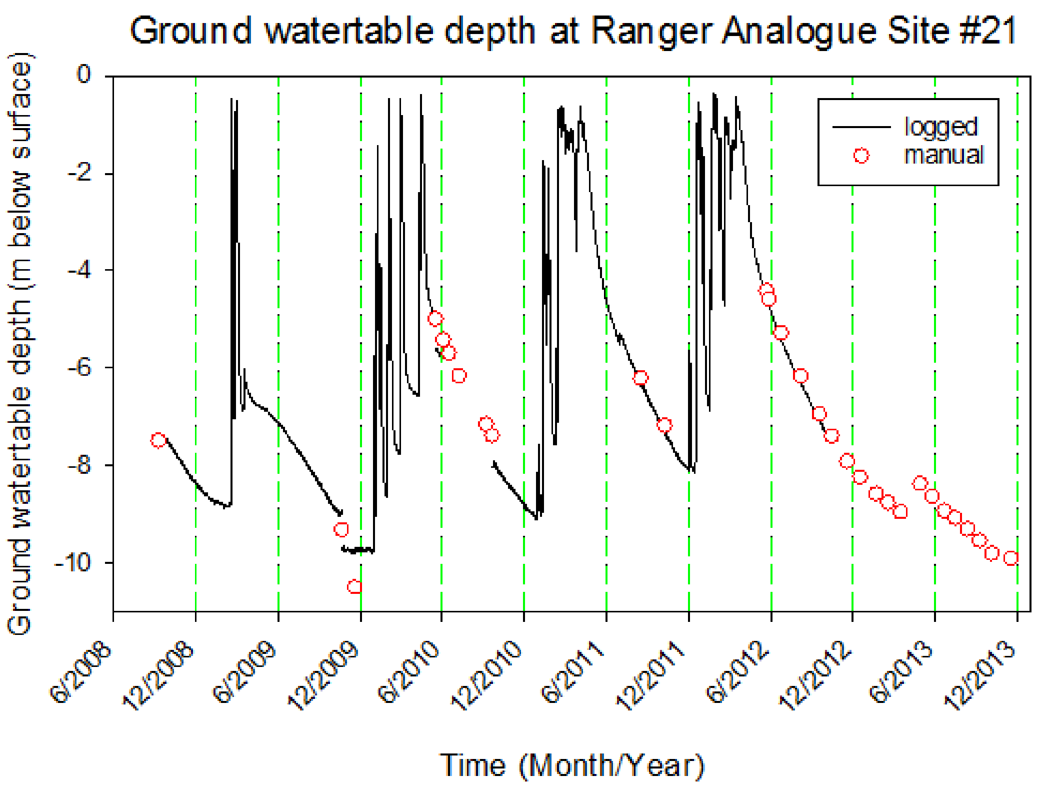


Figure 5-96: Temporal dynamics of the groundwater depth at Site 21

A comparison between soil water dynamics defined as relative extractable water content (REW) from varying depths below ground surface and the groundwater table level (GWT) at Site 21 is shown in Figure 5-97. The data shows maximum REW for the whole soil profile occurred late in the wet season. As the dry season progressed, soils quickly dried out within one month near the surface and in depths up to 1 m. Following drying of the shallow soil, water was progressively extracted from deeper levels, up to 5.8 m. By November 2012, extractable water in the entire 5.8-metre thick profile was almost depleted. Measuring sap flow suggests trees maintain a substantial level of transpiration (Figure 5-95) during this period demonstrating that tree root systems exploit soil water from deeper soil.

The depth to the ground water table decreased progressively with, but faster than the decreasing REW. The depth difference between the REW and the ground water table depth broadly corresponds to the capillary fringe height.

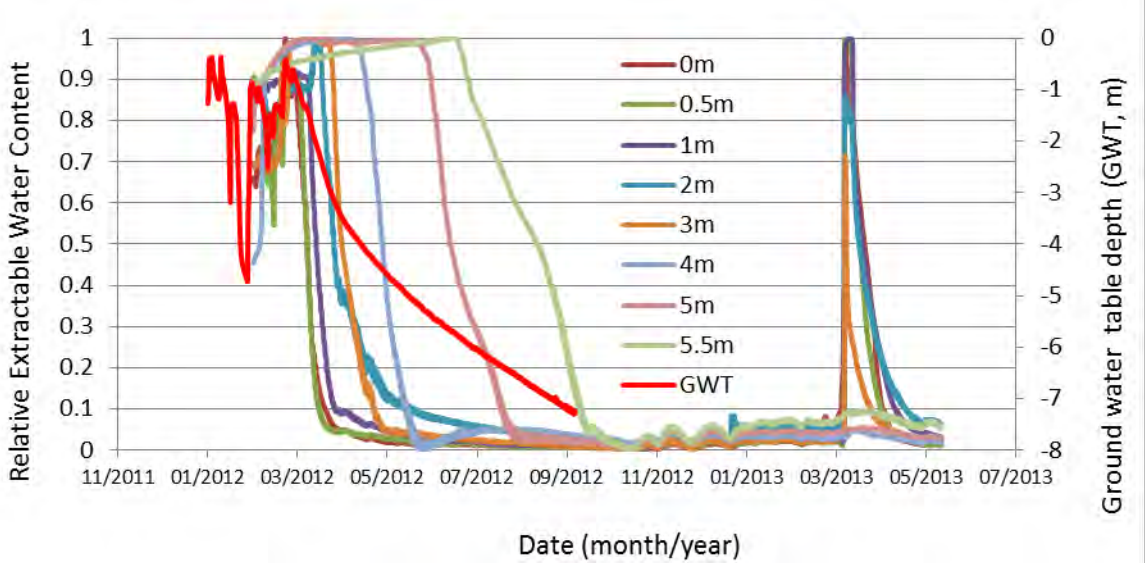


Figure 5-97: Relative extractable water contents measured at different depths and ground water table depth (GWT, in Red) at Site 21

Plant water uptake patterns can often be inferred from soil water depletion pattern (Knight 1999). From Figure 5-97 it is evident that as the dry season progresses, extractable water was progressively depleted from the surface to deeper depths reaching depths of 5.5 to 5.8 m. This suggests that the natural savanna trees at the Ranger Georgetown Creek reference site are able to extract water at depth close to 6 metres below ground level consistent with the findings by Sharma *et al*. (1987) where a significant amount of soil water extraction in Eucalypt forests in Western Australia occurs to a depth of at least 6 m.

Soil evaporation and under storey transpiration are highly dependent on the shallow soil water content. Based on the soil moisture results shown in Figure 5-97 it is reasonable to expect that the evapotranspiration from the soil and understorey would decrease to near zero within a couple of months after the dry season starts. Therefore, the major component of evapotranspiration during the dry season is over and midstorey transpiration. This is consistent with other evapotranspiration studies in the Top End of the NT (Hutley 2008).

Despite the dry season understorey ET and soil evaporation being negligible and not directly measured at the Ranger reference site, they were simulated using the locally calibrated WAVES model discussed earlier in this section to obtain the total dry season vegetation ET (Dawes *et al*. 1998, Zhang & Dawes 1998, Segura 2016)

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5.4.2.3 Chemical characteristics and nutritional processes

Chemicals in substrates play a vital role in revegetation success, including as a limiting nutrient, a toxicant above a threshold effects level, a modifier or facilitator of other chemical processes/interactions or a combination (Bayliss 2018).

It is important to have site specific and species-specific information on the nutrient requirements and toxicity risks for target species for rehabilitation of the Ranger Mine final landform. Some findings and observations may obscure specific effects resulting in sub-optimal vegetation establishment and development.

Waste rock material at Ranger Mine differs from natural soils by having higher pH, EC, CEC, Magnesium (Mg), total Phosphorous (P) and Sulfate (SO_4) concentrations, and lower levels of nitrogen (N) and extremely low organic carbon (C) at the beginning of landform establishment where the materials are run-of-mine without topsoil (Ashwath *et al*. 1993, Gellert 2014,Table 5-42**)**.

It is noted that compared to waste rock from other mines in the ARR, or natural soils, the Ranger Mine waste rock has higher total, exchangeable and water soluble Mg, and higher total P (Ashwath *et al*. 1993). Ashwath *et al*. (1993) also found that C:N ratio is significantly higher in Ranger waste rock (58:1) than in natural soils (19:1). The presence of high ratio of C:N in mine waste rock may restrict the net release of N to plants and soils.

Chemical toxicity

Bayliss (2018) assessed the potential chemical effects on seedling plant growth and survival relating to toxicity thresholds reported in the literature for species or genera that will be used in revegetation at the Ranger Mine, and their potential roles as either limiting nutrients, toxicants or chemical facilitators, concluding:

"In summary, the potential chemical risks from poor pH range (for ectomycorrhizal fungi at least) and low values of N, Ca and Mg can be discounted in the assessment given that TS can be enhanced at planting with fertilisers (e.g. broadcast or directed application) and water crystals whose effects may last up to 14 months (Daws & Gellert 2011; Gellert 2012). Additionally, Fe was discounted as a potential toxicant given the higher concentrations found on the Miniata and Heritage analogue sites, albeit closer to the minesite compared to Georgetown. Hence, in our assessment, risks to revegetation from mine-derived chemicals is assumed zero and, needless to say, a more thorough screening process needs to be undertaken of potential effects on seedling growth and survival to test that critical assumption. This may require experimental in situ research and pot trials to fill knowledge gaps."

ERA presented to ARRTC (May 2018) results of vegetation growing in the waste rock on the TLF and other areas around the mine site exposed to pond water (waste rock runoff and leachate). The observations and studies of the LAAs, irrigated with pond water for over a decade, indicate there are no observed negative effects on vegetation from waste rock contaminants.

Investigations into the effect of magnesium sulfate salinity on the germination of seeds of twenty plant species native to the Kakadu NP (Malden *et al*. 1994) found that the presence of magnesium sulfate salinity severely decreased the final germination percentages and decreased the rate of germination of most species. Whilst use of tubestock planting can decrease these specific germination impacts, these effects may impact subsequent growth or impact the subsequent establishment of mid storey and under storey species from seed. Thus, as discussed at ARRTC (May 2018), studies on plant establishment and growth rates for specific species may inform future management practices that could mitigate nutrient and toxicity effects. These studies are currently being undertaken by SSB in collaboration with the National Environmental Science Program (NESP) and CDU and will be summaried in this MCP once completed.

Table 5-42: Chemical analysis of waste rock samples taken in January 2010 compared to natural soils (source Gellert 2014)

	Section 1A TLF	Analogue sites
paste pH	8.0 (±0)	6.3 (±0.1)
paste EC (uS/cm)	260 (±49.2)	14.4 (±2.2)
Organic C (%)	0 (±0)	0.54 (±0.08)
P (ppm)	410 (±6.6)	0.2 (±0.1)
Total P (mg/kg)	460 (±25)	64.8 (±12.6)
Total S (%)	0.03 (±0.02)	0.02 (±0.01)
NO2-N (mg/kg)	Below detectable limit (BDL)	0.28 (±0.05)
NO3-N (mg/kg)	0.64 (±0.48)	0.24 (±0.08)
paste NH3-N (mg/kg)	0.07 (±0.01)	1.27 (±0.30)
Total N (mg/kg)	45.1 (±14.0)	422 (±20.5)
Ca (mg/kg)	85.8 (±23.8)	0.8 (±0.1)
K (mg/kg)	20.3 (±1.9)	4.9 (±0.0)
Mg (mg/kg)	61.7 (±18.3)	BDL
Na (mg/kg)	17.0 (±3.8)	1.2 (±0.1)
CEC	5.3 (±0.5)	3.2 (±0.2)
Al (me/100g)	0.4 (±0.1)	1.8 (±0.1)

Nutrient cycling

The diversity and sustainable growth of revegetated plants is closely related to nutrient cycling in soil-plant systems, driven by functional microbial communities in litter, surface soil and the rhizosphere. Microbial driven processes are critical to *in situ* litter decomposition and N/P mineralization in soil and plant uptake.

Rehabilitated sites rapidly redevelop nutrient pools in the soil, litter and understorey vegetation, but the pool contained within trees takes longer to develop. Litter accumulates rapidly in rehabilitated sites, sourced mainly from eucalypt and legume species. At bauxite mines in WA, rehabilitated areas have accumulated the same amount of litter within three to five years as unmined forest sites after the same period of time following burning (Ward 2000). Surface roughness provided by scarification or ripping aid these processes by ensuring that resources such as water, leaf litter and nutrients are captured and used *in situ* or recycled. The furrows also concentrate the litter, allowing decomposition processes to commence earlier.

Research by Grant *et al.* (2007) found that a critical aspect of re-establishing a self-sustaining jarrah (*Eucalyptus marginata*) forest ecosystem to mined areas is to ensure that vital ecosystem functions such as litter decomposition and nutrient cycling are returned. Significant research has been undertaken over the past twenty years relating to litter decomposition and nutrient cycling. Studies have shown that litter accumulates rapidly in restored areas (1–4 t/ha/a) and the accumulated litter tends to be richer in nitrogen due to intentionally elevated densities of nitrogen-fixing species. This leads to a lower carbon:nitrogen ratio (60:1 compared to 130:1 in unmined forests) that may promote mineralization of organic nitrogen to inorganic forms in restored areas. The major nutrient store in the unmined forest is in the soil and returning soil during the rehabilitation process largely conserves this resource, particularly in relation to phosphorus. Short-term plant macronutrient requirements for growth are readily restored by fertilizer application. Studies on the re-accumulation of nutrient pools in the successional development of restored areas have shown that pools equivalent to the unmined forest are established within ten to twenty years. Ongoing research is focusing on the rates of cycling processes in burnt and unburnt restored areas and comparing these to the unmined forest to ensure that key functions have been re-established.

ERA commissioned a study (Huang & You 2018, Huang *et al*. 2020) of nutrient cycling in revegetation of the TLF compared to Georgetown Creek reference sites. The 2018 study compared TLF-1A and Georgetown Site 21 while the 2019 assessed TLF-1A and Georgetown Site 30, where soil is more gravelly and shallower. The key findings of the 2018 study are summarised in Table 5-43.

Huang and You (2018) suggest low mineralisation rates in the 9 year-old revegetated TLF soils may be attributed to combined abiotic stress selection, solar radiation associated heat stress, rapid evaporation and water deficit in the surface “soil” – fine fractions of weathered rock and organic matter debris at the surface due to low ground cover vegetation and/or litter. Water deficit may be a key factor limiting microbial growth and soil functions.

The study assessed key microbial and nutrient cycling attributes of litters and surface soils from 10 year-old revegetated waste rock (TLF-1A and 1B) compared to the natural vegetation reference Site 30 (Huang *et al*. 2020). The investigation characterised litter properties including elemental and organic compound composition and a range of key soil molecular microbial, chemical and biogeochemical indicators to assess the potential capacity of organic carbon decomposition and nutrient cycling processes in surface soil of the TLF (1A and 1B).

The litter collected from the sites contained 40-50% organic carbon and low concentrations of N and P. The organic compounds within the litter were dominant by carbohydrate, followed by protein (especially the C=O amide I) and lipids. The differences of litter chemistry were not statistically significant between the reference and TLF sites (Table 5-44).

Compared to the rehabilitated waste rock sites, surface soil at the reference site was more fertile though (Figure 5-98) slightly acidic and associated with relatively high levels of organic matter (4.5% organic C) and N (>20mg/kg), especially in the form of ammonium-N. This might be attributed to long-term organic matter decomposition and humic compound accumulation, as a high density of understorey annual/perennial plant species was present. Surface soil at the reference site had the highest diversity of bacteria and fungi, particularly with abundant actinobacteria associated with N enrichment and fungi genera associated with woody and later stage organic matter decomposition. Metagenome prediction and *in situ* enzymatic activities showed that bacterial communities from the reference sites also had the highest capacity to drive organic matter metabolism as an indicator of nutrient cycling.

The TLF surface soil is slightly alkaline and less fertile than the reference site; comprised of freshly formed/weathered rock fines and decomposed organic matter. The organic matter levels of TLF soil samples were approx. one third of the reference site, with much lower levels of total nitrogen (<5mg/kg). Microbial communities in the surface soils were highly diverse and dominated by organoheterotrophs across all sampling sites. Bacterial and fungal communities from reference site soils showed the highest diversity. The microbial communities in the reference site appeared structurally different to other sites. Some Actinobacteria associated with N enrichment as well as fungi associated with later decomposition stage were abundant in the reference site soil. The soils from TLF-1A and TLF-1B sites were enriched with microbes well adapted to habitats of low moisture and infertile soils.

The surface soil from the reference site also showed the highest capacity of microbial driven organic matter decomposition and N metabolism among the sites sampled. The metagenome prediction and induced metabolic activities suggested that microbial communities from the reference site had the highest capacity to metabolise simple carbohydrate. The activities of selected enzymes involved in cellulose, hemicellulose and protein decomposition were not significantly different among the sampling sites.

The TLF soil microbial communities expressed a lower potential capacity of organic matter decomposition, especially for simple carbohydrates (e.g. sugar). Enzymes involved in cellulose, hemicellulose and protein decomposition were at similar level as the reference site. As sugar metabolisms are usually associated with opportunistic bacteria requiring moist habitats, enhancing the water availability and the accumulation of organic matter with favourable C:N ratios (eg. understorey plant biomass) is critical to enhance the microbial functions and coupled nutrient cycling.

The 2018 and 2019 findings collectively point to the importance of establishing productive understorey species including N2-fixing leguminous species to increase labile organic matter (biomass residues and root debris) and N inputs. This is critical to restore nutrient pools and maintain biological functions in surface soil. Importantly, the increased understorey vegetation provides shading effects helping alleviate radiation heat and drought stress in the surface soil of the TLF sites in future, favourable for soil microbial activities and nutrient cycling.

Table 5-43: key findings of 2018 nutrient cycling study (TLF-1A and Site 21)

Area	Finding
Nutrient status in litter and surface soil	After 9 years of revegetation, litter accumulated in the trial landforms showed relatively higher levels of nutrients concentrations than those collected from the analogue. Soil in the trial landforms showed lower level of nutrients concentrations than those in the analogue.
Characteristics of bacterial and fungal decomposers	Microbial communities in both litter and surface soil of the three sites were dominated by heterotrophic bacteria. Bacterial and fungal communities in trial landforms appeared to be more diverse than those in the analogue soil, however seemed to be under selection pressure which constrained their functions. Some N-fixing and plant growth-promoting bacteria were 3 times more abundant in the analogue soil than in TLF. TLF soils had abundant bacteria colonizing nutrient limiting environment, and Rozellomycota associated with early stage of soil development. Also, there was a smaller portion of stress response stain assigned to class of Bacillus enriched in soils from TLF-1A than the analogue site.
Nutrient cycling processes in surface soil	As is expected for a 'new soil', the microbial functions related to C and N cycling in the surface soil of trial landforms were constrained, compared to the soil from the analogue site. The TLF surface soil exhibited significantly lower levels of net mineralisation rates and higher levels of metabolic quotient (representing lower carbon utilization efficacy) than those of analogue site in the wet season when microbial biomass was supposed to be significantly boosted with increased moisture and availability of C and N.

In summary, 10 years after the revegetation, the TLF growth media has significantly improved their nutrient level compared to the initial stage of the revegetation. The microbial communities in the surface soils were highly diverse, similar to the reference site. The TLF soil microbial communities expressed a lower potential capacity of organic matter decomposition, especially for simple carbohydrate (eg. sugar), due mainly to relatively dry surface material, and relatively low accumulation of organic matter with favourable C: N ratios (eg. understorey plant biomass).

To improve the TLF nutrient status and cycling, it was recommended to:

- minimize surface drought and heat;
- enrich high quality organic matter through understorey growth; and
- improve N-supplying capacity by introducing diverse deep-rooting understorey legumes.

Table 5-44: Elemental composition in the litter among sites

Element	Reference site	TLF-1A	TLF-1B
OC (%)	42.3	47.8	42.9
N (%)	0.71	0.68	0.78
P (g/kg)	0.30	0.27	0.31
K (g/kg)	0.72	0.76	0.97
Ca (g/kg)	14.19	13.36	13.80
Mg (g/kg)	1.86	2.95	5.69
Fe(g/kg)	8.70	0.68	3.28
Al (g/kg)	2.51	0.85	4.02
S (g/kg)	0.63	0.74	0.69
Mn (g/kg)	0.38	0.12	0.15
Cu (mg/kg)	7.8	4.4	10.2
Zn (mg/kg)	18.5	16.4	20.6

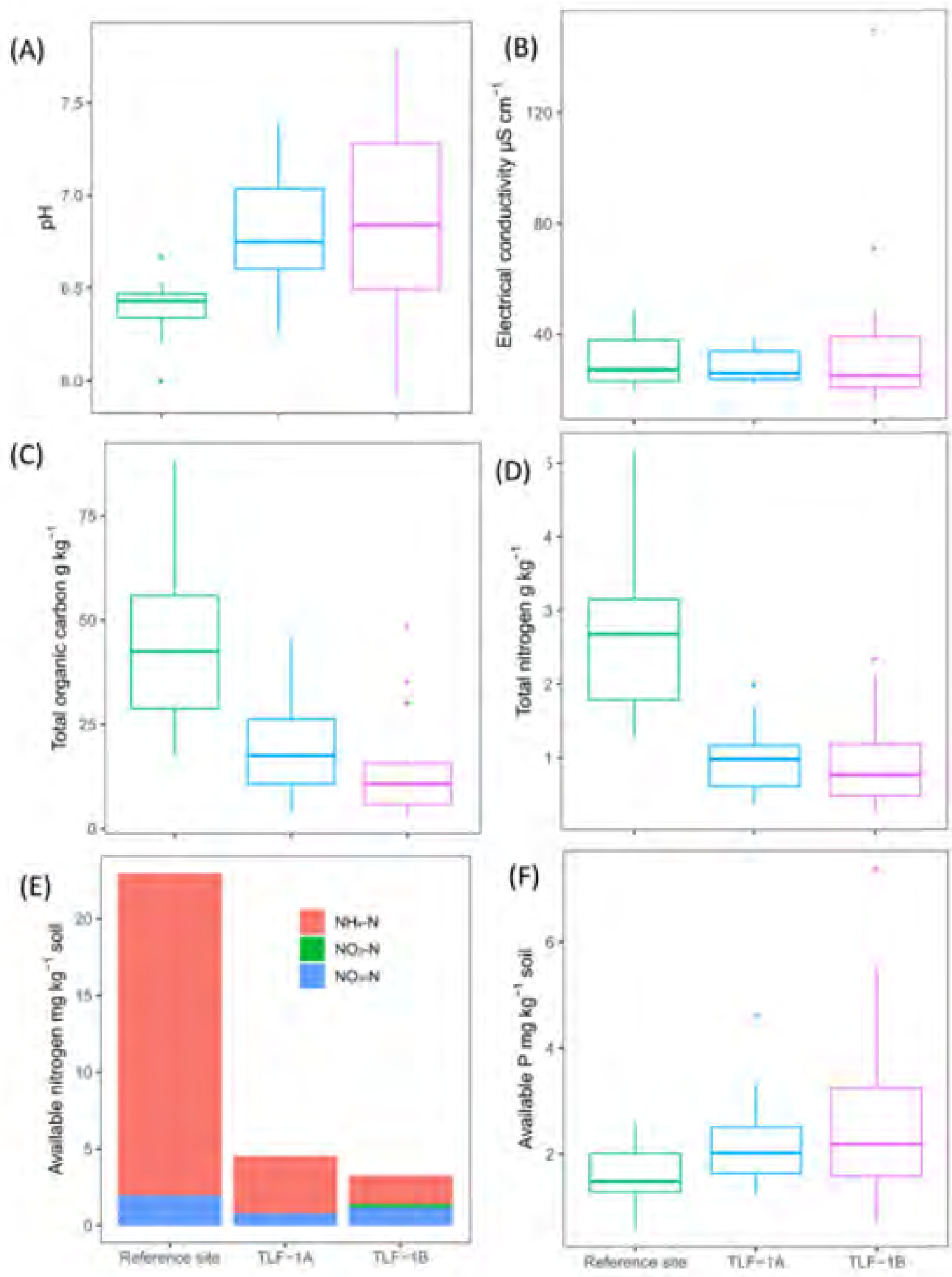


Figure 5-98: Selected soil chemical properties pH (A), EC (B), and nutrient availability, including total organic carbon (C), total nitrogen (D), Available N in the form of NH4+-N, NO2--N and NO3--N (E) and Available P (F) among reference Site 30, TLF-1A and TLF-1B.

5.4.3 ESR3 Understanding how to establish native terrestrial vegetation, including understory species

KKN title	Question
ESR3. Understanding how to establish native terrestrial vegetation, including understory species	ESR3A *How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?*

5.4.3.1 Mine rehabilitation and revegetation methods

The establishment methods for revegetating most species on previously mined land generally include a combination of topsoil return, direct seeding, tubestock planting and/or volunteer colonisation. Which revegetation method/s are used often depend on the type of mine (eg. strip versus hard-rock), location and climate, the characteristics of the planting substrate available, the amount of seed available and/or allowed to be collected, and final land use objectives.

Vegetation is reintroduced to most strip-mines in the wet-dry tropics by both transport of propagules in fresh topsoil and by direct seeding, using a range of methods (from hand broadcasting to tractor mounted seeders to aerial sowing). Occasionally ‘enrichment’ planting of nursery-grown stock is used to increase the density of important species. The success of direct seeding at these strip-mines can be variable, but in general, with good topsoil handling techniques (minimising weed presence in the transported seed bank) and the use of appropriate seed mixes, good early establishment results have been obtained.

In contrast, on some hard-rock mines, direct seeding has been more problematic and unreliable compared to tubestock planting for establishing important, dominant species (Gordon *et al* 1995; Reddell and Hopkins 1994; Reddell & Spain 1995; Reddell & Zimmermann 2002). Hard-rock mines, such as Ranger, often do not have access to topsoil and are required to revegetate on mined substrate that can be barren and coarse, with near zero organic matter or fungi/microbial presence (*Section ESR7*). These characteristics combined with extreme and variable climatic conditions on the substrate surface, including high reflectance, ambient temperatures and fluctuating moisture levels, create a challenging environment for successful seed survival, germination and seedling persistence. Another limitation with direct seeding is the amount of seed required to establish vegetation at appropriate densities. Considering establishment from seed in the field is often very low (<10 % reported in Merritt & Dixon 2011), a significantly greater quantity of seed is needed for direct seeding as compared to tubestock planting. This can present another obstacle for mining operations where seed must be sourced from relatively small local provenances.

Tubestock planting can also accelerate the speed of ecosystem development. Revegetated plants need to quickly capture space and other resources, reach a certain size to be fire resilient, and have sufficient roots established at a depth to support better survival through harsh conditions. If plants are slow to establish and capture the site, resilience to weed invasion and fire can be significantly delayed, incurring greater maintenance requirements and costs.

Another passive establishment method that is common in mining revegetation is the 'volunteer colonisation' of species from surrounding environments, usually through dispersal by insects, animals and wind. These species often include grasses and fruiting species.

5.4.3.2 Historical Ranger ecosystem rehabilitation research

Over more than thirty years, numerous small-scale rehabilitation trials have been undertaken at Ranger Mine by ERA, SSB, CSIRO and other parties in relation to final landform morphology, revegetation and ecosystem establishment. All this research has culminated in an extensive body of applied techniques, designed to give confidence that the Ecosystem Establishment Strategy proposed for the closure of the RPA will result in a self-sustaining, long-term ecosystem.

A myriad of revegetation trials were undertaken at Ranger Mine between 1982 and 2002 (refer Table 5-45 and Figure 5-99). Almost all of these trials were discontinued at various stages, due to research programs finishing or the need by operations for additional waste rock storage areas as mining progressed. However, these trials enabled important lessons to be learned early and in turn influence subsequent trials. This historical knowledge and experience was used to inform the first Ranger Revegetation Strategy (Reddell & Meek 2004, Appendix 5.4). In 2001, Reddell and Zimmermann (2002) completed a comprehensive assessment of 11 earlier waste rock revegetation trials and identified a number of examples of success and failure, and addressed key issues that were highly relevant to ERA's revegetation strategy.

Table 5-45: Small-scale revegetation trials conducted on the RPA (1982 – 2002)

Project	Location	Date
First revegetation – germination trials	Waste rock piles	1982
Irrigation using RP2 water to 35 hectares of mature savanna woodland, along with fire exclusion	Ranger Mine lease	1984-1995
Fire trial	Waste rock piles	1986
1:5 slope erosion trial	Waste rock piles	1986-1987
Constructed wetlands experiments and aquatic plant transplantation	North-west seepage collector	1987-1988
Slope erosion trial	Waste rock piles	1988-1991
Wetland filter trials using RP4 water directed through 3 hectares of Djalkmarra Creek catchment	Djalkmarra Creek catchment	1988-1991
Topsoil spread. Hydroseeded (grass and fertiliser ± eucalypt seed). *Pandanus basedowii* planted	Waste rock piles	1988-1995
Topsoil trials ± fungi	Waste rock dump	1989
Revegetation trials and rainfall simulation	Waste rock piles	1990-1993
Direct seeding via tractor spread of 3 ha with pasture grasses	Northern waste rock dump	1991-1992
Hydromulching, tree and grass seed spreading, and aquatic plant transplantation (*Eleocharis, Nymphaea*	RP1 wetland filter	1991-1992

Project	Location	Date
and *Azolla*)		
Tubestocks ± inoculation. Various seed mixes, grass, aggressive and non-aggressive acacias. Planting on angle of repose batter west of plots	Ecological islands	1992
Topsoil trial	Waste rock piles	1992
Topsoil spread	RP5	1992
Application of hydromulch and grass seed to batter slopes facing Pit 1	Pit 1	1992
Tubestock planting, seedling and fungi trials	Northern waste rock dump	1992
Native seed and tubestock planting at tailings seepage sumps	North-western, north-eastern and southern seepage collectors	1992-1993
Tubestock and native tree seedling planting	VLGS (stockpile, north-west of the TSF)	1992-1994
Tubestock planting and fungi and varied density of nitrogen-fixing acacias. Inoculation of different seed mixes	RP4 irrigation	1992-1994
Seeded (grass and fertiliser with broadcaster)	Northern waste rock dump	1993
Log shelter/baits, termite baiting, pitfall trapping and casual soil fauna collecting	Northern waste rock dump	1993-1994
Native tubestock	VLG (west of Pit 1)	1993-1995
Native tubestock planted (grown by ERA and Djabulukgu Association)	Southern waste rock dump	1993-1997
Rhizobia trial	Waste rock piles	1994-1995
Effect of seed imbibition mulch, fertiliser *Scleroderma* and eucalypt applications rates	Southern waste rock dump	1994-1995
Angle of repose and 1:3 batter slopes. Randomised block hydromulched seed and *Pisolithus ectomycorrhizal* fungi	RP5	1994-1995
Establishment and growth on waste rock and magnesite to determine rate of self-thinning in high density eucalypt and non-aggressive acacias and slow release fertiliser	RP5	1994-1995
Effect of mulch type on germination and early growth	Waste rock piles	1994-1995
Native tubestock planting	Waste rock piles	1994-1996
RP1 wetland filter expansion and aquatic plant transplanting (*Nymphaea* and *Eleocharis*)	RP1 wetland filter	1995
Effect of mycorrhizal associations on survival and growth of *Eucalyptus miniata* seedlings.	RP5	1995
Direct seedling fertiliser and tubestock planting	Sleepy Cod Farm Dam walls	1995-1996

Project	Location	Date
Transplanting native tree root section trials	Southern waste rock dump	1996
Irrigation with RP4 water, introduced grasses (*Chloris gayana*), tubestock and seed mix trials	Waste rock dump	1996
Large-scale planting (seed and tubestock) composition, density, irrigation, mulch, fungi, fertiliser	Waste rock and Retention Pond	1996-1997
Hydromulch and native grass trials ± fertiliser	Northern waste rock dump	1996-1997
Elevated wetland trials, tubestock, seed and herb transplanting	Southern waste rock dump	1997
Measure indicators of rehabilitation success on the RPA. Fauna surveys and landscape function analysis	Ranger Mine lease	1997
Direct seeding	Old light industrial area road	1997-1998
Hydromulch with native grass seed and fertiliser applied to 3 kilometres of table drain	Main access road	1997-1998
Direct seeding, tubestock and fertiliser application	Northern waste rock dump	1997-1998
Hydromulch with native grass seed and fertiliser application	TSF waste rock dump	1997-1998
Direct seedling, tubestock and fertiliser application	Southern waste rock dump	1997-1998
Direct seeding and tubestock planting following deep ripping	Borrow pit north-west of Pit 3	1998
Seed (*Grevillea* spp.) under erosion control matting	RP5	n.d.
Removal and remediation/rehabilitation of road infrastructure. Tubestock and direct seeding trials of native woodland species on freshly cultivated waste rock	Various roads, tracks and former low-grade ore stockpiles	1998 - 1999
Grass direct seeding trials with and without fertiliser	Borrow pits	1999 - 2002

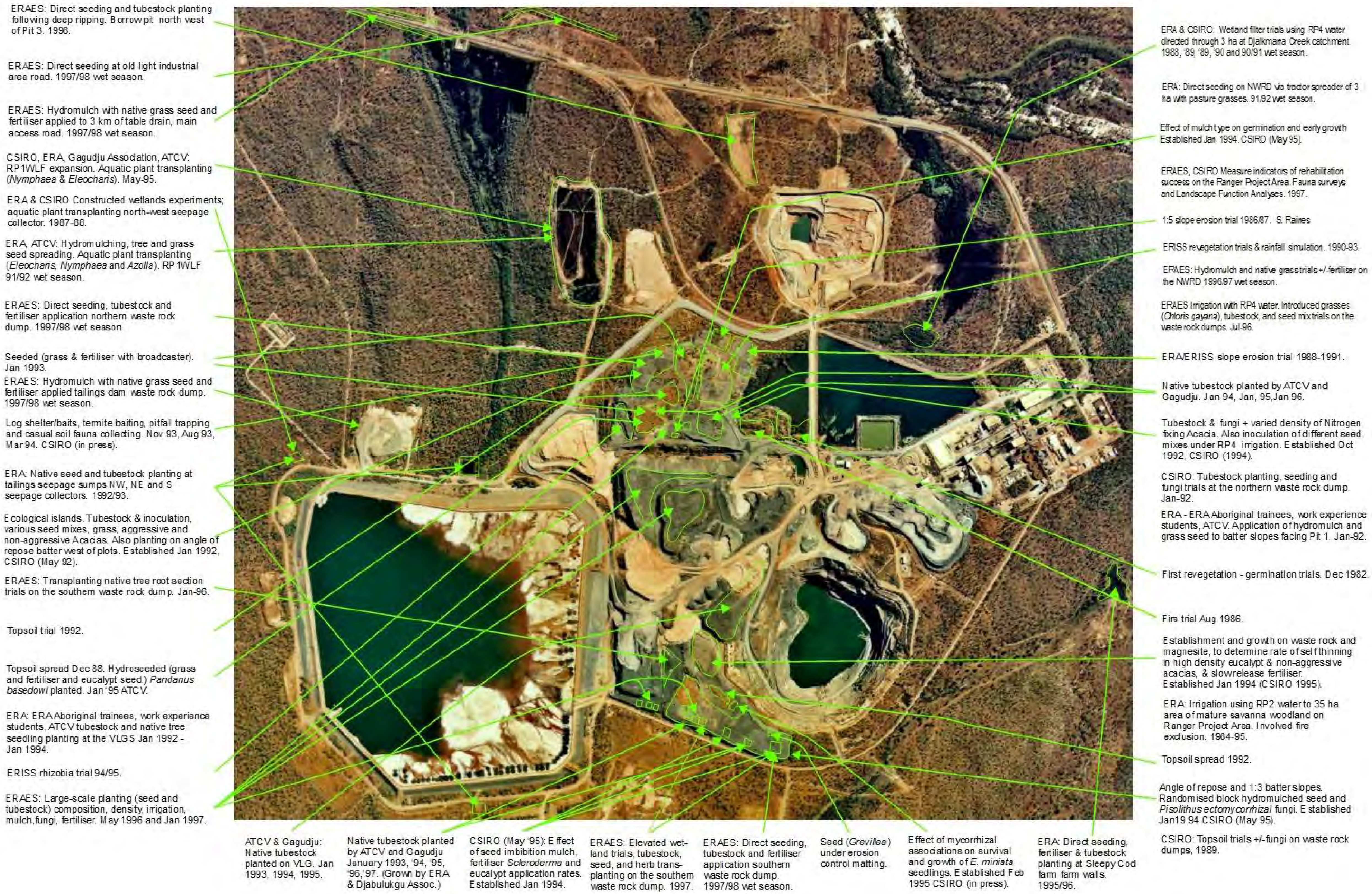


Figure 5-99: Revegetation conducted on Ranger Mine (1982 – 1998)

5.4.3.3 Ranger species establishment research program

In more recent years, the focus has been to expand on local species-specific knowledge as part of a Species Establishment Research Program (SERP). The SERP has been developed to systematically work through all of the potential revegetation species and identify the best way to establish them in the rehabilitation of Ranger Mine; it is informed by experience and a series of progressive trials to determine the most efficient and effective establishment method for each species (or for an indicative species for a group of related or similar species). The SERP is continuously working to improve understanding of practical aspects of species establishment. This knowledge has been captured in a SERP database and includes overarching themes of:

- seed management - including species phenology and seed collection, storage longevity, viability and germinability;
- propagation strategies - including seed treatments, potting materials, inoculation, plant growth, seasonality of propagation and alternative propagation methods; and
- revegetation and ecosystem development - including initial and intermediate establishment phases.

The revegetation species list has been considerably developed and modified over the last 15 years. In 2007, reference sites were used to develop a species list with relative densities for the revegetation of the TLF by ERA in collaboration with SSB, which and was provided to GAC for consultation in 2014 (Lu 2014). In 2015, the Mirarr developed a list of culturally important flora based on various criteria that pertain to an end use continuum, including but not limited to whether the plant is used as a cultural resource (e.g. for food, medicinal, aesthetic, material culture and/or ritual purposes), provides faunal linkages, and promotes biodiversity (Garde 2015). In March 2016, the flora and fauna closure criteria technical working group reached a consensus on a Ranger Mine revegetation tree and shrub species list, which was developed based on:

- previous analogue vegetation studies in undisturbed RPA and surrounding areas by SSB and ERA (125 studied analogue sites, including 10 sites from Kakadu NP with a land surface similar to the Ranger Mine final landform);
- culturally-important plant species, as identified by the Mirarr Traditional Owners in Garde (2015); and
- learnings from progressive revegetation activities and in particular the learnings from the TLF.

Over the last six years, the species list has further evolved based on consultation with CDU researchers and bininj ecology experts (Lu *et al.* 2017; Dr Sean Bellairs and Peter Christophersen *pers comm.* 2019) and recent reference site surveys. The ERA SERP database currently comprises 165 species (mostly terrestrial), including 21 overstorey tree species, 74 midstorey tree and shrub species, and 70 understorey species (or genus). The species included in the database will continue to be refined as outcomes from ongoing CRE work, revegetation trials, risk assessments, expert elicitation and further consultation with Traditional Owners are completed (including appropriate formal review by stakeholders).

To help focus research efforts, priority has been placed on tree and shrub species that are common and dominant in the surrounding landscape, therefore resulting in the majority of stems per hectare during initial revegetation, and on species that have been identified by Traditional Owners as important for re-establishment (Garde 2015, Cultural Reconnection Working Group *pers comm.* 2021, 2022). There is also a lot of research underway on how and when is best to establish understorey species, considering the important ecosystem services they provide and their significant contribution to species richness in the surrounding woodlands. Progress on the ERA SERP was presented during ARRTC46 in February 2021.

ERA has been working and collaborating with Kakadu Native Plants Pty Ltd (KNPS), a wholly bininj owned and operated business, for over 17 years on the progressive revegetation that has occurred both at Ranger Mine and Jabiluka. This supplier has extensive expertise on local ecosystems and plants, which has been invaluable for the seed collection, tubestock propagation and revegetation programs at Ranger (Section 9). The knowledge and expertise that has been shared by KNPS form an integral component of the SERP, particularly the seed and propagation knowledge base.

5.4.3.4 Seed knowledge

Provenance and use of seed collected within Kakadu NP

The use of seed collected only from within Kakadu NP ensures that the genetic make-up of the revegetation is consistent with locally adapted populations of each species and provides a buffer for adapting to future global change (Zimmermann 2013). To this end, a ‘conservative provenance zone’ has been adopted based on assessment of environmental factors, species distributions, taxonomy, present and past gene flow and species traits known to influence genetic variation in plants (Zimmermann & Lu 2015).

In 2011 to 2013, ERA conducted an extensive study investigating the provenance boundaries of the Ranger Mine in order to possibly extend the 30 km seed collection zone (Zimmermann 2013, Zimmermann & Lu 2015). The usefulness of genetic and non-genetic methods was assessed, and a non-genetic approach, based on the methods developed by FloraBank, Greening Australia and other experts in the field, was adopted. The method assessed environmental factors, gene flow and species traits known to influence genetic variation in plants and identified zones of least likely genetic variation. The resulting zones match the eco-geography of the Ranger Mine area and hence maintain the 'home site' advantage of local plants. Some genetic diversity that may be present in more distant seeds is welcomed, as it may allow plant populations to respond to environmental changes such as climate change (e.g. Prober et al. 2015). This 'composite provenancing' approach ensures increased genetic diversity whilst reducing the risk of genetic pollution and outbreeding depression.

The Atlas of Living Australia was identified as the most suitable and accurate environmental modelling tool, in the absence of fine-scale regional soil, vegetation and climate data. Environmental layers relevant to plant species distribution in the Top End (mean annual evaporation, annual precipitation, mean annual temperature, annual drainage, and topographic wetness index) were combined to predict a zone with a similar environment to the Ranger Mine, representing the Ranger Mine 'environmental provenance zone'. Investigations into revegetation species distributions found that each is well represented within the conservative provenance zone.

An assessment of potential gene flow indicated that there are no major geographic barriers within the Top End that may hinder the exchange of genetic material. As far as is known, there were no historical barriers in the Top End in the more recent geological past and the evolution in climate and vegetation was most likely uniform. Pollination takes place for the large majority of the investigated species not only by insects, but also by birds and bats, with most birds being generalists and hence being able to use other species as stepping stones between populations. Dispersal mostly takes place within 1 km of the source, but birds and bats can carry seeds over longer distances (e.g. 100 km).

Considering the abundance of birds, a continuous vegetation cover and that most revegetation species are common and widespread across the Top End, genetic exchange is likely to happen over large areas, if not the entire region. Any localised environmental variations that could cause genetic variation were eliminated by composite provenancing, which identified the 'environmental provenance zone' eco-geographically similar to the Ranger Mine. This was further narrowed by applying the conservative provenance zone. Seed collection guidelines further define and match the vegetation community and local environmental characteristics with the disturbed and created environments to be revegetated.

The seeds collected within the proposed conservative provenance zone (Figure 5-100) should be well adapted to the current conditions of the Ranger Mine, 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. However, larger changes in climate may require seeds to be sourced from environments currently dissimilar to the Ranger Mine area, with the risk that they may not perform well under the current environmental conditions at the mine. The scope of changes in climate and associated risks for revegetation has a high degree of uncertainty at this point in time and should be reassessed in the future.

The outcomes of this study were presented to ARRTC and submitted to the GAC Board for endorsement. The GAC advised that "… after long and careful consideration… [the GAC Board] …are comfortable with seeds being collected for rehabilitation only within the borders of Kakadu" (Melanie Impey 2015, *pers. comm.*, 12 August). This makes provision for harvesting seeds from the southern part of Kakadu NP, where edaphic conditions are closer to the future conditions at the Ranger Mine under global climate change scenarios.

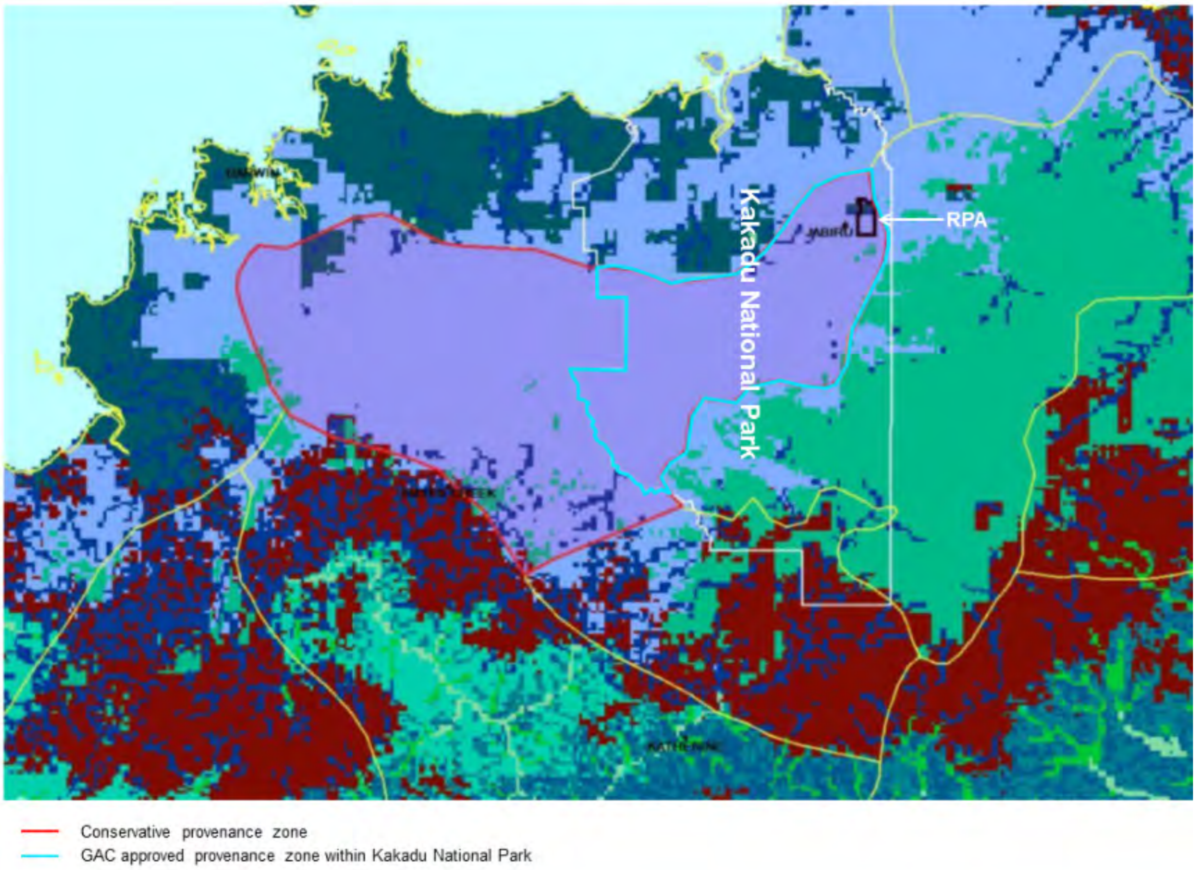


Figure 5-100: Proposed conservative provenance zone (bordered by the red line) and the GAC approved provenance zone within Kakadu NP (bordered by the blue line)

Species phenology and seed collection

Species flowering and fruiting periods are comprehensively documented in literature and field guides (Brock 2001; Crowder & Saggers 2010; Dunlop et al. 1995; Flora NT 2021; Fox & Garde 2018). However, many local species in Kakadu NP are variable seeders, some being highly reliable with year on year seeding whereas others only having 'good' seeding every few years (Brennan 1996; KNPS 2021 pers. comm). Another important consideration is when to time seed collection. If collected too early the seed can be immature and not fully developed, and if collected too late seed can be lost to natural dispersal, herbivory, insect or pathogen infection, or simply be too old. These factors can change annually depending on the prevailing weather and fire history, and some local species are more vulnerable to seed spoilage than others (KNPS per comms.). Carefully timed collection can ensure optimised seed quality and longevity (Pedrini et al. 2020). This is why knowledge on seeding behaviour (eg. extremely brief periods of ripe seed, extended periods of progressively maturing seed etc.), and local vegetation communities (eg. stands even relatively nearby can have different seeding times) is critical. KNPS use traditional knowledge, which is continuously developed by spending time on country and by performing reconnaissance surveys and *in situ* seed cut tests, to ensure that seed is collected at the best possible time.

Seed processing, storage, viability and germinability

Sub-optimal preparation of seed can impact viability and storage longevity (Frischie et al. 2020). After collection, seed lots are carefully processed (e.g. cleaned, purified, dried etc.) so that excess material is removed and moisture content is reduced. This ensures that potential vectors for seed spoilage, such as pests and fungi, are minimised, whilst also simplifying the storage and later seed management process. Each species has a specific processing method guided by current literature and standards, and further developed by KNPS from years of experience. Once the seeds are processed they are given to ERA, at which time the seed is generally dried a second time in a climate-controlled room prior to storage.

It is well understood that seed longevity in storage is highly dependent on seed moisture content and storage temperature (De Vitis et al. 2020). ERA have invested in two secure, climate-controlled storage rooms, as well as a short-term storage room for species that are generally used within a year (eg. grasses). The specific conditions of storage have been based on industry best practice and historical seed storage experiments. A small portion of the revegetation species are considered recalcitrant, with seed that is unsuitable for storage; this seed, deemed ‘perishable’, requires propagation immediately after collection for optimal germination.

ERA have periodically commissioned seed testing to help determine the viability, germinability and storage life of the revegetation species and individual seed lots (Figure 5-101). Some of this testing has been to interpret direct seeding trial success (e.g. TLF in 2008, understorey trials in 2018 and 2020 etc.), and others have been for targeted research, quality control and/or risk management purposes. A comprehensive research project was conducted by CDU (Bellairs & McDowell 2012), titled *Seed biology research to optimise germination of local native species to support the rehabilitation of the Ranger mine site 2006 -2011.* The project investigated viability, germination, dormancy and storage longevity of over 70 native species that were being considered for revegetation at the time; it also aimed to develop protocols for species that had been identified as being difficult to germinate. The majority of species studied were native understorey, because of “the death of seed biology information available for shrubs and ground cover species compared to the greater information available for trees” (Bellairs & McDowell 2012).

At the end of 2019, ERA commissioned CDU to perform viability (through tetroazolium chloride staining) and germination testing on over 80 seed lots from 49 species to assess the quality and longevity of their stored seed. Generally, the species that will make up the majority of stems in future Ranger revegetation (*Corymbias, Eucalyptus* and *Acacias*) maintained viability and germinability for well over five years in storage, with some thirteen year old seed lots still achieving 94% germination. Other important species such as Kakadu Plum (*Terminalia ferdinandiana*) were still achieving high germination after three years in storage, but not after eight. This comprehensive testing confirmed that the ERA storage facility conditions are appropriate for preserving seed longevity of key, dominant revegetation species. It also provided updated metrics to enter into the Seed Management and SERP databases. ERA is in the processes of setting up an ongoing, periodical seed testing campaign.

During propagation, germination data is carefully recorded for each seed lot and is fed back into the Seed Management and SERP databases. This ensures that seed quality and longevity knowledge is continuously developed and updated, and that each seed can be used optimally.

Figure 5-101: Replicate from seed testing germination trials (*Heteropogon triticeus*)

Seed management and SERP databases

Each seed lot has information recorded and stored in the *ERA Seed Management Database*. Collection information includes an identification code, date, location (including GPS coordinates), collector, method, and amount of seed collected. Seed quality information includes mean individual seed weight, purity, viability and laboratory germinability (if tested), and nursery germinability. This information is then used to quantify the approximate amount (by weight or individual seeds) of total, viable, and germinable seed in storage.

Species-specific seed knowledge captured in the SERP database includes:

- flowering and fruiting periods;
- seeding behaviour (including annual variability and seed maturing periods);
- vulnerabilities to spoilage (eg. weevils, mould, cockatoos etc.);

- optimal period for seed collection;
- collection method(s);
- quantities generally collectable in one effort;
- collection ease and risks;
- processing method;
- seed storage longevity;
- general viability; and
- general germinability.

5.4.3.5 Propagation knowledge

Potting materials

ERA are currently investigating the potential use of plantable, biodegradable pots (biopots) as an alternative to traditional nursery tubes at Stage 13.1 and Pit 1, for reasons outlined below.

Standard plastic nursery tubes

Nursery tubes were used at Ranger for all tubestock planting pre-2017, including the TLF. The obvious benefit of using nursery tubes is that they are the commercial standard, meaning there is a wealth of knowledge, experience, research and published literature involving the use of nursery tubes. Additionally, KNPS have well over a decade's worth of experience growing tubestock for ERA using nursery tubes. However, there are still concerns that nursery tubes may not be the best option for the large-scale revegetation of Ranger mine.

Issues with root growth in nursery tubes is well documented, some of which are associated with the impermeable nature of the pot sides (eg. root circling, even in square pots). Many of these root development issues can be exacerbated by prolonged bench time. Although the full-scale revegetation of Ranger is carefully planned and scheduled, unexpected delays or interruptions can occur (as has been demonstrated by the COVID-19 outbreak). When TLF construction was delayed for two months due to material sourcing difficulties and road inaccessibility, the tubestock were held in the nursery for longer than anticipated. By the time the TLF was ready for revegetation, many of the tubestock were pot-bound and some plants had to have portions of their roots removed to facilitate depotting, as the roots had grown through the bottom of the tube (Daws & Gellert, 2010). Conversely, if an area of the final landform is available ahead of schedule it may be advantageous to plant tubestock earlier than planned. There is a risk with nursery tubes that if the roots are underdeveloped, they may not hold the potting material adequately and loss of material may occur during planting.

There are also potential overheating issues with traditional nursery tubes. They are black which absorbs heat and have solid sides, which although improves water efficiency, does not allow for evaporative cooling of the potting substrate. These factors can cause the substrate in nursery tubes to heat up. Root growth stops when temperatures exceed species-specific thresholds, and root death can occur if exposure to these temperatures is prolonged. The risk of pots overheating is very real at Ranger mine; it is not uncommon to have > 40 °C days during the October – December period. The most dangerous time for nursery tubes to overheat is during planting when the pots are sitting exposed on the waste rock surface, which can reach well over 50 °C (Daws & Poole, 2010).

The process of removing the plant from the nursery tube can be time consuming, particularly given the care that needs to be taken to ensure the plant is not damaged. Although depotting ideally only takes an additional few seconds, this still equates to a significant amount of time when extrapolated for over 1 million stems. Additionally, the process can often take longer depending on the species and how long the plant has been in the pot. Even when performed carefully, depotting can lead to loss of roots and potting material. Given the extreme conditions of the waste rock final landform, tubestock need to be in the best condition possible to ensure their survival. High levels of transplant shock have been observed historically at Ranger mine when depotting was performed incorrectly by inexperienced planting crews (per comms. Dr Ping Lu).

Lastly, although it is not a factor that impacts the revegetation success of Ranger mine, another consideration is the excessive plastic involved when using nursery tubes. The tubes can be reused to some extent, however given that hundreds of thousands of plants will need to be grown at the same time during peak revegetation, reuse will be limited.

Biodegradable pots

Plantable biopots can be made from a wide range of organic materials, such as rice straw and hulls, peat and wood fibre, coconut husk, paper, poultry feathers and cow manure. In theory, plantable biopots are an attractive option for large-scale tubestock revegetation as they eliminate many of the risks outlined above. However, the use of biopots introduces new factors that need considering such as their durability, water retention, impact on plant growth, rate of field decomposition and plant field performance (Evans et al. 2010; Sun et al 2015). Furthermore, revegetation of mine waste rock in the wet-dry tropics using biopots is (at this stage thought to be) unprecedented. The majority of research conducted on biopots concerns the production of agricultural and horticultural species planted into natural soil; therefore, the performance of native savanna species in waste rock substrate will inherently be different.

The plantable biopot that has been sourced for trials at Ranger Mine is a slotted, square rice-hull pot. Wood fibre pots were also briefly investigated, however those trials have discontinued due to their lack of durability and wet strength during nursery propagation.

Pots need to be durable enough to last 2 – 6 months on a nursery bench, where they are frequently watered and handled. They also need to survive transport to the planting site. Solid, compostable rice-hull pots have been found to be amongst the strongest types of biopot, with vertical and lateral strength (dry and wet) comparable to plastic nursery tubes (Evans et al 2010). The plantable rice-hull pots are still highly durable, but differ to the solid rice-hull containers in that they use a less resilient binder and contain slots, which allows them to decompose in the field (Cypher & Fulcher 2015a; Summit Plastic Company 2020). For the purposes of Ranger Mine revegetation, the slotted rice-hull pots have been found to be suitably durable for nursery propagation and planting.

Most plantable biopots have either porous or slotted sides which aid field decomposition. Although this has an advantageous cooling effect, it also means the potting substrate has a faster rate of drying than nursery tubes. Depending on the type of biopot, they can require up to three times the amount of nursery irrigation as plastic tubes (Cypher & Fulcher 2015a). Slotted rice-hull pots are considered to have moderate water requirements, needing similar or slightly more water than nursery tubes depending on the species that are being grown (Cypher & Fulcher 2015b). At Ranger, the nursery irrigation needs of plants in plastic and biopots has been found to be similar. However, plants in biopots have been disproportionally impacted by nursery irrigation failure incidents that occurred at the end of 2019 and mid-2021, so much so that considerable biopot stock was unsalvageable after both events. This was likely due to the biopot substrate drying faster than the solid-sided plastic pot substrate because of their slotted-sides and smaller size.

Studies comparing biopots to nursery tubes in regards to plant growth have had mixed results depending on the pot type and species being grown; however overall, biopots and nursery pots generally appear to have similar results in regards to plant growth (Conneway 2013; Cypher & Fulcher 2015a; Nambuthiri et al 2015). A wide range of local species have been grown at the ERA nursery since 2019, with no obvious differences in seedling condition and growth between the two pot types when grown under optimal conditions. However, during irrigation incidents (as discussed above) or when planting was delayed and seedlings spent additional time on the nursery benches, biopot plants were in poorer condition than same-aged plastic pot plants.

Field decomposition is an important component of what makes biopots truly ‘plantable’. Slow decomposition post-planting may cause restricted movement of water and nutrients, poor root formation, and impede the plant’s ability to anchor and perform (Nambuthiri et al 2015). The different type of materials used to create biopots can impact their rate of field decomposition. Biopots high in cellulose, such as cow pat, have been found to decompose faster than biopots high in lignin, such as coconut fibre (Evans et al 2010; Sun et al 2015). It has also been suggested that the high levels of nitrogen present in cow pat containers may increase microbial activity, thereby increasing decomposition (Evans et al 2010). Slotted rice-hull pots have been found to have amongst the lowest rates of field decomposition (Conneway 2013; Sun et al 2015).

The location where biopots are planted can also significantly influence rate of decomposition, in some cases more than the material of the biopot (Sun et al 2015). Temperature, rainfall, soil pH and moisture, and microbial activity can highly impact biopot decomposition rates (Cypher & Fulcher 2015a; Evans et al 2010; Nambuthiri et al 2015; Sun et al 2015). The plant species grown in the biopot may also influence rate of decomposition (Conneway 2013; Sun et al 2015).

There is no known available information on field decomposition rates of biopots in mine waste rock. ERA has used rice-hull biopots for infill planting of understorey species on the TLF in 2018 and 2020, where opportunistic excavation of some plants showed significant pot decomposition. However, this planting was conducted on a 10-year-old revegetated waste rock landform, which has considerably different conditions (eg. increased shade and organic matter) to a newly formed landform. The species infilled were also predominately grasses, which have fibrous roots rather than taproots, therefore could easily spread and establish through the slotted biopot sides. Being aware of the potential risks to root formation from slow biopot decomposition, a step was added to planting procedures to 'crack' the biopot once it is in the planting hole, before substrate is infilled, to minimise potential root restriction. Stage 13.1 and Pit 1 provide opportunities to investigate biopot decomposition rates and root formation.

Despite the difference in decomposition rates, plant establishment and growth post-transplant have been found to be relatively similar across different biopot types, and compared with control plants grown in nursery tubes (Conneway 2013; Sun et al 2015). Preliminary field results from Stage 13.1 and Pit 1 are discussed in the revegetation section below.

Seed treatments, germination and growing seedlings

There has been several extensive research projects investigating treatments to improve seed germination of native species for Ranger revegetation (Ashwath et al. 1994; Bellairs & McDowell 2012). A variety of treatments were examined depending on the species, including different medias (filter paper, sand and vermiculite), heat (submersing seed in water at various temperatures), smokewater, soaking or leaching, sulphuric acid (H_2SO_4), gibberellic acid ($C_{19}H_{22}O_6$), nitrate (NO_3), scarification (including nicking, drilling, rubbing on sandpaper, and mechanical stirring of seed with sand), cleaning (removal of mesocarp), partial or full endocarp removal, as well as combinations of treatments. This historical research has been the foundation of seed germination trials at Ranger, with treatments further refined and developed by KNPS using traditional knowledge.

Until recently, propagating and planting of tubestock has only been performed for revegetation in the wet season, which is standard industry practise. A unique challenge for Ranger Mine is the requirement for year-round revegetation during peak rehabilitation periods (originally 2024 / 2025 before reforecast). Efforts over the last three years have been focussed on 'unseasonal trials', to familiarise with germinating seeds and growing species during different times of year (eg. during dry, cooler months when seed germination and plant growth are typically very slow, or completely dormant). Two years of unseasonal propagation trials found that some species significantly benefit from being placed in a greenhouse (Figure 5-102), either for the initial germination period or for the entire growing season, during certain months of the year. Other species simply require sowing a few weeks earlier than usual, and many are not impacted at all by unseasonal propagation.

Figure 5-102: Greenhouse tunnel trials at the ERA Nursery

Other work that is being undertaken is refining optimal growing times for each species. Previous experience has shown that prolonged nursery bench time can result in 'leggy' seedlings that are root bound, nutrient stressed and more prone to parasites, herbivory and fungal attacks. Other times, seedlings that were initially considered 'young' and small actually performed better than standard aged seedlings, likely because of a better root-shoot ratio which decreased the seedling's initial water demand after planting (Dr Ping Lu 2019 *pers comms*). This concept of 'standard-aged verses younger' seedlings is being investigated at the large-scale revegetation trial on Pit 1. If younger seedlings are found to perform similarly or better than standard-aged seedlings there is the added benefit of freeing up nursery bench space during peak revegetation, potential helping take pressure off the schedule.

Tubestock grown at the Ranger Mine nursery are fully exposed to the sun and wind during the entire propagation process. This has resulted in 'hardy' plants better suited to the harsh moonscape environment of the waste rock FLF. ERA have trialled 'hardening off' the seedlings further by slowly reducing irrigation in the weeks leading up to planting, however this has had unpromising field results (discussed in revegetation section below).

Tubestock inoculation

Microorganism inoculation has become standard practice in many commercial nurseries due to the vital role microbes perform in plant nutrient acquisition. The importance of symbiotic microorganisms for the revegetation of post-mining land has been well documented (Johnson & Milnes 2007; Chandrasekaran et al. 2000; Corbett, M 1999). Mycorrhizal and Rhizobium inoculation of tubestock has been found to alleviate nutritional problems and promote plant growth during early establishment (Reddell & Zimmerman, 2002). *Eucalyptus miniata* tubestock had significantly improved establishment on Ranger waste rock when inoculated with *Pisolithus* and *Laccaria*, or when 'locally contaminated' by *Nothocastoreum* (Gordon et al. 1997; Reddell et al. 1999). Inoculated seedlings had significantly greater shoot growth and leaf phosphorous concentrations than uninoculated seedlings, and seedling dry weight was found to increase consistently with levels of fungi colonisation (Reddell et al.1999). Hinz (1997, as reported in Corbett M 1999) also found that *Nothocastoreum* mycorrhizal associations were important for *E. tetrodonta* growth and development at Gove mine. Inoculation of Rhizobium has also been found to alleviate Acacia seedlings' nitrogen deficiencies when growing on Ranger waste rock (Reddell & Milnes, 1992).

From their review of revegetation research at Ranger Mine, Reddell and Zimmermann (2002) concluded that "inoculation of framework species with spores of ectomycorrhizal fungi would seem a very cheap and effective way of partially alleviating nutrient limitations to seedling establishment on the waste rock stockpiles" (note: 'framework species' are species that are ubiquitous in the *Eucalyptus tetrodonta-miniata* dominated savanna woodland, that generally will be actively introduced at higher densities across the whole Ranger Final Landform). Tubestock used for the revegetation of the TLF and Jabiluka were inoculated using locally collected fungi, and all tubestock in the last four years have been inoculated using local and/or commercial microbes, other than at Stage 13.1A where a combination of different inoculation treatments were explored (Table 5-46).

Alternative propagation methods

As discussed previously, a small portion of the revegetation species have perishable seed and require immediate sowing after collection (typically during early wet season); this presents a challenge for year-round revegetation. ERA have been working with KNPS to develop alternative propagation methods for these species. One of these alternatives has been to hold the seedlings longer in the nursery, repotting into larger pots as needed to minimise stress and allow the plant to continue developing as normally as possible. Species that have been propagated and planted at Stage 13.1 and Pit 1 using this method include bushfoods such as Bush Apples (*Syzygiums*), Cocky Apple (*Planchonia careya*), White Currant (*Fluggea virosa*) and *Breynia cernua*.

SERP database - Propagation

Species-specific propagation information summarised in the SERP database includes:

- seed treatments;
- general nursery germinability, with consideration of different seasons;
- required growing times, with consideration of different season;
- propagation issues (e.g. susceptible to herbivory, low germination in the dry season, perishable seed); and
- controls (e.g. insecticide, greenhouse germination in the dry season, older plants in larger pots).

Table 5-46: Stage 13.1A propagation treatments and rationale

Treatment		Rationale
1- 4	Different sources of microbes [1] local microbes [2] no microbes [3] commercial only [4] combination of local and commercial microbes	These treatments are to assess whether tubestock seedlings have improved growth/survival when inoculated with microbes from different sources. Commercially produced microbial additives for potting mix are becoming routinely used by nursery and horticultural industries. Locally sourced microbes may perform better than commercial microbes because they are adapted to the environmental conditions of Kakadu and have evolved with the plant species that are being used for revegetation. However, there is concern that inoculation with a local microbe mix sourced from inside the RPA (which historically has been frequently disturbed by fire) will not have sufficient quantities or diversity of micro-organisms. It may be that a combination of local and commercial microbes are needed for improved plant growth and survival.
5	Plastic nursery tubes (50 x 120 mm)	Although nursery tubes are the commercial standard for revegetation, past experience at Ranger suggests biodegradable pots may be a preferable option as they eliminate the need to depot and will speed up planting.
6	Irrigation “hardening off”	By slowly reducing the frequency of watering a few weeks before transplanting, the tubestock may be better adapted to ‘cope’ with the harsh field condition of the final landform.

5.4.3.6 Revegetation

The revegetation trials conducted over the last decade have continued to reinforce many aspects of the first ARRTC-endorsed Ranger Revegetation Strategy (Reddell & Meek 2004, Appendix 5.4), which was first formed over 15 years ago based on research conducted in the 80s, 90s and early 2000s. However, the current ERA Ecosystem Establishment Strategy continues to evolve from further propagation and revegetation experience. Some of the key learnings from recent revegetation trials (discussed in greater detail in the following sections) include:

- The final landform growth medium layer will be predominately waste rock material with no purposely mixed laterite incorporated as was previously considered (over a decade ago). This is due to: 1) a lack of suitable laterite material of sufficient quantity for the final landform; 2) vegetation performing well on waste rock only substrates in terms of survival and establishment; and 3) areas with high proportions of laterite material showing higher risk of weed infestation;
- The majority of revegetation will be performed through tubestock planting. In almost all cases, tubestock areas have out-performed direct seeded areas in terms of plant survival, growth, stem density, species diversity, production of flowers and fruit, and recruitment; and
- Irrigation with be installed prior to revegetation to ensure seedlings can be watered during the first few months following planting, regardless of season, as initial plant survival on waste rock is significantly influenced by water availability.

Trial Landform

The TLF has been continually monitored for over a decade to assess revegetation performance and ecosystem development on waste rock-only and waste rock/laterite mix substrates (Figure 5-103 and Table 5-47). A range of trials and management actions have been undertaken on the TLF during this time (Table 5-48).

Table 5-47: TLF Permanent Monitoring Plot details

Plots	Substrate Type	Establishment Method
0 – 4	Waste rock only	Tubestock
5 – 9	Laterite mix (5m depth)	Tubestock
10 – 14	Laterite mix (2m depth)	Tubestock
15 – 19	Waste rock only	Direct seeding
20 - 24	Laterite mix (2m depth)	Direct seeding
25 – 29	Laterite mix (5m depth)	Direct seeding
30 – 34	Waste rock only	Tubestock & Direct seeding
35 – 39	Laterite mix (2m depth)	Tubestock & Direct seeding
40 - 44	Laterite mix (5m depth)	Tubestock & Direct seeding

Figure 5-103: Trial Landform layout from northwest to southeast are sections 1A & 1B (waste rock only) and 2 & 3 (waste rock / laterite mix). Includes 15 x 15m permanent monitoring plot locations

Table 5-48: Vegetation establishment activities conducted on the Ranger Mine TLF, 2009 – 2020, not including routine weed management

Month/Year	Action	Details	Reference
March 2009	Tubestock planted on the TLF	1473 tubestock planted in section 1A, 3029 planted in section 3 – each with 21 g slow release fertiliser tablet	Daws & Gellert (2010)
July 2009	Direct seeding of TLF (irrigated sections)	Seed mixes, made up of 31 species, sown at a rate of 3 kg ha^{-1} in sections 1B and 2	Daws and Poole (2010)
December 2009	Direct seeding of TLF (unirrigated sections) Fertiliser application	Direct seeding of the northern edge in sections 1B and 2, using the same sowing rate and species mix as the previous areas 50 kg ha^{-1} of Osmocote Plus to whole landform – applied at the base of tubestock and broadcasted in direct seeded areas	Daws and Gellert (2011)
January 2010	Infill tubestock planted	699 tubestock planted in section 1A, 1317 planted in section 3 – each with 21 g slow release fertiliser tablet	
November 2010	Fertiliser application	50 kg ha^{-1} of Osmocote Plus to whole landform – applied at the base of tubestock and broadcasted in direct seeded areas	
January 2011	Infill tubestock planted	1449 tubestock planted in section 1B, 2432 planted in section 2 – each with 21g slow release fertiliser tablet	Gellert (2012a)
January 2011	Understorey trials	Five grass species were sown in section 1A and 3	Gellert (2012b)
January 2012	*Xanthostemon* tubestock planted	Approximately 300 planted in the track between sections 1A and 1B; 75 planted in section 3	Gellert (2013)
November 2012	Understorey trials Fertiliser application	Seven grass species were sown in section 1A Small handful of Osmocote applied to each of the Jan-2011 infill planted tubestock. Smaller amount applied to direct-seeding plants on an ad-hoc basis	Gellert (2013; 2014)
May 2016	Burn	Cool burn of the laterite mix sections (2 and 3)	Wright (2019a)
April 2018	Understorey direct seeding trial	Five understorey species were sown in sections 1A and 1B with six amelioration treatments	Parry et al (2022)
June 2018	Understorey tubestock trial	Five understorey species were planted in sections 1A and 1B	
January 2019	Understorey planting in 'islands'	Nine understorey species that were grown in 2018 nursery trials were planted in 'islands' on sections 1A and 1B – some with litter	NA
June 2019	Burn	Cool burn of the laterite mix sections (2 and 3)	Wright (2019b)

Month/Year	Action	Details	Reference
February 2020	'Secondary' introductions	Eighteen species tubestock planted (10x understorey and 8x midstorey/overstorey), and seven understorey species seeded in patches with and without added mulch (21 species total, mostly 1A and 1B)	TLF Research and Monitoring Plan 2020 – 2026
February 2020	Understorey direct seeding trial	Twelve understorey species were sown in section 1A in plots with and without naturally occurring organic matter	
December 2021	*Xanthostemon paradoxus* direct seeding trial	Approximately 300 seeds per site at 40 sites across sections 1A and 1B	NA

Overstorey and midstorey species

Survival and establishment

Plant mortality is often highest in the first few months following planting, as the seedlings recover from any transplant shock and adjust to the new, harsher field conditions. At the TLF, initial mortality of the 2009 tubestock was very high. Overall survival after six months was 40% in section 1A and 36.3% in section 3 with irrigation; this was still significantly greater than the non-irrigated areas, which had 13% and 22.7% survival in 1A and 3 (Daws & Gellert 2010). It should be noted that there were issues in the 2009 planting relating to tubestock quality and irrigation reliability that may have contributed to this high initial mortality. Overall initial survival was considerably better for the tubestock planted in January 2010, with 73.6% and 55.3% survival in the irrigated areas of 1A and 3 eight months after planting (Daws & Gellert 2011). Surprisingly, survival in the non-irrigated areas was not significantly different to the irrigated areas; this is presumably because of the high and consistent rainfall between January – April in 2010, which was 16 % above the mean for that period (Jabiru Airport, Bureau of Meteorology 2020) (Figure 5-104) (Daws & Gellert 2011). Over 109% more rainfall was delivered in March and April 2010 compared to the same period in 2009 (Jabiru Airport, Bureau of Meteorology 2020). These results clearly demonstrate that annual rainfall variability can have a significant impact on initial tubestock survival, and that irrigation is critical to avoid complete revegetation failure in the event that Jabiru experiences a poor wet season.

Initial results from the TLF direct seeding appeared promising. Although sowing was performed during the dry season, a considerable number of seedlings emerged in both sections of the TLF (approximately 25% greater density in the waste rock only substrate). Interestingly, the irrigated seeding in July 2009 was significantly more successful than the non-irrigated seeding in December 2009, despite the above-average rainfall over the 2009/2010 wet season (Daws & Gellert 2011). It's possible that the lower temperatures experienced in July were actually beneficial for germination, as the waste rock substrate surface can reach well over 50°C in the heat of the day during the build-up. However, it is likely that the consistent irrigation also contributed to the initial success of the July seeding.

Whilst the TLF direct seeding seemed successful in the first year due to the high initial stem density, species compositions were skewed due to the different rates of germination. In both sections *Acacia sp.* and *Terminalia* were amongst the more 'successful', with many of the framework Myrtaceae overstorey species germinating at lower rates (Daws & Gellert 2011). Within 18 months of seeding, infill planting was required to improve both sections' species compositions and stem densities.

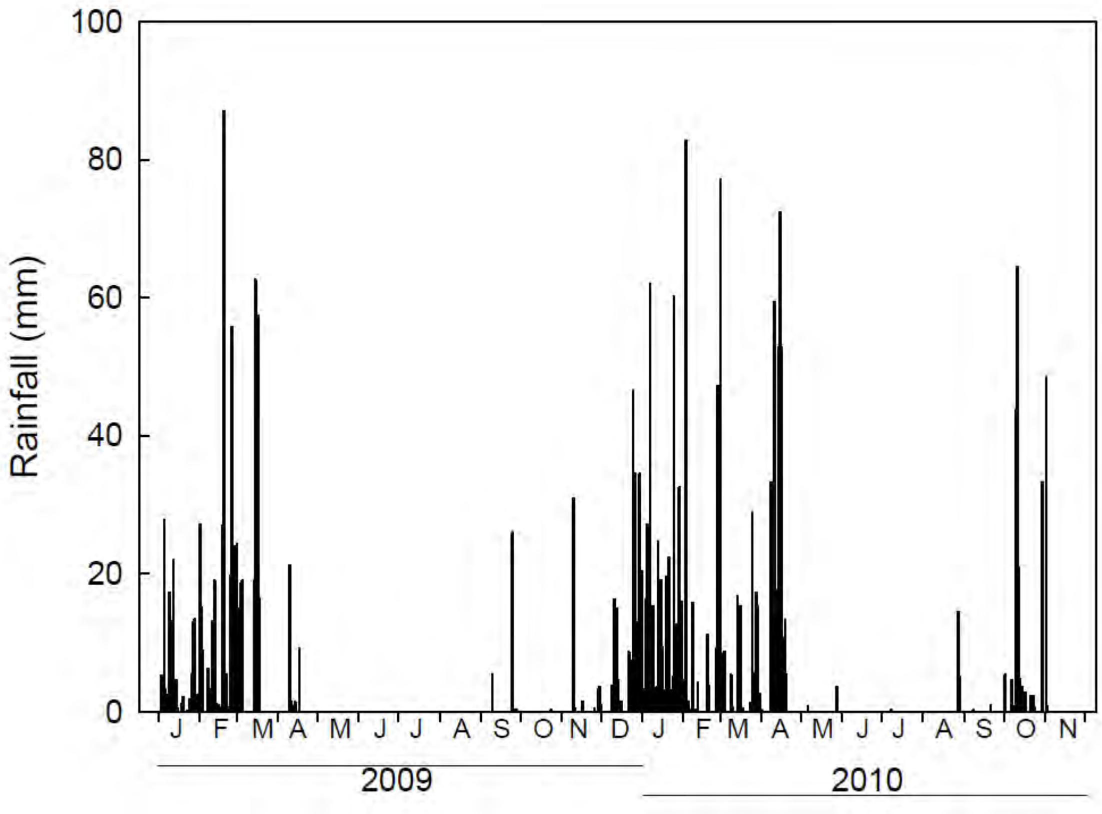


Figure 5-104: Daily rainfall for 2009 – 2010. Data up to 17 April 2009 from Jabiru Airport (Bureau of Meteorology): subsequent data from the TLF.

Overall, 39 of the 42 tree, shrub and palm species that were planted or direct seeded on the TLF are still present in 2022. Two of the species which completely failed to establish, *Erythrophleum chlorostachys* and *Stenocarpus acacioides,* were only direct seeded; *E. chlorostachys* germinated in section 2 but failed to persist beyond two years, and *S. acaciodes* seed failed to germinate despite the seed having ~94% viability (Daws & Gellert 2011). The other species that was actively introduced that is no longer present is *Grevillea pteridifolia,* which initially established really well but began dying out in 2018; the last large adults died in 2021, and although some small recruits were observed for this species, they failed to persist through the dry season. *Grevillea pteridifolia* typically occur in low lying and seasonally inundated areas, or near permanent freshwater streams, so it is likely that the harsh conditions on the TLF were not suitable for this species. All of the other midstorey and overstorey species actively introduced are still present on the TLF, however some have disappeared from one or more sections of the landform over time, and others have persisted but with very few individuals (*Jacksonia dilitata*, *Petalostigma pubescens* and *Owenia vernicosa*).

The full TLF survey in 2019 found that mean survival after ten years in the tubestock planted areas is relatively low (32 ± 4.4% in section 1A; 18 ± 3.3% in section 3) (Figure 5-105). This is partly due to the high initial mortality rates of the 2009 tubestock and the shorter-lived species senescing in recent years (e.g. some of the *Acacias* and *Grevilleas*). One of the species that had particularly low survival during the revegetation of the TLF was *Xanthostemon paradoxus.* Mortality was extremely high in the six months following planting (over 95 %) which prompted a master's research project. It was found that *X. paradoxus* tubestock survival and growth was significantly improved with shading, likely due to less light and reduced heat stress (Gellert 2014). These results indicate that this species may be better suited for introduction once the overstorey has had time to develop canopy and provide shade, therefore it has been delegated to a 'secondary introduction' species.

The species with the greatest survival on both sections of the TLF is *Eucalyptus tintinnans*. This species naturally grows on rocky ridges and appears well adapted to the Ranger waste rock media. *Eucalyptus tintinnans* does not occur within a 10 km radius of the mine unlike the currently proposed CRE sites. However, it is native to Kakadu NP and is on the agreed list of species for revegetation of Ranger by the flora and fauna closure criteria technical working group. Because of this, it has continued to be trialled at Stage 13.1 and Pit 1. ERA are conscious of unintentionally creating an inappropriately 'mixed' vegetation community on the final landform (Brady et al 2021); therefore, further Traditional Owner consultation has begun on the inclusion or removal of this species from the SERP.

Stem Density

Throughout the life of the TLF, stem densities have consistently been greater in the waste rock sections compared to the laterite mix sections due to better germination and/or survival of the trees and shrubs (Figure 5-106). A survey of the entire TLF in 2019 found that section 1A had the greatest stem density (plants >1.5m) at approximately 727 stems/ha^{-1}, followed by 1B, 3 and 2 at 534, 354, and 200 stems/ha^{-1} respectively (Table 5-49). Self-recruitment was also highest in 1A, with approximately 290 recruits, followed by sections 3, 1B and 2 with approximately 146, 98 and 75 recruits respectively.

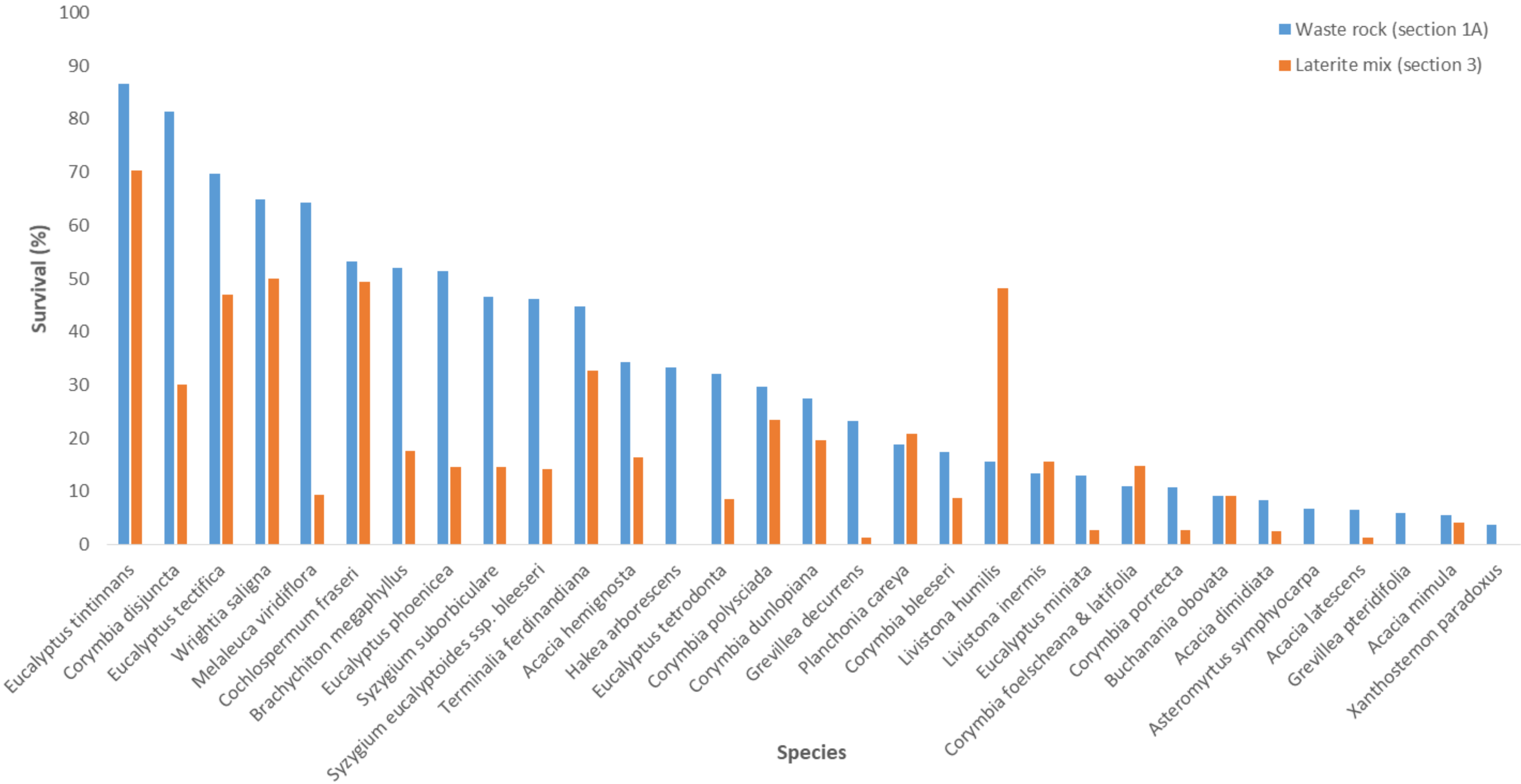
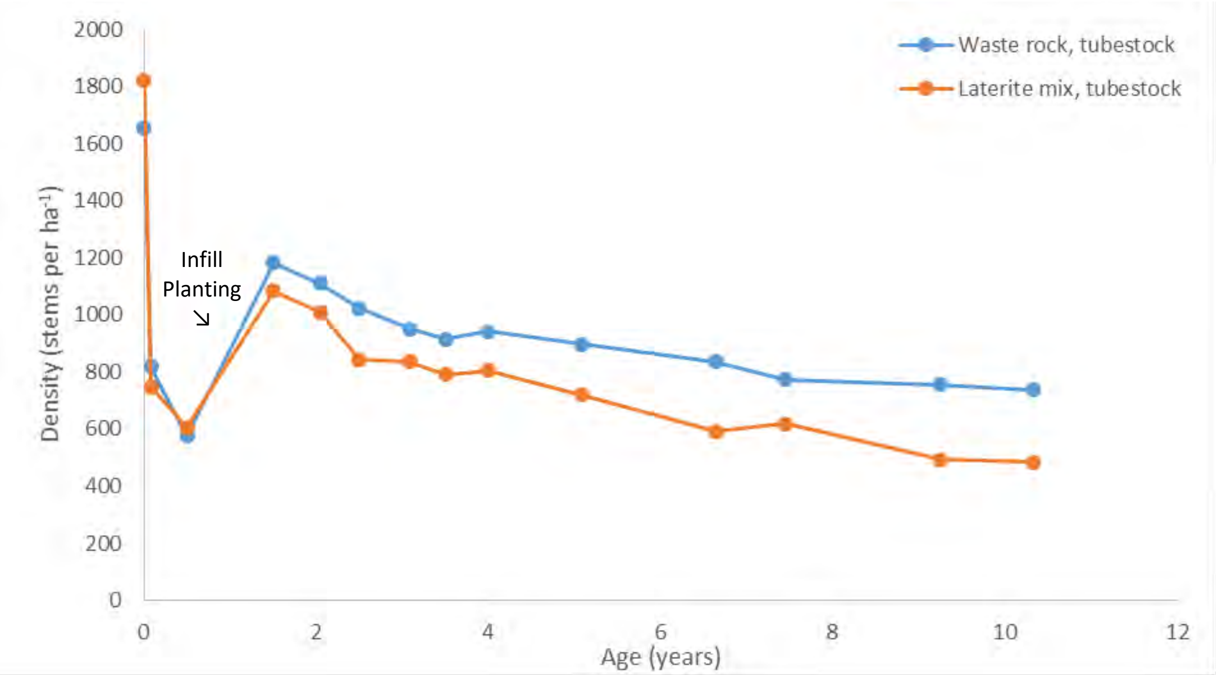


Figure 5-105: Tubestock Survival on 1A and 3 after ten years.

Calculated = (# of non-recruits present in 2019 / # planted in 2009 + 2010) * 100



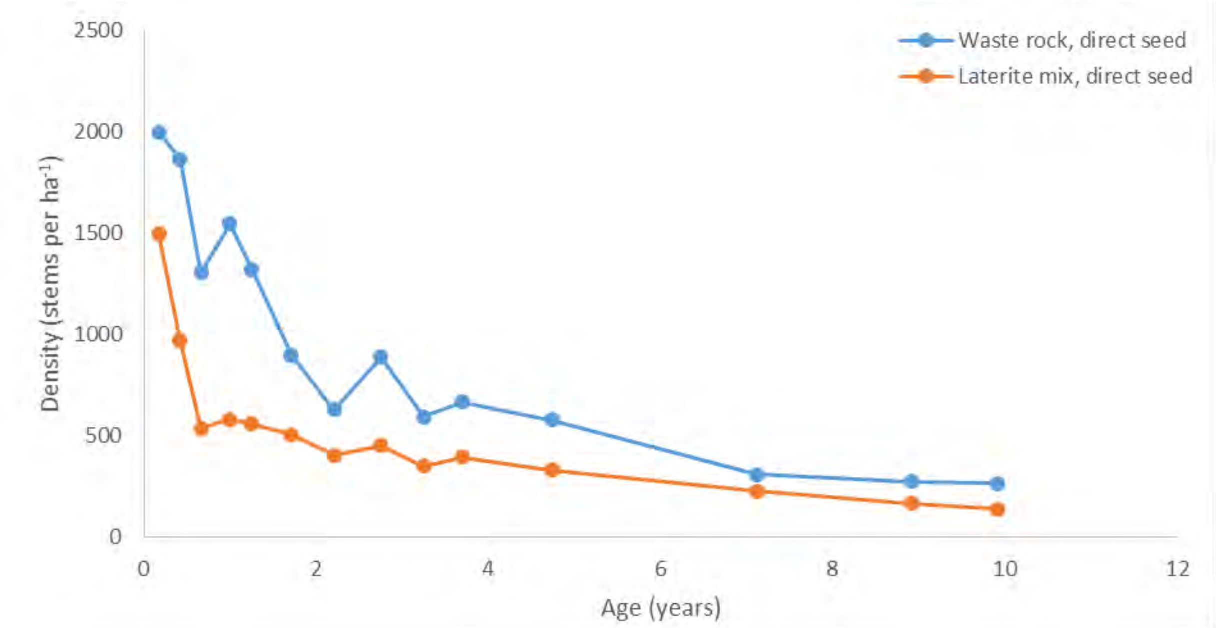


Figure 5-106: Longitudinal plant density (stems per ha^{-1}) based on the tubestock only (0 -14) and direct seeding only (15 – 29) Permanent Monitoring Plots on the TLF, not including recruits.

Note: Density is based on all introduced individuals inside the permanent monitoring point regardless of height. Density before 0.5 years was calculated using the total number of seedlings in each section (estimates for direct seeded areas); the direct seeding densities do not include infill planting. It is believed that the increases in density in the directly seeded areas during the first few years were likely due to ongoing germination of the broadcast seed.

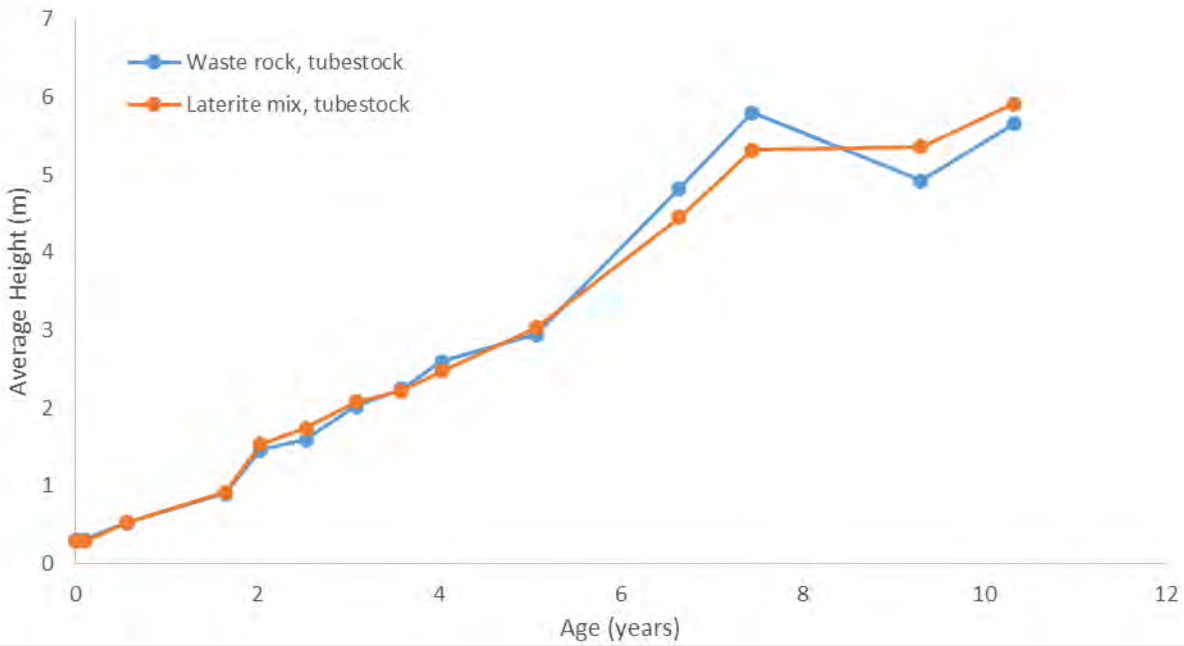
Table 5-49: Approximate total overstorey and midstorey stems on the TLF in 2019, including recruits.

	Total # of individuals (approx.)	Total # of individuals >1.5 m	Stems per hectare (>1.5 m)
1A	967	727	727
1B	863	534	534
2	564	400	200
3	864	708	354
Total	3258	2369	296

Plant Growth

Plant height on the TLF has not varied significantly by substrate in the tubestock areas (Gellert & Lu 2015, Parry 2019 unpublished data; Figure 5-107). In the first five years, mean height in the waste rock and laterite mix tubestock sections was almost identical, with around 60 cm of plant growth per year. Mean height almost doubled in the following 2.5 years, reaching a peak average height of 5.8 m in the waste rock section in August 2016. Cyclone Marcus brought heavy destructive winds to the area in March 2018, disproportionately effecting the waste rock end of the TLF. This combined with tall Acacias reaching the end of their natural life-span, accounts for the reduction in height between August 2016 and June 2018. Diameter at breast height (DBH) is slightly greater in the laterite mix substrate, with a mean DBH of 8.6 ± 0.4 cm in section 3 compared to 8.05 ± 0.46 cm in 1A (based on 2019 permanent monitoring point data).

Growth differences between the substrates is more pronounced in the direct seeded areas of the TLF, with lower mean plant height in the waste rock section. Plant DBH is also lower in the waste rock, with a mean DBH of 6.11 ± 0.8 cm in 1B compared to 7.73 ± 0.92 cm in section 2 (based on 2019 permanent monitoring point data). The considerable differences in growth between the two direct seeded areas are likely due (at least partially), to a greater proportion of taller species in section 2 (Gellert 2013). It is also possible that the TLF's mean plant height and DBH has been somewhat skewed towards larger plants in the laterite mix areas (particularly the direct seeded section), considering a greater proportion of smaller plants died in the 2016 burn conducted on those areas (discussed in Section ESR8).



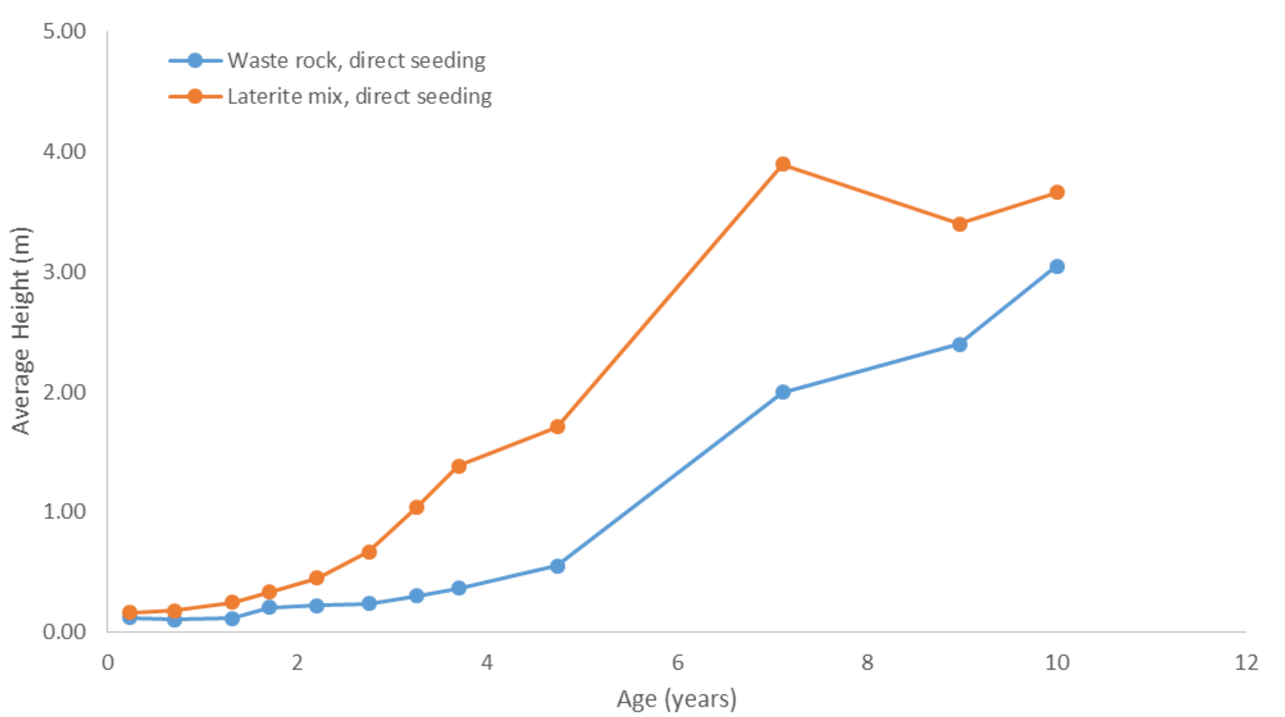


Figure 5-107: Longitudinal plant growth (height) based on the tubestock only (0 -14) and direct seeding only (15 – 29) Permanent Monitoring Plots on the TLF, not including recruits

Flowering, fruiting and self-recruitment

Of the 40 overstorey/midstorey species that were introduced on the TLF between 2009 and 2011 and are still present today, 37 have flowered and fruited at least once since September 2018 (when regular walk-through monitoring began, see Section 10). Over half of the species have flowered and fruited in every section that they are still present, including the majority of *Corymbia* and *Eucalyptus* (Table 5-50, Figure 5-80). The three species that have not flowered and fruited at all include *Gardenia megasperma*, *O. vernicosa* and *Pandanus spiralis*, which have grown very slowly (most <1 m) and are generally still too small to flower and fruit.

Over three-quarters of the overstorey/midstorey species on the TLF have self-recruited, either via seed and/or vegetative reproduction (suckering). Although the majority of the overstorey/midstorey species have had at least one observed instance of self-recruitment, most seedlings survive for a few months before disappearing, typically towards the end of the dry season. Only nine of the TLF species, many of which began self-recruiting within five years (Gellert 2014), have obvious recruits that have survived for over twelve months.

The species with the greatest levels of self-recruitment are *Acacia hemignosta* and *Cochlospermum fraseri*. It appears that *C. fraseri* in particular is very suitably adapted for the waste rock only substrate, with almost one hundred recruits greater than 1.5 m in section 1A (Parry 2019 unpublished data). Not only does this significant level of recruitment contribute to 1A's high stem density, it also skews the section's species composition, which Gellert (2014) predicted may occur. It appears that the head-start the species received being tubestock planted rather than direct-seeded, combined with the rocky substrate, allowed *C. fraseri* to thrive and aggressively recruit.

Fire also appears to be an important factor influencing self-recruitment. *E. tetrodonta* and *W. saligna* in particularly have considerably more recruitment in the laterite mix sections compared to the waste-rock only sections, with the recruitment being almost entirely through vegetative reproduction (suckers) in section 2 and 3, compared with mostly seed in sections 1A and 1B.

Overall, section 1A has had the greatest number of species self-recruit. This section has also had the most species fruiting and the highest density of shrubs and trees, therefore more individuals to potentially drop seed and recruit. Section 1A also has greater canopy cover and ground litter than the other sections of the TLF; although in natural systems shade and litter may impede recruitment, it is possible that on the harsh conditions of the TLF they provide a beneficial microclimate for early seedling establishment (Parry et al 2022). Lastly, section 1A has never had a dense weedy groundcover, unlike sections 2 and 3, which can outcompete young emerging recruits.

Table 5-50: Flowering, fruiting and self-recruitment of tree, shrub and palm species present on the TLF

Species	Flowering and Fruiting	Self-recruiting
Acacia dimidiata	At least 1 section	At least 1 section
Acacia hemignosta	All sections species is present	All sections species is present
Acacia latescens	All sections species is present	All sections species is present
Acacia mimula	At least 1 section	At least 1 section
Asteromyrtus symphyocarpa	All sections species is present	Not observed
Brachychiton diversifolius	At least 1 section	Not observed
Brachychiton megaphyllus	All sections species is present	At least 1 section
Buchanania obovata	All sections species is present	All sections species is present
Cochlospermum fraseri	All sections species is present	All sections species is present
Corymbia bleeseri	All sections species is present	At least 1 section
Corymbia disjuncta	All sections species is present	At least 1 section
Corymbia dunlopiana	All sections species is present	At least 1 section
Corymbia foelscheana	All sections species is present	At least 1 section
Corymbia latifolia	All sections species is present	At least 1 section
Corymbia polysciada	All sections species is present	All sections species is present
Corymbia porrecta	All sections species is present	At least 1 section
Eucalyptus miniata	All sections species is present	All sections species is present
Eucalyptus phoenicea	All sections species is present	At least 1 section
Eucalyptus tectifica	All sections species is present	At least 1 section
Eucalyptus tetrodonta	All sections species is present	All sections species is present
Eucalyptus tintinnans	All sections species is present	At least 1 section
Gardenia megasperma	Not observed	Not observed
Grevillea decurrens	All sections species is present	At least 1 section
Grevillea pteridifolia	All sections species is present	At least 1 section
Hakea arborescens	All sections species is present	At least 1 section
Jacksonia dilatata	All sections species is present	Not observed
Livistona humilis	At least 1 section	At least 1 section
Livistona inermis	At least 1 section	At least 1 section
Melaleuca viridiflora	All sections species is present	All sections species is present
Owenia vernicosa	Not observed	Not observed
Pandanus spiralis	Not observed	Not observed
Petalostigma pubescens	At least 1 section	All sections species is present
Planchonia careya	All sections species is present	At least 1 section
Syzygium eucalyptoides	At least 1 section	At least 1 section

Species	Flowering and Fruiting	Self-recruiting
ssp. bleeseri		
Syzygium eucalyptoides ssp. eucalyptoides	At least 1 section	Not observed
Syzygium suborbiculare	At least 1 section	At least 1 section
Terminalia carpentariae	All sections species is present	At least 1 section
Terminalia ferdinandiana	All sections species is present	All sections species is present
Wrightia saligna	All sections species is present	All sections species is present
Xanthostemon paradoxus	At least 1 section	Not observed

Figure 5-108: Flowering and fruiting on the Trial Landform. Top left to bottom right: *Brachychiton megaphyllus, Jacksonia dilatata, Eucalyptus tectifica, Cochlospermum fraseri*

Understorey species

Between September 2018 and August 2022 there have been approximately 100 native understorey species observed on the TLF. Over the almost four-year period of regular monitoring, 84 species were observed on Section 1A, 51 species on 1B, 36 species on section 2 and 28 species on section 3. This diversity is predominately driven by natural colonisation, with some species introduced via tubestock planting and/or direct seeding.

Direct seeding

All attempts at direct seeding grasses on the TLF in the first few years following construction were ultimately unsuccessful. The grass trials either had minimal seed germination (Gellert 2014), or when germination did occur, seedlings failed to recruit and persist for longer than a year (Gellert 2012b). It's likely that irrigation and/or fertiliser would have improved the outcome of these trials. The 2012/2013 wet season was particularly dry and warm, with 21% less rainfall than normal and December - February being in the 95th temperature percentile (December 2012 the hottest on record) (Jabiru Airport, Bureau of Meteorology). During a 1993 directly-seeded grass trial, some native understorey cover was able to establish and persist on an old waste rock dump capsite (Gray & Ashwath 1994). However, multiple factors likely contributed to this trial's success, including:

- A favourable study site – the trial was conducted on a 'substantially weathered' section of the dump located below the upper level batter slope. The site was ripped and graded, and each plot was raked to remove as many rocks with a >20cm diameter as possible.
- Irrigation – substantial irrigation was provided throughout the first few months of the trial.
- Favourable microsite conditions – shade cloths were secured over the experimental plots during germination and early establishment of the seedlings (for up to two months). This was to protect against seed loss from wind, but it also would have provided shade, which likely reduced irradiance, surface temperatures and soil water evaporation.

Direct seeding on the TLF has been somewhat more successful in recent years. In the 2018 section 1A trial, mean emergence from germinable seed ranged from 0 – 19 % for all species with the exception of *Galactica tenuiflora* in the surface litter treatment, which had 46 % emergence from germinable seed (Parry et al 2022). All the species had greatest emergence and number of surviving seedlings in the surface litter treatments, likely because the litter improved the seedlings microclimate by retaining water and reducing surface temperature. The surface litter may also have protected the seeds/seedlings from rain wash or uprooting, and predation. A corresponding shade house trial was also conducted in 2018; interestingly, treatments with fertiliser were the most successful in terms of growth and onset of flowering and fruiting. This suggested that under well-watered shade house conditions, waste rock nutrient deficiency was the factor limiting understorey establishment (Parry et al 2022).

The TLF direct seeded plants experienced considerable mortality during the first build-up after irrigation was stopped, however generally, seedlings that survived until the end of the following wet season have since persisted with most having low levels of self-recruitment. The best performing direct seeded plots had fertiliser, surface litter, or a combination treatment (Figure 5-109). One exceptionally successful plot was *G. tenuiflora* in a combination treatment. What likely contributed to the success was a large Acacia being blown over the plot, which provided shade and pinned down the surface litter that had been applied so that it did not get washed away. The *G. tenuiflora* stems have regrow with more vigour each year, and in 2022, over 28 self-recruits were observed within 2 m of the original plot.

The same species were also direct seeded without any amelioration treatments (controls) on section 1B in 2018, which was considerably more open than 1A with virtually no canopy. However, there was minimal germination with no seedlings surviving after a few months.

Figure 5-109: Directly seeded *Galactica tenuiflora* in a mixed treatment plot with fallen tree, March 2022

During a rainy period in February 2020, twelve understorey species from different genera were direct seeded in section 1A without irrigation; they were sown onto areas where organic matter/humus was naturally present, as well as bare areas (TLF Research and Monitoring Plan 2020 - 2026). All species had seed that germinated within a year of sowing; however, five species had very low germination (<5 seedlings total) and two of the species failed to persist after the first year. The most successful species have been *Cymbopogon bombycinus* and *Heteropogon triticeus*, which both had greater germination in the bare plots but larger, more vigorous seedlings in the organic matter plots (

Figure 5-110). Also interestingly, the grasses in the organic matter plots began flowering and fruiting in 2022, whereas the grasses in the 'bare' plots are yet to reach that maturity. It should be noted that many plots that were considered 'bare' in February 2020 had accumulated some litter within two months of sowing.


Figure 5-110: Directly seeded *Heteropogon triticeus* in an 'organic matter' plot in February 2021 (left) and March 2022 (right)

Tubestock planting

As part of the 2018 understorey trial, the same five species were also tubestock planted on sections 1A and 2. Tubestock planting overall was considerably more successful that direct seeding, resulting in a great number of larger, more robust seedlings (Parry et al 2022). Most seedlings that survived until the first wet season have persisted over the last four years. All three grasses began self-recruiting within the first year, with many plots now having three generations of recruitment that has spread over 10 m away from the original planted plots (Parry 2022 unpublished data). Successful self-recruit of the two legume species was observed during surveys in March 2021, with considerably higher levels evident in March 2022. In January 2019, plants from the 2018 shade house trial were planted in 'islands' on sections 1A and 1B and are still thriving three years later (Figure 5-111).

Figure 5-111: Understorey 'island' on section 1A of the TLF

Species colonisation

Native colonisation from external sources has been closely monitored on the TLF since September 2018. During this time, close to 100 native species have been observed to colonise, with approximately 80 identified to a genus level and 48 to a species level. Nine of these species are overstorey and midstorey species, five of which colonised many years ago and are now several metres tall (including *Acacia difficilis, A. oncinocarpa, Alstonia actinophylla, Ficus racemosa and Lophostemon lactifluus*). Understorey species with the greatest abundance include *Blumea, tenellula, Boerhavia coccinea*, *Brachyachne convergens*, *Crotalaria brevis, Ectrosia leporina, Eragrostis sp.*, *Indigofera linifolia, Phyllanthus sp., Sporobolus australasicus* and *Tacca leontopetaloides*. Much of the understorey diversity, particularly in 1A, comes from annual grasses, sedges and herbs, however an increasing number of perennial species are also appearing.

Section 1A has had considerably greater diversity than the other sections (Figure 5-112). Over the four-year monitoring period, a total of 82 species colonised 1A compared to 46 on 1B, 38 on section 2 and 31 on section 3. This is likely due to a more favourable microclimate for seed germination at 1A (increased shade and organic matter) and the section having minimal weedy groundcover (therefore more open area, less competition, and requiring minimal herbicide application).

The rate of recruitment has generally increased on all sections over the four years of monitoring, with seasonal fluctuations. This would support the theory that species richness, particularly the understorey, will increase over time as the ecosystem develops (e.g. soil formation, nutrient cycling, overstorey canopy etc). Section 1A has consistently had the highest levels of colonised species richness over the four-year period; however, the other waste-rock only section,1B, has also shown an increase in the number of species recruiting, particularly over the last two years as the diversity becomes increasingly similar to that seen at 1A. Interestingly, the levels reached in 1B in the wet season of 2021 are similar to the levels reached in 1A during the wet season of 2019. The roughly two-year delay in colonisation between the two sections likely stems from 1B being initially tubestock planted rather than direct-seeded, with follow-up tubestock infilling two years later. The two laterite mix sections' rate of native colonisation is also increasing, however more slowly than the waste rock only sections.

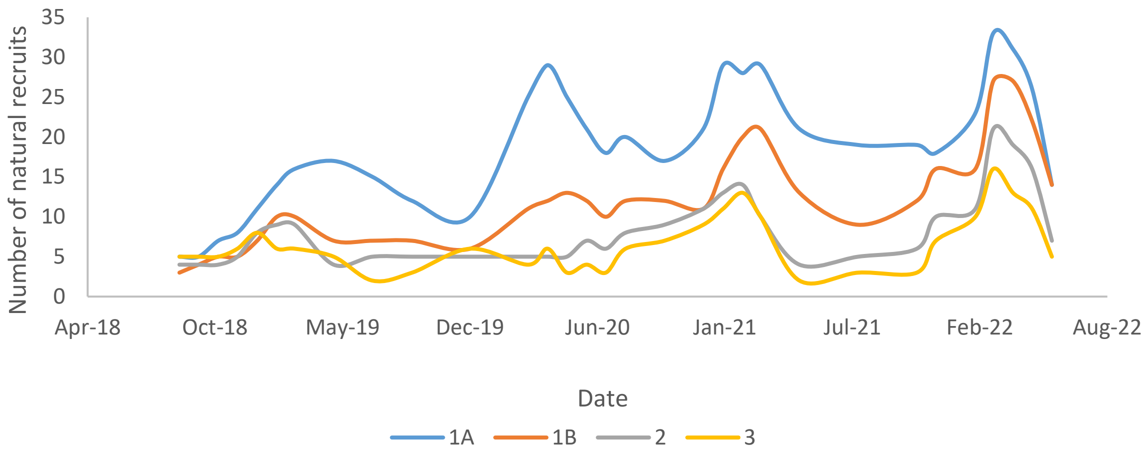


Figure 5-112: Rate of native understorey species naturally colonising the TLF since September 2018

Figure 5-113: Natural colonisation of species, including multiple *Brachychiton megaphyllus, Livistona sp.,* and *Tacca leontopetaloides* individuals underneath a large tree on Section 1A, February 2021.

Stage 13.1

Stage 13.1 Areas A and B have served as pilot studies for the large-scale Pit 1 revegetation trials (Figure 5-114). A key learning from this area has been that ‘finer’ waste rock exists underneath certain stockpiles, and that careful substrate preparation is needed to avoid significant depressions. In areas where depressions and saturated substrate may be unavoidable, it could be strategic to introduce more ‘waterlogging-tolerant’ species, such as Melaleuca and Pandanus. In addition, appropriate weed management is critical throughout the revegetation execution process, including pre-emergent herbicide prior to planting, and consistent follow-up management during the initial plant establishment phase.

Figure 5-114: Stage 13.1 revegetation. Research trial area A (0.52 ha) planted in April 2020, research trial area B (1.18 ha) planted in November 2020, and progressive revegetation area C (2.37) planted in August 2021 and infill planted January 2022.

Survival and Establishment

Stage 13.1A was planted in April 2020. Unfortunately, tubestock health was not optimal at the time of planting due to a nursery irrigation failure incident at the end of 2019 and unanticipated planting delays due to the COVID-19 pandemic. Despite this, seedlings had reasonable survival during the first few weeks. After two months mean survival was 89.9 ± 1.4% then over the following four months it slowly dropped further and appeared to stabilise around 70%. However, in the eight months that followed, at 14 months post-planting, survival was down to 56 ± 2.8 %. Much of this mortality appeared to occur during the first few months of the wet season, when areas of the substrate became waterlogged for extended periods of time. Many E. miniata and E. phonecia in particular appeared to be impacted by saturated substrate; after closer inspection of standing dead or dying individuals, the roots appeared to be 'rotting' in anerobic conditions (Figure 5-115). One year later, at 25 months post-planting, survival appeared to have again stabilised at 52 ± 2.8 %.

Overall, six of the twenty-two planted species in Area A had a survival less than 40 % and two species had a survival less than 20 % (Figure 5-116). The poorest performing tree species, E. phoenicea, is naturally found on sandstone escarpments and rocky rises which are generally well drained habitats unlike the finer saturation prone substate seen at Stage 13.1. Although some species experienced high mortality, none of the species planted at Area A completely failed to establish.

Some species have performed well in Area A, such as *M. viridiflora* and *H. triticeus* which had greater than 85 % survival at 25 months post-planting. It is unsurprising that *M. viridiflora* has been the overstorey/midstorey species with the greatest survival, as this species naturally grows in a wide range of seasonally flooded habitats and hence is not sensitive to ‘wet feet’.

Figure 5-115: Dead *Eucalyptus* in saturated substrate at Stage 13.1A

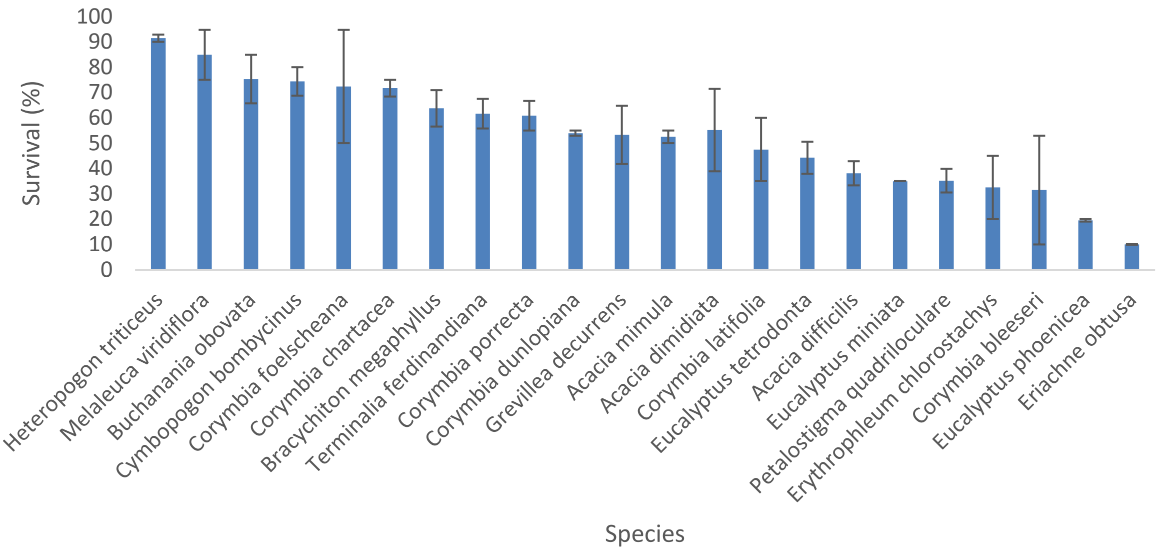


Figure 5-116 Average species survival on Stage 13.1 Area A after 25 months.

Area A also investigated seven different propagation and planting methods with the aim of optimising plant survival and establishment (see Table 5-46 in the propagation section above). All seven treatments were trialled on three species, *E. tetrodonta, Terminalia ferdinandiana* and *Petalostigma quadriloculare*. Four of these treatments were trialled on an additional three species, *Brachychiton megaphyllus*, *Buchanania obovata* and *Grevillea decurrens,* and the final two treatments (puffball and combination microbe) were trialled on all species. Unfortunately, due to COVID-19 staffing issues in April 2020 when planting was performed the treatments were not properly randomised. This should be taken into account when interpreting the effect of treatment on seedling performance.

When comparing the survival of the three species with the full treatment suite, the plastic pot method produced the best average survival (65 ± 9.4 %) (Figure 5-117). The poorest performing treatment was the commercial-only microbe treatment with an average survival of 34 ± 5.2 %.The plastic pot method was also generally most successful for the species that were trialled with four treatments, achieving an average survival of 71 ± 9 % compared to the other three treatments which all achieved an average survival of around 50% (Figure 5-118). The plastic pot method obtained the greatest survival for four of the six species.

It is still unclear from the species only trialled with the two treatments whether solely native microbes or a combination of native and combination microbes are optimal for species establishment. Half of the species had better survival with the puffball treatment and the other half with the combination microbe treatment (two species had equal survival) (Figure 5-119). Although species with the puffball treatment generally had a higher survival, this could be due to, at least in part, topography and location conditions rather than treatment. With the inappropriate level of randomisation in the field trial it will be difficult to determine actual treatment effects with the other confounding factors.

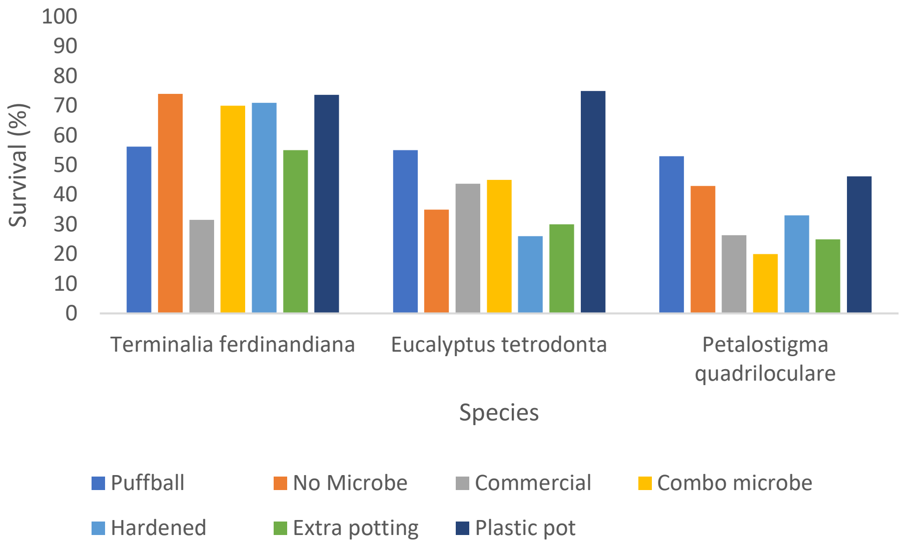


Figure 5-117 Species survival on Stage 13.1 Area A after 18 months for the full suite of treatments

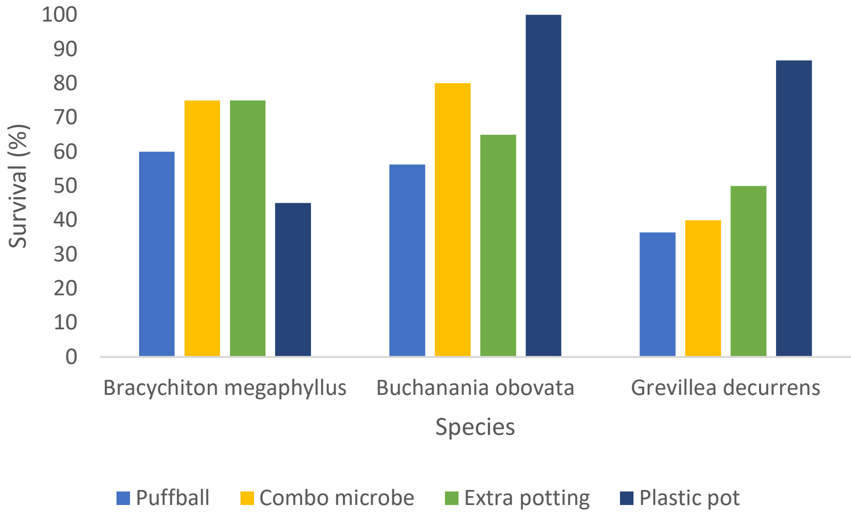


Figure 5-118 Species survival on Stage 13.1 Area A after 18 months for the partial suite of treatments

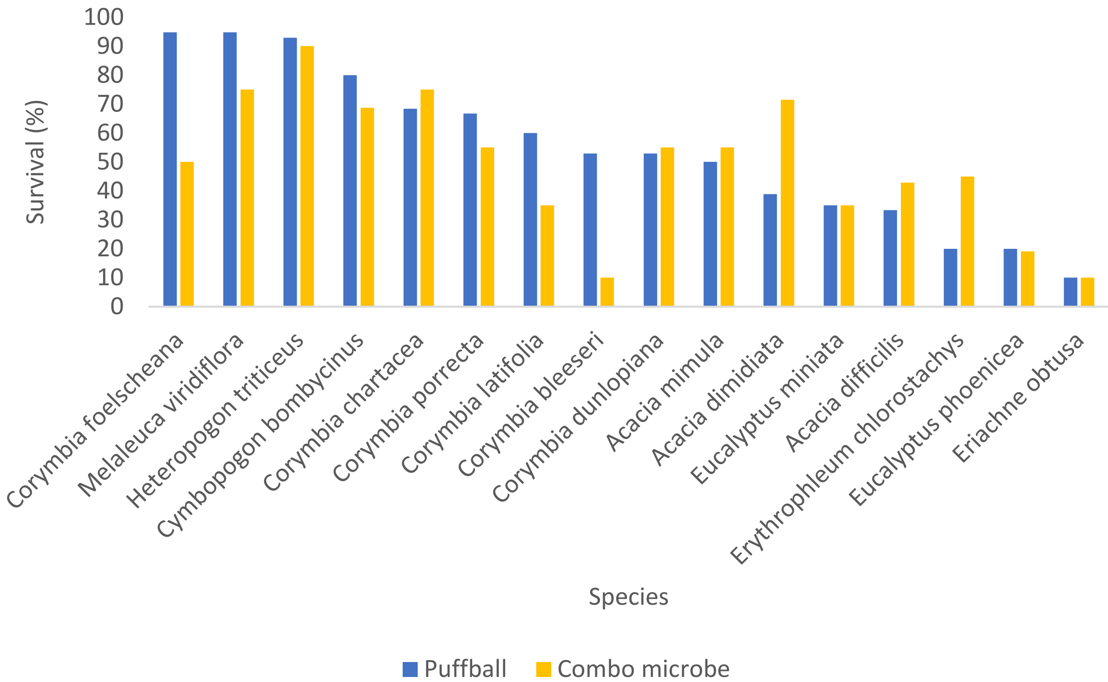


Figure 5-119 Species survival on Stage 13.1 Area A after 18 months with puffball and combination microbe treatments

Stage 13.1B was planted in November 2020. The seedlings were the first to be propagated at the ERA nursery during the dry season and as a result, some were small and/or stressed. That, combined with planting at the hottest time of the year, followed by heavy rainfall flooding and washing away seedlings or burying them in sediment, resulted in high initial mortality. After six months, mean survival was 64 ± 3.6 %. It again was apparent that surface conditions can have a significant impact on plant survival. The first four rows of Stage 13.1B only had 36 % survival compared to 68 % in the remaining area (Figure 5-120 and Figure

5-121); this dramatic difference is likely due to the significant depressions and water pooling present in that section, where waterlogged plants appeared to 'cook' in a manner of days during a warm period in January. Over the following 12 months survival dropped only slightly to 61 ± 3.5 % at 12 months post planting and then again to 58 ± 3.5 % at 18 months post planting, slightly higher than the survival in Area A at a similar age.

Three species had a survival less than 20% including Acacia dimidiata and Haemodorum coccineum and one species, Stenocarpus acacioides, failed to establish (Figure 5-121). Like the poorer performing species in Area A, it appears that the finer substrate found at Stage 13.1 is not well enough drained for Stenocarpus acacioides which generally grows on rocky soils. Despite the challenges, several species have performed well in Area B. Overall, 22 % of the planted species had a survival greater than 80 % and 4 species had 100 % survival; these were Corymbia polysciada, M. viridiflora, Acacia gonocarpa and H. triticeus, noting that only two individuals were planted for A. gonocarpa and four for C. polysciada.

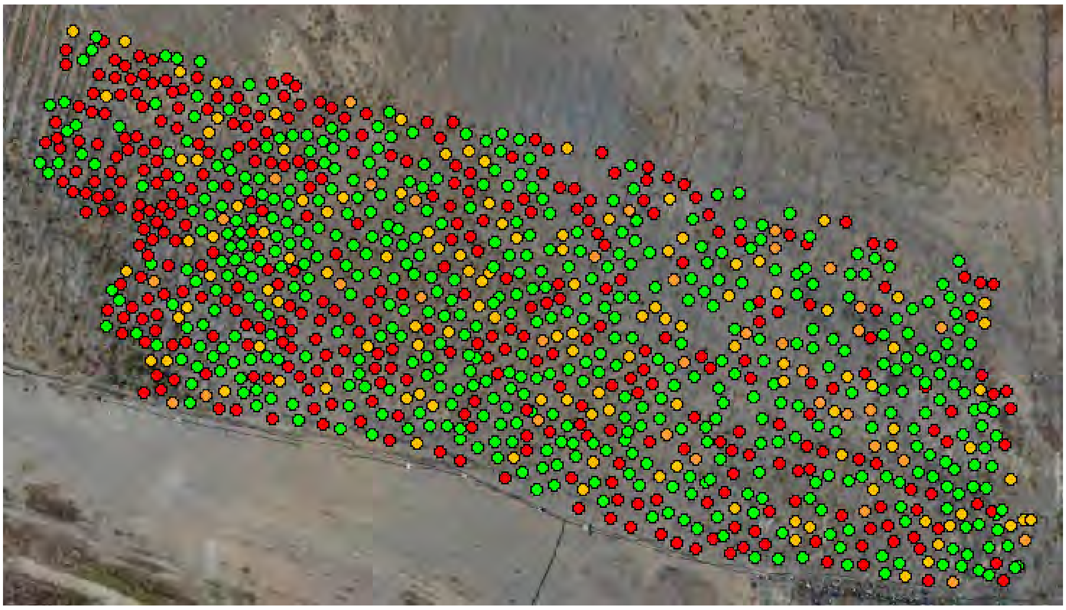


Figure 5-120: Seedling survival and health at Stage 13.1B at six months after planting when substrate impacts became apparent. Green is an alive seedling, yellow is a stressed seedling, and red is a seedling that appeared dead.

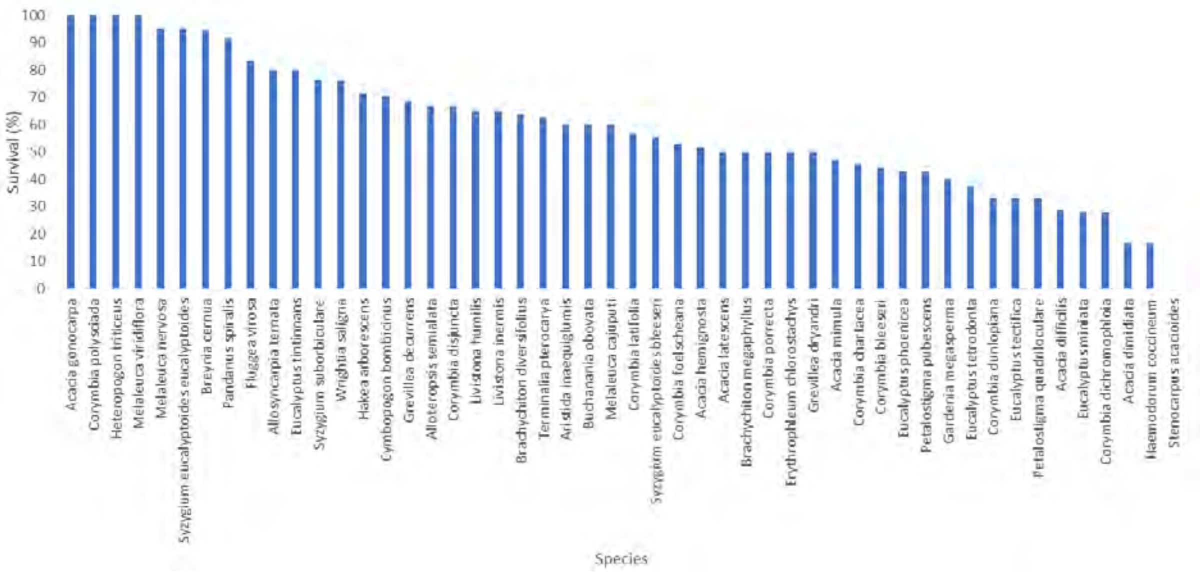


Figure 5-121: Overall species survival on Stage 13.1 Area B after 18-months

Stem Density

Stem density on Stage 13.1 differs greatly between Area A and Area B, predominantly due to the significantly higher initial planting density in Area A. The seedlings were planted at approximately twice the standard planting density due to issues in surface preparation and a smaller than anticipated area being suitable for planting at that time. As Stage 13.1 was a pilot study for Pit 1 with the main focus being on initial seedling establishment, it was decided that the trial go ahead, noting that competition issues will likely become apparent as the seedlings mature.

As of May 2022, Area A still had a considerably higher stem density than Area B, despite also experiencing higher mortality (Figure 5-122). The stem density of all midstorey and overstorey species regardless of height at Area A was 1015 stems/ha-1, more than double Area B's density of 413 stems/ha-1 (Table 5-51). For stems over 1.5 m, the density is more similar between the areas with Area A at 425 stems/ha-1 compared to Area B at 341 stems/ha-1 (Table 5-51).

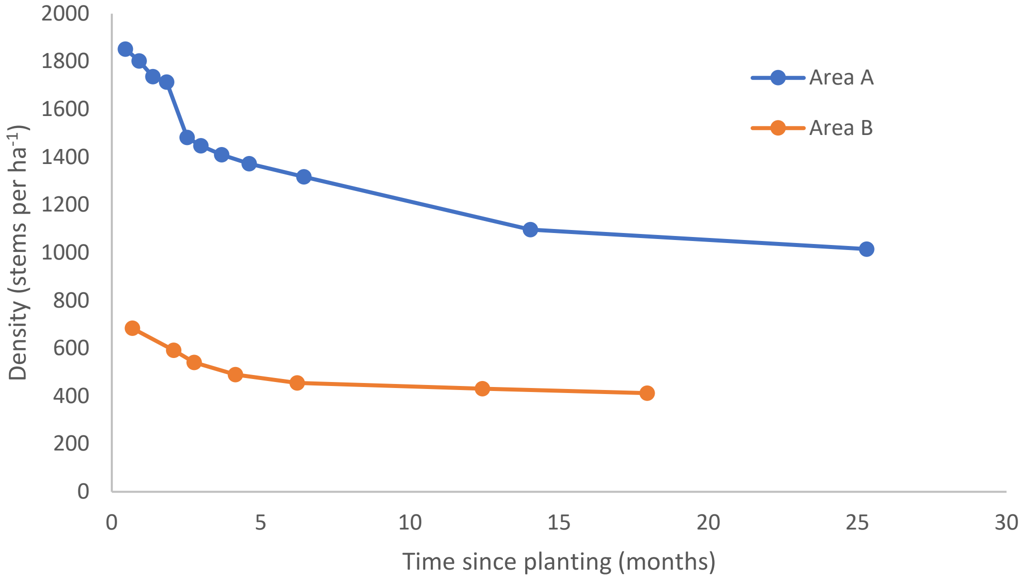


Figure 5-122: Plant density (stems per ha^{-1}) based on all midstorey and overstorey individuals on Stage 13.1 Area A and B regardless of height, not including recruits.

Table 5-51: Total overstory and midstory stems on Stage 13.1, excluding recruits.

	Total # of individuals	Stems per hectare	Total # of individuals >1.5 m	Stems >1.5 m per hectare
Area A	528	1015	221	425
Area B	487	413	403	341

Plant Growth

Despite the challenging conditions at Stage 13.1 the seedlings on Area A had a mean height of 47 cm at six months post planting. Over the next year and a half, the seedlings grew at an approximate rate of 55 cm per year, reaching a mean height of 133 cm at 25 months post planting. In comparison, the TLF had a slightly higher average plant growth rate of 60 cm per year in the first 5 years post planting, however, this rate was not linear over the 5-year timeframe and the species composition at TLF differs to Stage13.1.

At Area B the mean growth in the first 6 months was similar to Area A, reaching a height of 45 cm. Over the next year, the mean growth increased to 93cm at 18 months post planting, slightly lower than the growth at Area A when it was the same age (Figure 5-125). Although, it should be noted that when comparing Area A and B the species composition varies (Table 1).

The species with the greatest growth at Area A was *E. phoenicea*, which had a mean height of 2.4 m at 25 months post planting. Species *Grevillea decurrens* and *E. tetrodonta* also performed well with both reaching mean heights over 2 m (Figure 5-123). The species with the least growth was *Erythrophleum chlorostachys* which had a mean height of only 40 cm.

At Area B, *E. tintinnans* grew fastest reaching a mean height of 2.2 m at 18 months post planting (Figure 5-124). Like in Area A, *E. chlorostachys* was slow growing in Area B reaching a mean height of 30 cm. The sand palms, *Livistona humilis and L. inermis*, had the least growth, reaching 25 cm and 23 cm respectively. These three species are known to be slow growing

At both areas some Corymbia species had seedlings which appeared to be stunted in growth. At Area A, several *C. porrecta* and *C. latifolia* individuals were stunted and both species had average heights less than one metre. Stunted *C. porrecta* individuals were also observed at Area B.

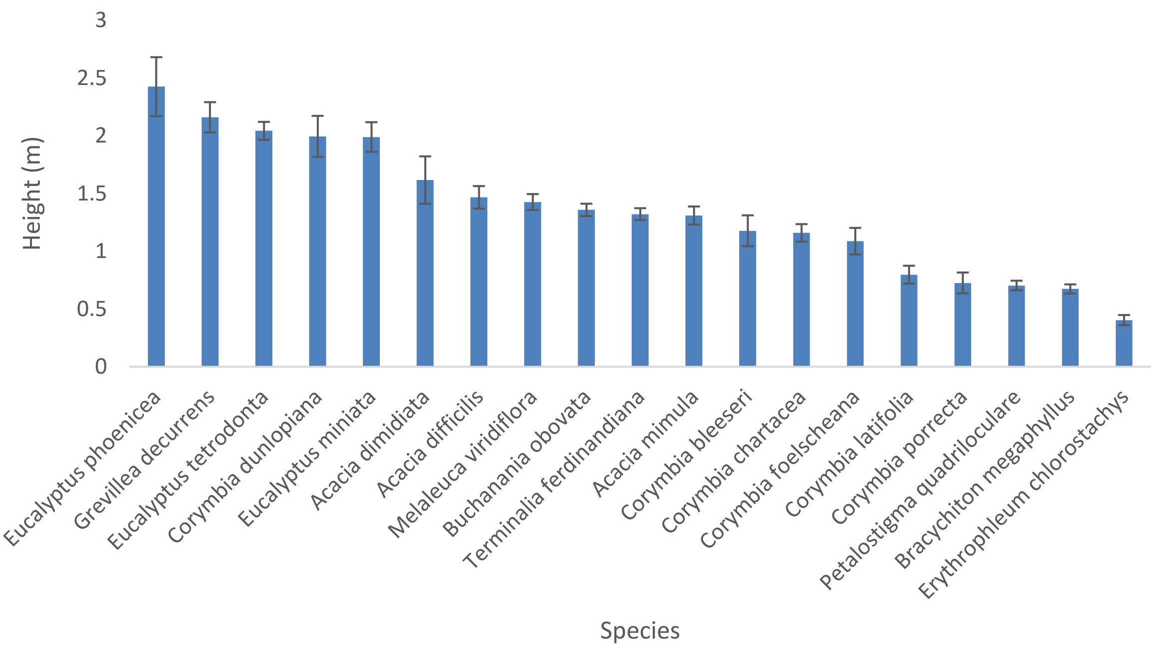


Figure 5-123: Species average height at Stage 13.1 Area A after two years

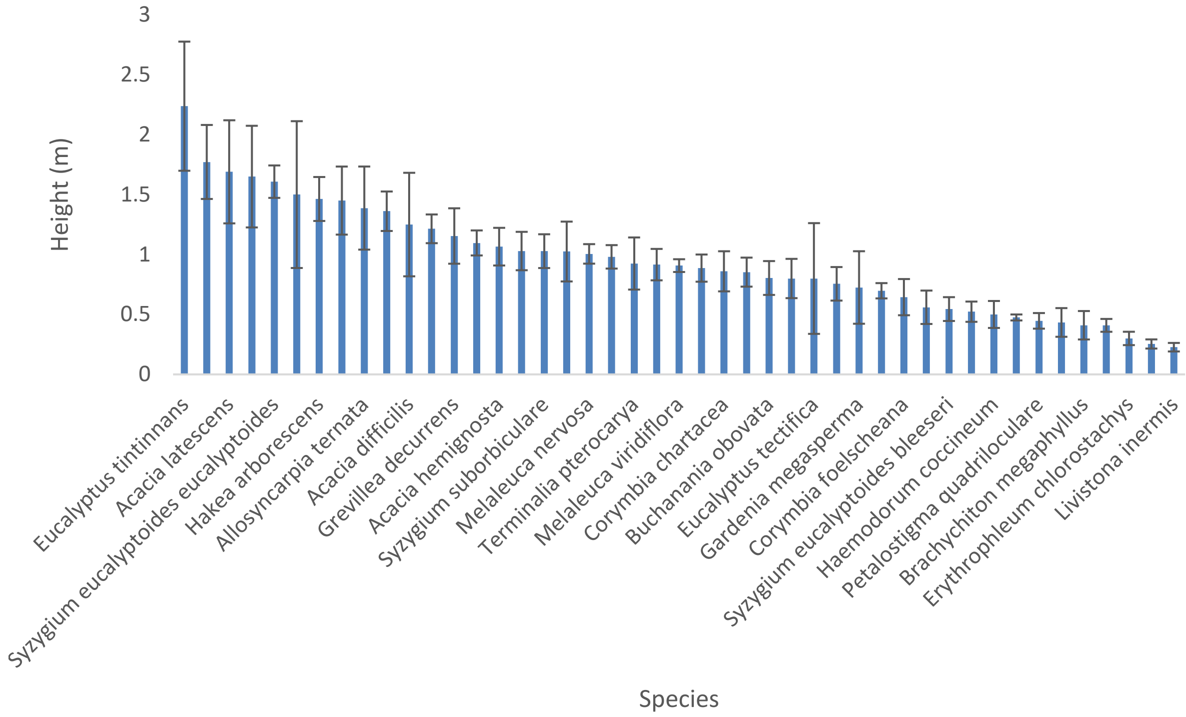


Figure 5-124: Species average height at Stage 13.1 Area B after 18-months

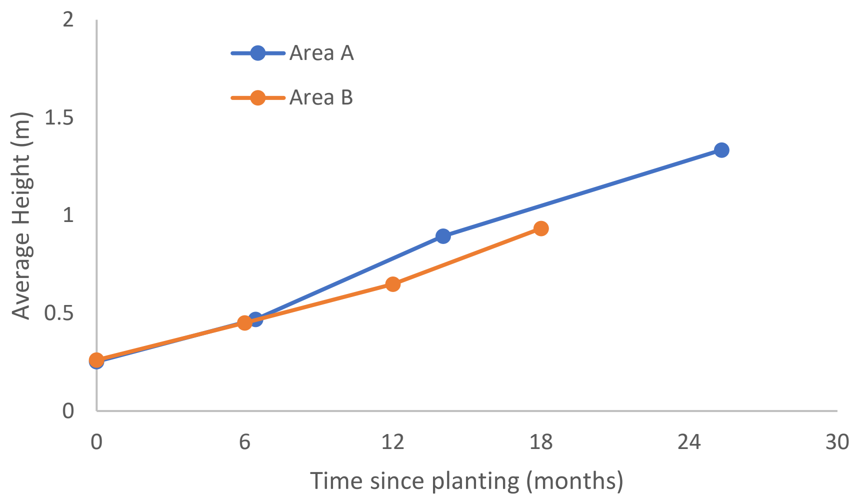


Figure 5-125: Plant growth at Stage 13.1 Areas A and B over two years.

Flowering, Fruiting and Self-recruitment

At Area A, 7 of the 22 species have been observed to flower and fruit in the two years since planting. All four understorey species have flowered and fruited as well as three midstorey species – *A. dimidiata*, *B. megaphyllus* and *G. decurrens*. At Area B, 10 of the 50 planted species have flowered and fruited in the 18 months since planting. This includes all understory species (excluding *Acacia gonocarpa*), and three midstorey species – *Acacia dimidiata*, *Flueggea virosa* and *Terminalia pterocarya*.

All four understory species have self-recruited at Area A. However, no self-recruitment has been observed at Area B. More species may have flowered, fruited and recruited on Stage 13.1 A and B since planting, however observations were only recorded during set monitoring times. It may be that the flowering and fruiting seasons of some species were outside of the periods that were monitored. It is also possible that species had seed germinate, but that the small recruits did not survive until the next scheduled survey. This is where monthly walkthrough monitoring, such as those performed at TLF, can be beneficial. Before the end of 2022 this type of monitoring program will be deployed at Stage 13.1 and Pit 1.

Species colonisation

In the two years since planting, 23 native species have been observed naturally colonising at Area A. The majority of these were understorey species, dominated by *B. convergens*, *E. leporina*, *S. australasicus* and including *B. coccineum*, *Eragrostis sp.*, *Oldanlandia sp.*, *Scoparia dulcis* and *U. reptans*. Three overstorey/midstorey species have also colonised the area, *C. fraseri*, *L. lactifluus* and *Melaleuca sp*.

At Area B, 16 native species have naturally colonised, including two overstorey/midstorey species – *B. megaphyllus* and *M. viridiflora*. Similar to Area A, the understory species are dominated by *E. leporina*, *S. dulcis* and *S. australasicus* followed by *B. convergens* and *Fimbristylis sp.*

Pit 1

Three research trial areas were established on Pit 1 in 2021 with the objectives of (ERA, 2021c):

- determining if revegetation can be performed all-year-round whilst minimising remediation actions required;
- determining specific methods and materials used for revegetation to optimise initial survival (first 2 years after planting); and
- gaining experience establishing species that have not been investigated previously.

Three variables were investigated; planting season (Wet, Dry and Build-up), seedling age (‘older’ and ‘younger’) and pot type (standard nursery tubes and biopot). Each research area was divided into three strata. The four treatments, older biopot, older plastic, younger biopot and younger plastic, were randomised into subplots within each stratum (Table 5-52). The rest of Pit 1 was progressively revegetated in May and December 2021, and January 2022.

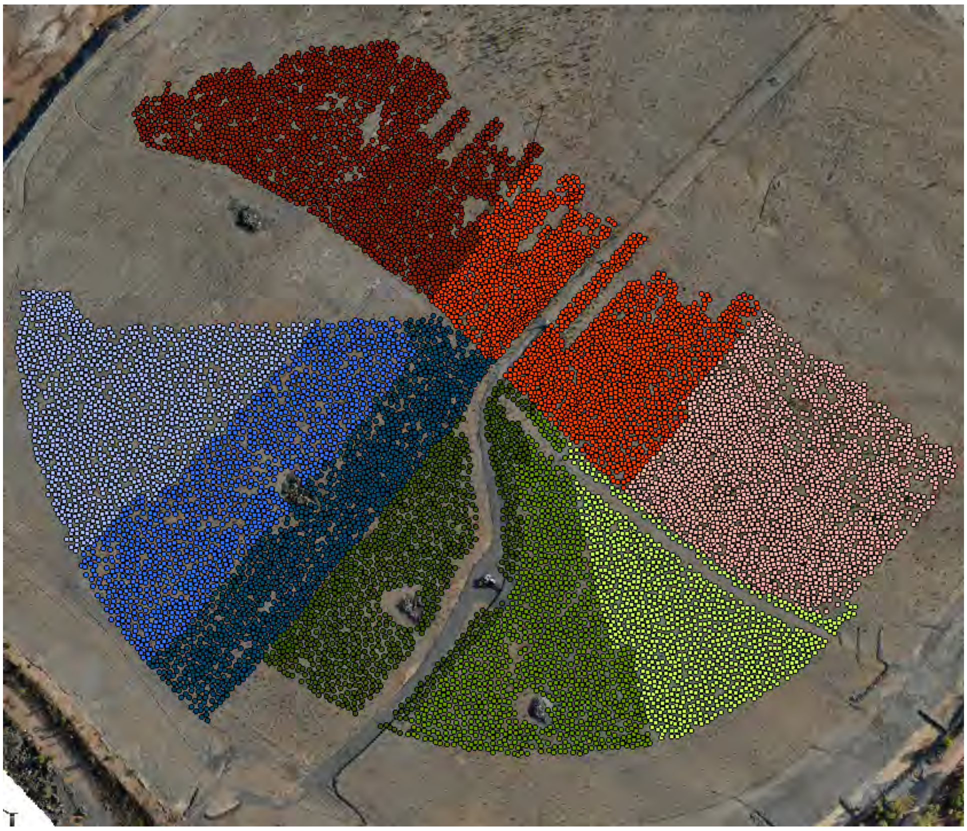


Figure 5-126: Pit 1 research areas: March 2021 'Wet season' planting (6.6 ha), July 2021 'Dry season' planting (3.8 ha) and October 2021 'Build-up' planting (3.1 ha)

Table 5-52: Overstorey/midstorey (OS) and understorey (US) species investigated in the Pit 1 research trials

Species	Strata	Mar	Jul	Oct	Species	Strata	Mar	Jul	Oct
Acacia dimidiata	OS			Y	*Erythrophleum chlorostachys*	OS	Y	Y	Y
Acacia gonocarpa	US	Y	Y	Y	*Eucalyptus miniata*	OS	Y	Y	Y
Acacia lamprocarpa	OS	Y	Y		*Eucalyptus phoenicea*	OS	Y	Y	Y
Acacia mimula	OS	Y	Y	Y	*Eucalyptus tectifica*	OS	Y	Y	Y
Acacia oncinocarpa	OS	Y		Y	*Eucalyptus tetrodonta*	OS	Y	Y	Y
Alloteropsis semialata	US	Y	Y		*Eucalyptus tintinnans*	OS	Y	Y	Y
Ampelocissus acetosa	US	Y			*Galactia tenuiflora*	US	Y		
Aristida holathera	US	Y			*Gardenia fucata*	OS	Y		
Austrodolichos errabundus	US	Y			*Gardenia megasperma*	OS	Y		
Banksia dentata	OS	Y			*Grevillea decurrens*	OS	Y	Y	Y
Brachychiton megaphyllus	OS	Y	Y	Y	*Haemodorum coccineum*	US	Y		

Species	Strata	Mar	Jul	Oct	Species	Strata	Mar	Jul	Oct
Buchanania obovata	OS	Y	Y	Y	*Heteropogon triticeus*	US	Y	Y	Y
Calytrix exstipulata	OS	Y			*Indigofera saxicola*	US	Y		
Cartonema spicatum	US	Y			*Livistona humilis*	OS	Y	Y	Y
Cayratia trifolia	US	Y			*Livistona inermis*	OS	Y		
Chrysopogon latifolius	US	Y	Y	Y	*Melaleuca viridiflora*	OS	Y		
Cochlospermum fraseri	OS	Y			*Petalostigma quadriloculare*	US	Y	Y	Y
Corymbia bleeseri	OS	Y	Y	Y	*Planchonia careya*	OS	Y	Y	Y
Corymbia chartacea	OS	Y	Y	Y	*Stenocarpus acacioides*	OS	Y		
Corymbia disjuncta	OS	Y			*Syzygium eucalyptoides ssp. bleeseri*	OS	Y	Y	
Corymbia dunlopiana	OS	Y			*Templetonia hookeri*	OS	Y		
Corymbia foelscheana	OS	Y		Y	*Tephrosia subpectinata*	US	Y	Y	
Corymbia polysciada	OS	Y			*Terminalia ferdinandiana*	OS	Y	Y	Y
Corymbia porrecta	OS	Y	Y	Y	*Terminalia pterocarya*	OS	Y	Y	Y
Dolichandrone filiformis	OS	Y			*Uraria lagopodioides*	US	Y		
Eriachne obtusa	US	Y	Y	Y	Total		50	26	25

Overall survival

Pit 1 revegetation has been the most successful in recent Ranger history. Post-planting surveys performed in the immediate weeks following planting found overall tubestock survival rates of 99.1 %, 95.5 % and 93.3 % for the Wet, Dry and Build-up trials respectively (Figure CC). It was expected that the post-planting survival rates for the Dry and Build-up trials would be lower than the Wet season trials, as the seedlings were propagated and planted during more challenging times of year, either when plants are typically dormant or when temperatures are extremely high.

The first three months after planting is when highest mortality is typically experienced as seedlings overcome initial planting shock and begin establishing in the waste rock. Overall survival dropped by 14.9 %, 17.9 % and 12.7 % for the Wet, Dry and Build-up respectively during this time. It is unsurprising that the Dry season seedlings experienced the highest mortality, considering they were planted whilst relatively dormant then spent the next three months heading into harsh build-up conditions.

At the six-month survey, overall survival for the Dry and Build-up trial areas remained at similar levels to the three-month survey. The Dry trial survival dropped 3.1 %, sitting at 74.6 %, and the Build-up trial survival dropped 2.1 %, sitting at 78.5 %. The Wet season trial area had higher mortality at the six-month survey, with survival dropping an additional 8.0 % between June 2021 and November 2021, sitting at 76.2 %. As discussed, this is the harshest time of year. Comparatively, at similar timeframes post-planting, Stage 13.1A and Stage 13.1B had 66.9 % and 62.1 % overall survival respectively Figure (CC).

At 12-months post-planting, the Wet season trial overall survival reached 70.6 %; the Stage 13.1 trials at similar ages were at 55.4 % and 58.6 % for Area A and B respectively (Figure 5-127). It is expected that Pit 1 research trials' mortality rate will reduce and generally stabilise during the second year post-planting, as has been observed in Stage 13.1A and 13.1B (Figure 5-122).

It should be noted that it is not necessarily meaningful to compare the overall survival of the five research areas, particularly between Pit 1 and Stage 13.1, because the treatments and species compositions are very different.

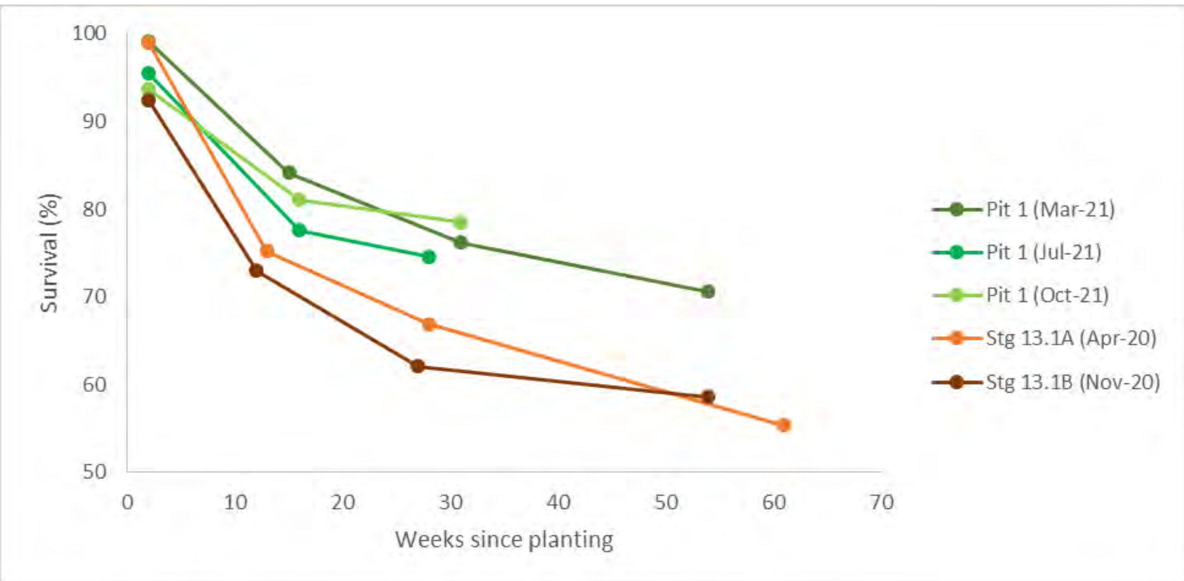


Figure 5-127: Overall tubestock survival of the research trial areas on Pit 1 and Stage 13.1 within approximately one year of planting

Location was found to impact tubestock mortality on Pit 1. Most notably, high mortality was experienced around a large depression in the Wet season trial area (Figure 5-128). During planting, obvious depressions were avoided as it has been established from previous revegetation experience that many of the savanna woodland species do not tolerate any waterlogging. However, as the Pit was still experiencing subsidence from waste rock infill, the area of depression continued to develop a few months after planting. This resulted in seedlings that were planted around the original depression to become waterlogged. This sort of subsidence issue will be unavoidable for large, infilled sections of the FLF, and will likely also occur in some areas on Pit 3. Management options for depressions will be to 1) not plant directly into an obvious depression, 2) avoid planting waterlogging-intolerant species around the edge of depressions, then 3) introduce waterlogging-tolerant species (such as *Pandanus*) into the area in the following wet season once subsidence has stabilised and the extent of the depression is understood. It is possible that there are more factors influencing the high mortality in that specific area of the Wet season trial, for example high levels of surface salts. Substrate testing will be conducted to investigate this possibility further.

There is no obvious topography or location impacts on tubestock survival for the Dry season trial area. Potentially there is a small effect in the Build-up trial area where there has been preferential water flow in the third strata. That area also did not receive a pre-emergent herbicide spray due to the planting area shape being changed prior to planting (due to damage to the pivot irrigation system the week earlier). Therefore, there could also be slightly higher mortality in that area due to small seedlings competing with weeds, which were visible in that section during the initial post-planting survey.

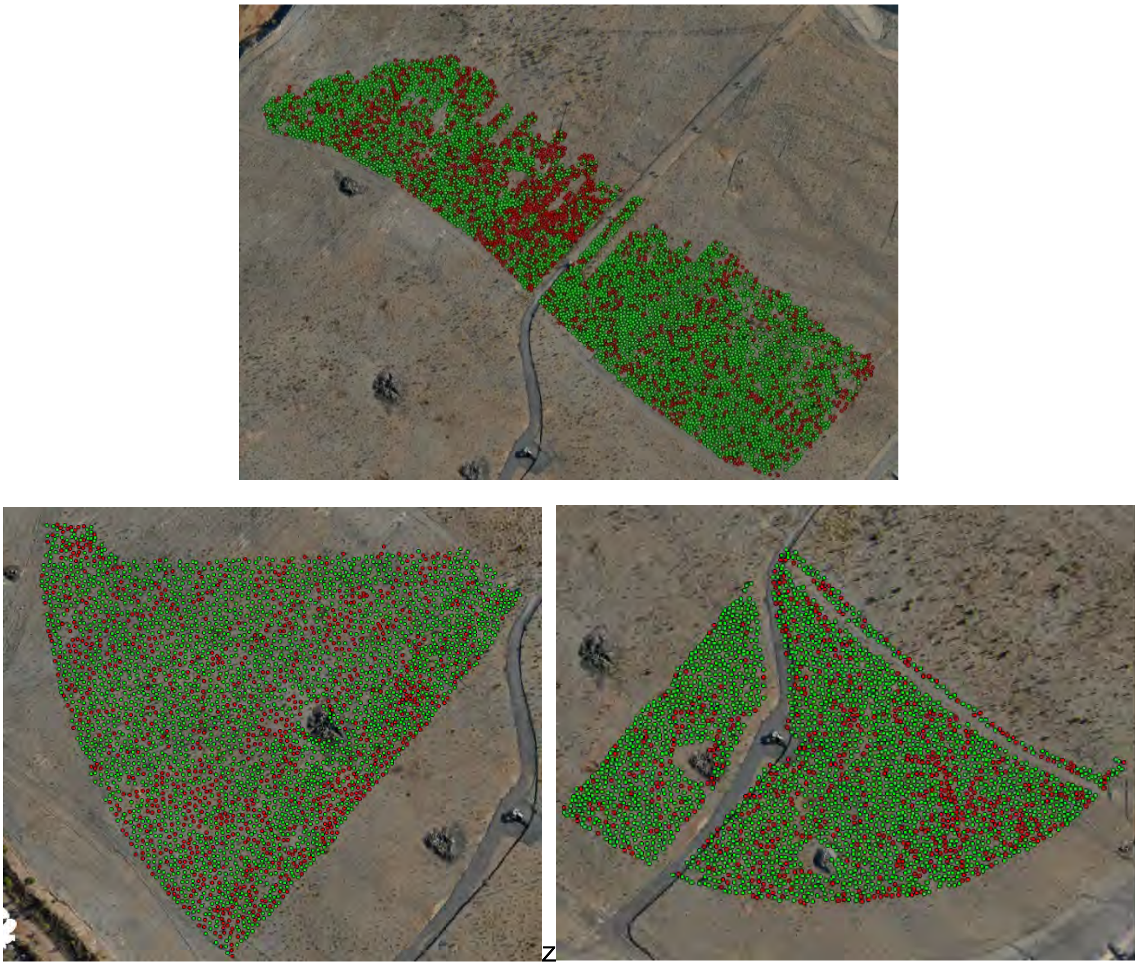


Figure 5-128: Survival maps at 12-months for the Wet season trial (Mar 2022, top), and 6-months for the Dry season trial (Feb 2022, left bottom) and Build-up trial (May 2022, right bottom). Green is an alive seedling and red is a seedling that appeared dead.

Five new midstorey species were tubestock planted for the first time in the Wet season trial area. Most of the species have established well, with the exception of *Banksia dentata* at 44 % survival. *Banksia* typically occur in moist or seasonally flooded low areas, so even this level of survival on waste rock substrate is unexpectedly high. It would not be surprising if this species fails to properly establish over the next few years due to dry conditions on the landform. *Banksia dentata* is a traditionally important species (Garde 2015, Fox & Garde 2018) so it is desirable that it be included in the revegetation of Ranger Mine. However, it may be that this species is only suitable for specific locations on the FLF, such as drainage areas.

Seven new understorey species were also tubestock planted for the first time in the Wet season trial area. Most of the species had above 60 % survival, exceptions being *Austrodolichos errabundus, Cartonema spicatum* and *Tephrosia subpectinata* (42 %, 11 % and 43 % respectively at 12-months post planting). *Tephrosia subpectinata* is a weak perennial species so the tubestock are expected to start senescing within the first year or two; encouragingly, many seedlings have already self-recruited, indicating that the introduction of the species can be self-sustaining. *Austrodolichus errabundus* has an annual stem and therefore may actually have higher survival than what was observed during the survey periods; this species has also successfully self-recruited. *Cartonema spicatum* has had very poor survival on Pit 1 (4 % in older biopots and 18 % in older plastic pots), possibly because it is not suited for the harsh, open conditions of initial revegetation. During a Cultural Reconnection Working Group visit, Traditional Owners suggested this species as well as *Haemodorum coccineum,* another understorey species that has had low survival in Ranger revegetation, should be planted in sandy areas with soft ground (*pers. Comm.* 30th June 2022). Preferential planting of these species in specific types of substrate will be explored in future revegetation.

Two 'perishable' fruited species, *P. careya* and *Syzygium eucalyptoides ssp. bleeseri* were held in the nursery over 2021, repotted as needed, and introduced in the unseasonal research trials as larger plants. Preliminary results show this method to be highly successful, with 98 % - 100 % survival of *P. careya* tubestock in the Dry and Build-up trial areas, and 96 % surival of *S. eucalyptoides ssp. bleeseri* in the Dry season trial (there were not enough available stock for this species to also be trialled in the Build-up). Being able to introduce these low density, but important species during initial revegetation instead in the following wet season when seed becomes available will help reduce infill requirements and reduce additional disturbance in a revegetated area.

Treatment effect on survival

Preliminary results suggest that for overstorey and midstorey species, plastic pots will generally result in similar or higher seedling survival than biopots. Out of the midstorey and overstorey species trialled with both types of pots, 28 of the 31 species in the Wet season trial (Figure 5-129 and Figure 5-130), 13 of the 16 species in the Dry season trial (Figure 5-131), and 17 of the 19 species in the Build-up trial (Figure 5-132), had the same or higher suvival in a plastic pot treatment. Almost all of the 'older biopot' seedlings were unable to be included in the Build-up revegetation trial due to their high mortality or poor condition after an irrigation failure incident in the nursery.

The effect of age on overstorey and midstorey seedling survival has been less clear. Out of the species trialled with different ages, the majority of the Wet season species had better survival with older plants (11 out of 15, Figure 5-130), whereas in the other two areas, younger plants generally had higher survival (12 out of 16 for the Dry trial, 12 out of 19 for the Build-up trial). Further investigation and data interrogation is needed to determine optimal seedling age for propagating and planting during different seasons.

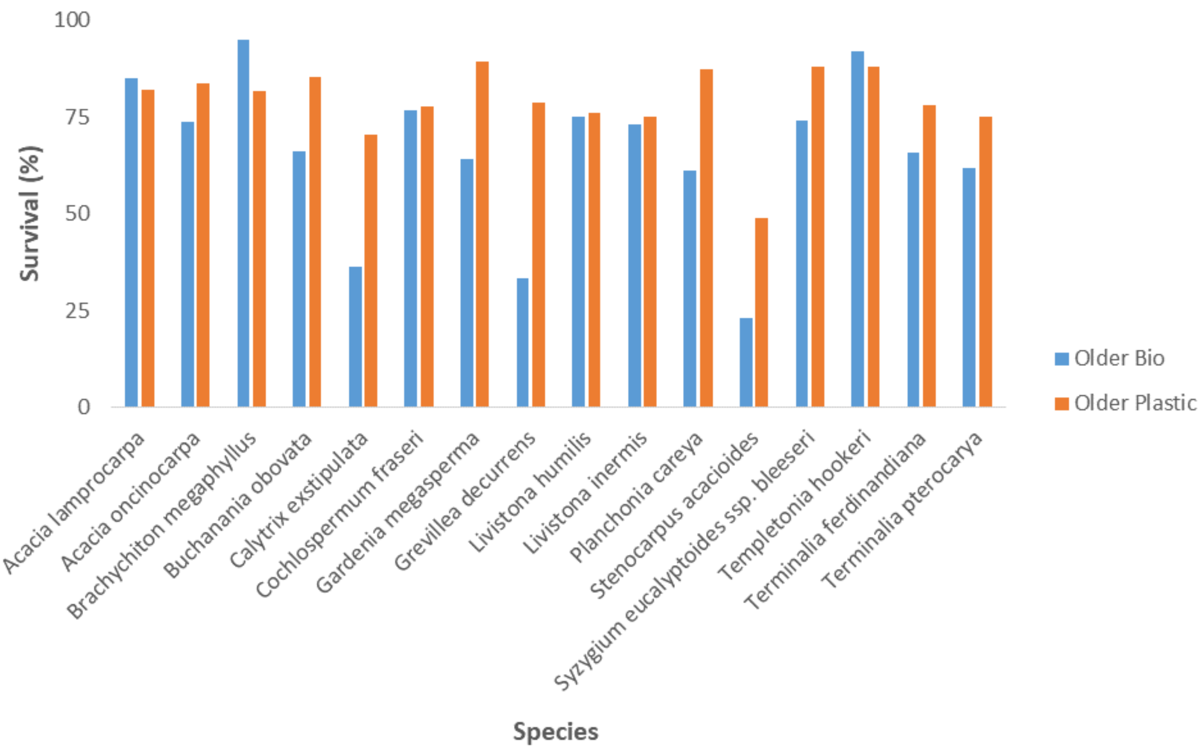


Figure 5-129: Survival of overstorey and midstorey seedlings with only ‘older’ treatments in Pit 1 Wet season trial 12-month survey

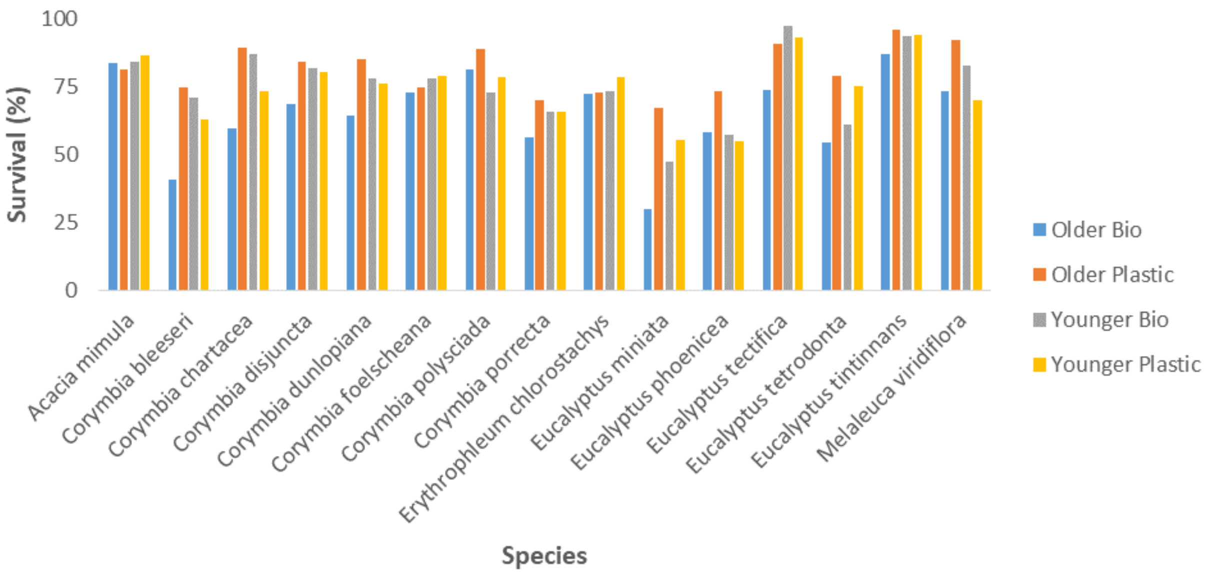


Figure 5-130: Survival of overstorey and midstorey seedlings with all four treatments in Pit 1 Wet season trial 12-month survey

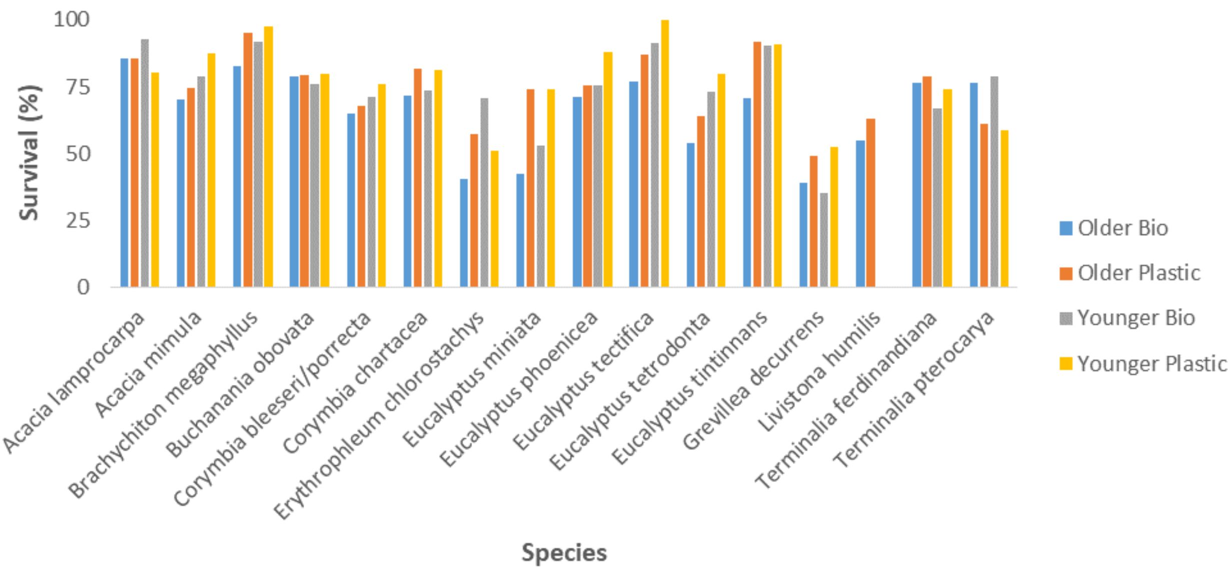


Figure 5-131: Survival of overstorey and midstorey seedlings with multiple treatments in Pit 1 Dry season trial 6-month survey

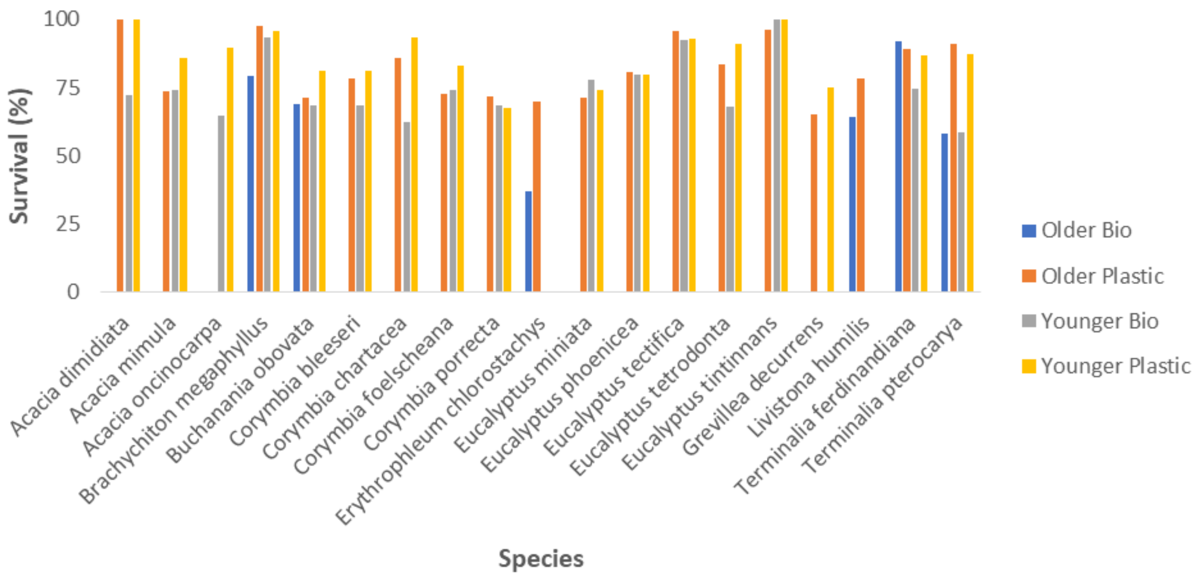


Figure 5-132: Survival of overstorey and midstorey seedlings with multiple treatments in Pit 1 Build-up trial 6-month survey

Preliminary results for the understorey species also suggest that plastic pot seedlings will generally have similar or higher survival than biopot seedlings regardless of propagation and planting season (Figure 5-133, Figure 5-134 and Figure 5-135). Similarly to the overstorey species, the younger understorey seedlings also generally had higher survival than the older seedligns in the Dry season and Build-up trials. The majority of the understorey species in the Wet season trial did not have an age treatment, but of the ones that did, older seedlings generally perferred similarly or better. Some species, such as *H. triticeus,* had high survival regardless of season, age or pot type (92 – 100 % survival across all three trials).

It should be noted that the data collected from the Pit 1 trials is yet to undergo statistical analysis, and that the findings in this iteration of the MCP are based on high level data interrogation. Whether any treatments have had a statistically significant impact on species survival will be reported in the 2023 MCP.

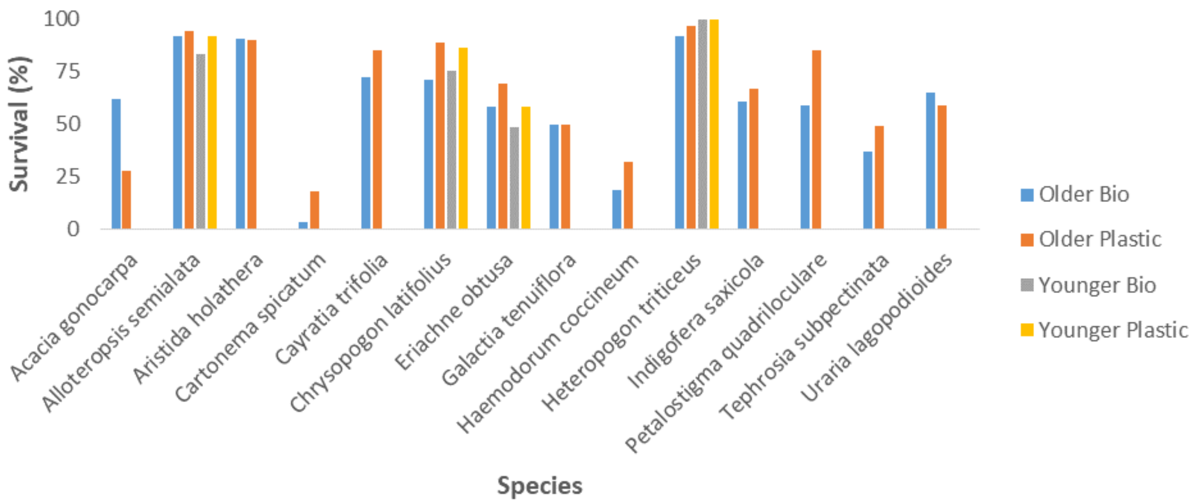


Figure 5-133: Survival of understorey seedlings with multiple treatments in Pit 1 Wet season trial 12-month survey

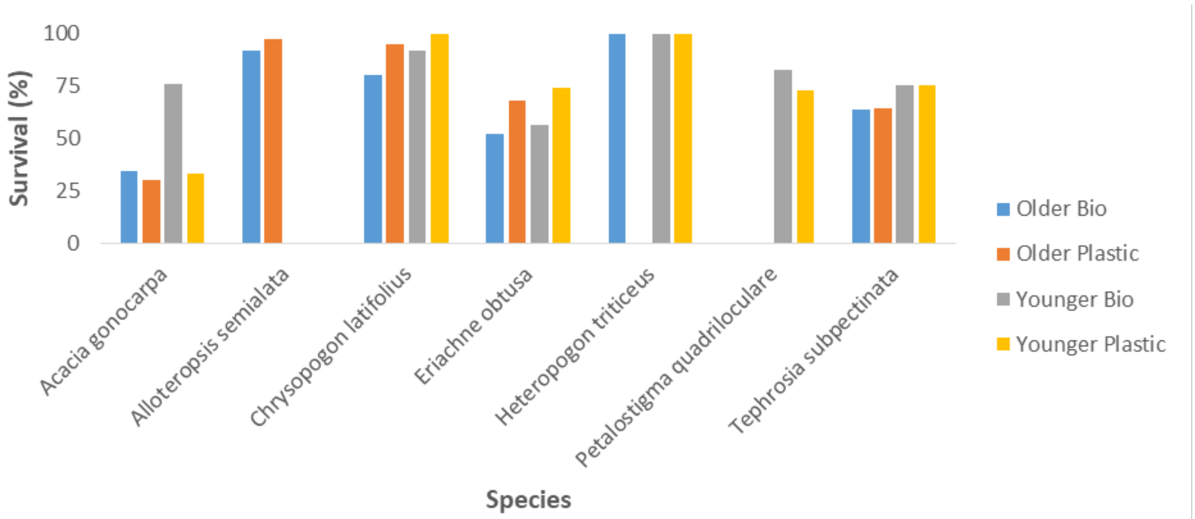


Figure 5-134: Survival of understorey seedlings with multiple treatments in Pit 1 Dry season trial 6-month survey

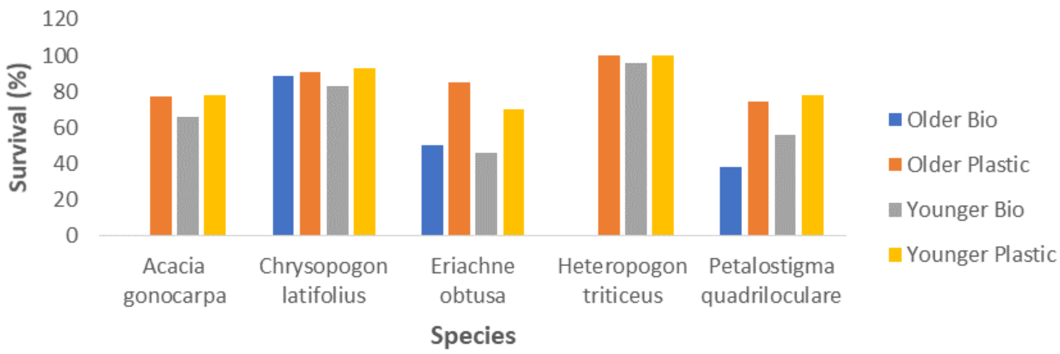


Figure 5-135: Survival of understorey seedlings with multiple treatments in Pit 1 Build-up trial 6-month survey

Flowering, fruiting and recruitment

All of the understorey species in all three trial areas have been observed to flower and fruit, and most of them have also self-recruited. *Terminalia pterocarya* has also flowered and fruited in all three areas. Other midstorey species that have been observed to flower and fruit include *Calytrix exstipulata, Templetonia hookeri, C. fraseri* and *Dolichandrone filiformis*, all of which were only planted in the Wet season trial area. A few individuals of *Syzygium eucalyptoides ssp. bleeseri* and *B. megaphyllus* have also flowered, however this appeared to be a stress response as the plants were very small.

5.4.3.7 SERP database - revegetation

Species-specific revegetation information summarised in the SERP database includes:

- whether a species has naturally colonised on waste rock, with references to where and if known, when (e.g. TLF after ten years, waste rock dumps etc.);
- history of research trials and/or progressive revegetation where species has been actively introduced onto waste rock, with specific reference to trial and/or area;
- whether the species has been successfully introduced (in this case, the species being present two years after introduction) via tubestock planting, direct seeding or other methods (eg. mulch islands). Level of success is categorically ranked from highly successful (eg. >90 % tubestock survival) to low success (eg. <3% emergence and persistence from viable seed);
- comments on initial (<2 years), early-intermediate (2 – 6 years), mid-intermediate (7-15 years) and long-intermediate (16 - 25 years) species establishment;
- whether a species has been observed to flower, fruit and recruit on waste rock, with consideration of appropriate age based on lifeform (e.g. a midstorey shrub species flowering within 1 month of planting at 20 cm height is likely a sign of stress). Type of recruitment observed (e.g. from seed or vegetative suckers) is noted where identifiable; and

- comments on any establishment concerns, e.g. Species senescing without recruitment, species particularly susceptible to termites etc.

5.4.3.8 Future work on establishing native terrestrial vegetation

Projects identified for continued work, the progress of which will be incorporated into future iterations of the Ranger MCP, will include:

- ongoing monitoring of the TLF, Stage 13.1, and Pit 1, with further and more detailed interrogation of results in relation to treatment effects, surface conditions, optimal species establishment methods and ecosystem development;
- targeted programs for important species that have been difficult to establish thus far; and
- begin SERP for species that may be better suited for seasonally-inundated areas, drainage features etc. on the final landform.

5.4.4 ESR8 Understanding fire resilience and management in ecosystem restoration

KKN title	Question
ESR8. Understanding fire resilience and management in ecosystem restoration	ESR8A *What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?*

5.4.4.1 Background

Fire is a major exogenous feature of Australian eucalypt-dominated ecosystems, especially subtropical savanna woodlands (e.g. Gill 1981; Bradstock *et al*. 2002; Russel-Smith & Whitehead 2015). Fire is the key disturbance that influences vegetation composition, structure and function in the northern savanna woodlands and forests of Australia. Fire can be natural (eg caused by lightening at the end of the dry season when fuel loads are cured and ready to burn) but is more commonly anthropogenic, having been used for thousands of centuries by Traditional Owners as part of managing the land and more recently by land managers such as Parks Australia and various ranger groups.

5.4.4.2 Fire regimes in natural surrounding woodlands and their influence on species composition and community structure

Fire regimes consider the intensity, frequency and timing of fires, which are all important factors that impact on the influence fires have on the environment (Gill 1981; Bradstock *et al*. 2002; Woinarski *et al*. 1999). Intensity is often related to timing, for instance late dry season burns are usually more intense as fuel is very dry, but can also be influenced by the type of fuel (e.g. fire-promoting grasses such as Gamba grass). Deliberately lit fires usually occur earlier in the dry season than wildfires, and therefore are generally less intense and less destructive to vegetation. Tropical savannas worldwide are intentionally burnt every 1 to 3 years (Andersen *et al*. 1998),

The RPA is surrounded by the eucalypt savanna dominated landscape of Kakadu NP. High annual wet season rainfall promotes extensive vegetation growth, particularly from annual grasses dominated by Sorghum. The subsequent curing of the vegetation during the long dry season results in a highly flammable landscape, where fire is an annual event (Russell-Smith *et al*. 1997) and a major force in shaping and altering the natural landscape (Edwards *et al*. 2003). Risk of fire becomes especially severe in September to November due to a combination of low humidity, average maximum temperatures above 35 °C and low soil moisture (Gill *et al*. 1996). Kakadu NP experiences high fire frequency with 2.7 – 7 fires per decade (Table 5-53). Changes to fire management practices in Kakadu NP since the late 1980s have resulted in more frequent early dry season fires and fewer late dry season fires (Russell-Smith *et al*. 1997). Fire is estimated to occur over 55 percent of the park annually (Russell-Smith *et al*. 1997, Lehmann *et al*. 2008 and NAFI 2015) .

The fire management plan for Kakadu NP from 2016 to 2026 aims to reduce the area impacted by large fires and the risk of wildfires entering, spreading, or leaving the park; it also plans for reduced frequency of large severe fires and reduced average fire patch size (Director of National Parks 2016). The management plan also identifies the importance of maintaining long-unburnt patches for vegetation regeneration and wildlife habitat (Director of National Parks 2016).

Table 5-53: Published fire frequencies for the region surrounding Ranger Mine (from Cook 2021)

Location	**Reference**	**Fire Frequency (fires per decade)**	
		All fires	Late fires
High rainfall Open Forest (National) 1988-2018	Cook *et al.* (2020)	2.66	1.85
High rainfall Woodland with mixed grass (National) 1988-2018	Cook *et al.* (2020)	3.62	2.22
Kakadu NP	https://firenorth.org.au/nafi3/ NAFI InfoNet report Kakadu NP 2000-2019	5.4	1.6
Kakadu NP 1980-2015	Gill *et al.* (2000)	4.6	1.6
Kakadu NP Lowlands (1980-2015)	Gill *et al.* (2000)	7	2
Kakadu NP savannah (1995-2009)	Russel-Smith *et al.* (2012)	2.68	1.48
WALFA area Savanna (1995-2009)	Russel-Smith *et al.* (2012)	4.11	2.56
WALFA area (1995-2004)	Russel-Smith *et al.* (2013)	3.96	3.2
WALFA area (2005-2011)	Russel-Smith *et al.* (2013)	3.18	1.09

Despite the adoption of early dry season burning by management agencies, total fire frequency (which includes both early and late dry season fires) has been shown to have a deleterious impact on the environment (Andersen *et al*. 2005, Lehmann *et al*. 2008). A higher early dry season fire frequency increases grass fuel levels, which in turn encourages higher intensity fires. Such a fire regime may have a similar negative impact on flora and fauna as infrequent late dry season fires (Woinarski *et al*. 2010) and frequent fire has adversely affected sensitive flora species in sandstone escarpment habitats (Russell-Smith *et al*. 1998). Further to this, a high fire frequency has been shown to have a propensity for producing a grass-fire cycle (D'Antonio & Vitousek 1992), resulting in an increase in the presence of annual grasses, particularly *Sorghum* spp. (Peter Christophersen *per comms.,* February et al. 2013; Parr et al. 2014; Scott et al. 2012; Werner 2012), that can eventually replace trees and shrubs. The presence of grassy weeds such as Mission grass and Gamba grass can exacerbate the effects of a grass-fire cycle (Rossiter *et al*. 2003).

Two major research projects in the NT, Munmarlary and Kapalga, have examined savanna dynamics in relation to different fire regimes at landscape scales (e.g. Bowman and Panton 1995; Andersen *et al*. 1998, 2003, 2005). Sites at Kapalga that had been unburnt for a number of years were found to have less grass cover (7% in November and 13% in March) than sites that had been burned annually (for 5 years) in the early or late dry season (Setterfield 2002). These previously-burned sites had 11% and 15% grass cover, respectively, in November and over 25% for both by the end of the wet season in March.

Frequent fires tend to simplify vegetation structure leading to the presence of a dominant tree layer and an understorey of grasses and resprouting shrubs and trees (Cook 2021). By contrast, a regime of less frequent fires will provide greater opportunities for saplings to escape the flame zone and for a mid-stratum to develop (Freeman et al. 2017; Setterfield 2002). Many species can persist and reproduce sexually or asexually in the long-term as woody resprouts; these facultative trees only enter the mid-stratum or overstorey rarely (Freeman et al. 2018). Resprouts make use of existing root systems to quickly recover after above-ground damage due to fires (Cook 2021). Their development arises from frequent fires, but are restricted from growing into the canopy from those frequent fires along with competition for light and water from overstorey trees (Fensham and Bowman 1992; Prior et al. 1997).

5.4.4.3 Vegetation adaptations and resilience to fire

The structure and composition of Australian savannas has developed under a regime of anthropogenic fires for many tens of thousands of years. As a result, native savanna vegetation is largely resilient to fires through a range of mechanisms that develop over time, and community dynamics such as structure and recruitment are heavily influenced by fire. Vegetation attributes that enable resilience to single fires can include (Lawes et al. 2011b):

- the ability to protect growing points from heat damage such as through thick bark; placement in tall canopy above common flame and scorch height; placement below ground; placement in moist bark or leaves; and/or
- the ability to recruit following fires through asexual reproduction or protection of seed.

For vegetation experiencing regular fires, the ability to restore protections damaged in one fire before the next fire, and the ability of top-killed plants to produce seed or asexual propagules before the next fire, become important. Most of the species planned for revegetation at Ranger Mine have fire resilient mechanisms (Table 5-54).

Table 5-54: Fire resilience mechanisms in natural ecosystems and 25 year old developing revegetation (Cook 2021)

Fire resilience mechanism	Mature, natural ecosystem	25 year old developing revegetated ecosystem
Recruitment processes	Asexual recruitment dominates for most woody and herbaceous species. Although herbaceous species may be able to develop strong tubers within the first year of growth, woody lignotubers of tree species may be decades to centuries old (Fensham and Bowman 1992). The establishment of woody species from seed is rare (Setterfield 2002), and little studied.	Little is known of the development of tubers of tropical herbaceous species or of woody species. It is unlikely that woody lignotubers will have developed to the density, size or diversity that occur in natural systems, but they may be on a trajectory towards it. Direct measurement of lignotuber development will be challenging, but could be inferred from resprout growth. The relative roles of seeding recruitment and asexual recruitment from lignotubers and root suckers (*Eucalyptus tetrodonta* and *Erythrophleum chlorostachys*) may be different to natural ecosystems because of incomplete development of the lignotuber population.

Fire resilience mechanism	Mature, natural ecosystem	25 year old developing revegetated ecosystem
Avoidance of heat from flames e.g. perennial grasses with deep growing points: *Chysopogon fallax, Alloteropsis semialata*. Annual grasses with buried seed: *Sorghum intrans, Aristida spp*. Herbs with tubers: *Galactia tenuiflora, Haemodorum spp*. Most Woody species with lignotubers	Grasses and herbaceous species are able to evade fire impacts through buried seed and growing points that allow rapid growth in the wet season (Scott et al. 2010a; Scott et al. 2010b). For woody species, lignotubers provide protection from heat and resources to support rapid post-fire growth (Freeman et al. 2017). Many woody species can flower and fruit within the understorey and do not need to become mid or overstorey trees to sexually reproduce (Freeman et al. 2018). Thick bark confers protection from fire to above-ground growing points of woody species (Lawes et al. 2011a)	Grasses and herbaceous species in revegetation should respond similarly to fire as those in natural systems. Many species of eucalypts in southern Australia can develop lignotubers capable of resprouting after fires within one to two years of germinating (Gill 1997), and this is likely to be the case in northern Australia for eucalypts as well as other genera of trees. The process of development of lignotubers and of resprout populations over time since germination and the consequent fire resistance is largely unknown (Fensham and Bowman 1992; Fensham et al. 2008). Even in small trees, mortality after a fire is low and topkill uncommon (Lawes et al. 2011b). Species with thicker bark will have greater ability to not be topkilled by fire, but eucalypts can survive, despite thinner bark due to deeply embedded epicormic sprouts (Lawes et al. 2011a).
Root suckering after topkill of mature individuals: *Eucalyptus tetrodonta, Erythrophleum chlorostachys*	Mature trees exist in canopy as well as in ground stratum. With adequate fire-free gaps suckers can recruit above flame zone. A semi-log distribution of tree sizes (Cook et al. 2020b) across the savanna zone indicates that trees are continuously recruiting into the canopy.	Many individual young trees still have potential to be top-killed by fire, but this should encourage root suckers to develop (Fensham and Bowman 1992). It is likely that the pool of root suckers will be less than that in mature, natural ecosystems – it will require more time and cycles of growth of saplings and topkill to develop pool of root suckers. The even-age stand that will develop may, for many decades, preclude recruitment of new canopy trees from root suckers.
Growing tall rapidly so that growing points above flame zone: *E. tetrodonta, E. miniata*	Multi-strata, presence of a fire-suppressed community of plants to rapidly take the place of topkilled plants. Mortality rate in Eucalypt open forest across all size classes from seasonal drought and fire is about 1 to 2% per year. A proportion of most woody species occurs as mature tall individuals with their canopy > 4 m and up to about 25 m.	Possibly still simple stratification, with a lack of recruits in ground layer and mid-storey. A multi-size pool may develop slowly. Mortality rate will be driven by the interaction of water use by the growing trees and the ability of the soil developing on the waste rock to store and provide that water. Trees will still be growing vertically, and none are likely to have reached their maximum height.

Fire resilience mechanism	**Mature, natural ecosystem**	**25 year old developing revegetated ecosystem**
Fire tolerant Corymbia and woodland *Eucalyptus spp*., more tolerant of shallow soils and not as strong growing as *E. tetrodonta and E. miniata:*	Mortality rate across all size classes from seasonal drought and fire = 2.7 % per year possibly reflecting harsher environments on shallower soils.	Mortality rate across all size classes may be lower because system not at carrying capacity. It is likely that the relative abundance of shorter stature Corymbia and tall growing *E. miniata and E. tetrodonta* will reach an equilibrium with soil conditions that will be difficult to predict. Allowance should be made in seedling mixes to provide for differential responses to substrate variability and the complex interactions with fire.
Production of seeds that can survive fires: *Acacia spp*.	Plants recruit from seed and occasionally from resprouting. Plants typically short-lived (5-7 and some longer years?).	Plants recruit from seed after fires and occasionally from resprouting. Plants typically short-lived (5 years?). A bad outcome would occur if these become dominant because they would outcompete framework species and could provide ladder fuels to carry fire into developing canopy.
Wide variety of responses to stresses and disturbances through overall species composition	High species richness ensures community has a wide range of responses to disturbances and stresses. In areas with a low frequency of less severe fires, the following species or groups of species may be present in the shrub or midstorey in higher density: monsoon forest species, mid-storey savanna species (e.g. *Erythrophleum chlorostachys, Terminalia ferdinandiana*). Higher fire frequency may lead to an absent mid-storey or support a high density of fast growing acacias.	In areas with a low frequency of less severe fires, the following species or groups of species may be present in the shrub or developing midstorey in higher density: monsoon forest species, mid-storey savanna species (e.g. *Erythrophleum chlorostachys, Terminalia ferdinandiana*). Higher fire frequency may lead to an absent mid-storey or support a high density of fast growing acacias.
Growing point protected by thick leaf bases and thick trunk: *Livistona spp., Pandanas spiralis*	Livistona and Pandanas trees in a range of size classes, able to persist and remain reproductive under most fires.	Livistona and Pandanas trees in even age (25 yr) stand, able to persist and remain reproductive under most fires. Some new recruitment from seed occurring.
Investing in thick bark and rapid regrowth from epicormic shoots or lignotubers if burnt: *Melaleuca spp.*	Usually survives fire and most commonly grows in wetter parts of landscape.	Usually survives fire and most commonly grows in wetter parts of landscape.

Fire resilience mechanism	Mature, natural ecosystem	25 year old developing revegetated ecosystem
Ability to persist and reproduce sexually in flame zone: *Buchanania obovata, Planchonia careya, Petalostigma quadriloculare, Planchonia careya, Terminalia ferdinandiana, Brachychiton spp*.,	Although often stated to be fire sensitive, these species can persist, flower and fruit at high densities within the flame zone. Occasional individuals may escape to become components of the mid-stratum.	Some individuals may be approaching mid-stratum (8 – 15 m), but many may be persisting in ground layer which is similar to a mature, natural system.
Ability to resprout rapidly from lignotubers and reproduce in one season: *Grevillea dryandra, G. goodii*.	An occasional component of understorey able to persist by regrowing each wet season, and survive in absence of fire.	An occasional component of understorey able to persist by regrowing each wet season, and survive in absence of fire.
Fire-proofing the stand through exclusion of most grasses: *Calytrix exstipulata, Dodonaea hispidula.*	On sites often with shallow soils, Calytrix stands can exclude most fires through reducing grass growth and persist (Scott et al. 2009).	Calytrix stands may be able to develop and persist on revegetation areas with shallow soils. Dodonaea may become aggressive and outcompete Framework species. In dense stands, they can exclude fires from rehabilitating savanna and alter trajectories.
Nutrient cycling and soil development	Mixture of biological and pyrogenic pathways for mineralisation of dead organic matter supports vegetation growth in nutrient poor soils (Cook 1994; Rossiter-Rachor et al. 2008) Termite and earthworm activity recycles dead organic matter (Dawes-Gromadzki 2008).	Slow establishment of decomposer populations may have led to excessive litter loads, creating a fire hazard. Careful implementation of burning may have mineralised dead organic matter (Cook 2012). Disturbance reduces the activity and diversity of termites and earthworms and reduces the soil forming activity of these groups (Dawes 2010a). Bare soil or a lack of termite activity may reduce recycling of organic matter and thereby fail to develop soil porosity, water storage and plant growth (Dawes 2010b). Provision of mulch and organic matter as islands may increase colonisation by termites

5.4.4.4 Rehabilitated ecosystem responses to fire

As outlined by Dr Gary Cook, a renowned expert in fire ecology that has been commissioned by ERA to support their work addressing KKN ESR8 (Cook 2021):

Developing ecosystems have a different structure and composition to natural ecosystems in which many plants are decades to centuries old. Although the same species may have been planted in rehabilitated landscapes as adjoining natural landscapes, they may take a long time to develop resilience to fire at both an individual and a population scale. Compared with natural ecosystems, there have been few published studies about rehabilitating ecosystems in Australia's savanna zone and fewer that focus on fire. It is likely that fire will impact developing ecosystems differently to natural systems.

On the waste rock / laterite mix sections of the TLF, trees greater than 2.5 m tall and 4 cm DBH were more likely to survive a fire than those less than this threshold (discussed further below, Wright 2019b). However, even if the majority of individuals in a reconstructed ecosystem have reached a size where they are likely to survive one or two fires, does not mean the ecosystem is resilient enough, or that it is desirable, to implement a fire regime similar to the surrounding Kakadu National Park.

5.4.4.5 Fire and nutrient cycling

Nutrient cycling in tropical, fire dependent ecosystems, such as the eucalypt-dominated woodlands of Kakadu NP, is driven by this disturbance regime (Cook 1994). Annual litter accumulation can be significant (depending on vegetation composition and structure), especially due to grass, fallen leaves and branches. In the humid wet season, this organic material is rapidly decomposed by soil micro-organisms, providing significant nutrient input, much of which is available to plants at the precise time they are growing most rapidly and require it. As the dry season progresses and soil moisture is depleted, and with the removal of the accumulated litter and grass biomass layer by fire, microbial activity declines (Cook 1994). Combustion of dead organic matter produces char and ash that has a high content of plant nutrients. These nutrients are highly available and provide for plant growth along with the first rains of the following wet season (Cook 1992; 1994); however, may contribute to nutrient movement in surface water run-off (Townsend and Douglas 2000).

Although fire has an important role in the cycling of nutrients in natural, established savannas, considering the novel waste rock substrate that will be used for revegetation of the Ranger FLF, future fire management must also carefully consider pedogenesis. The development of a litter layer has been seen as beneficial for soil development in natural and re-establishing ecosystems (Tongway and Hindley 2003; Tongway and Hindley 2004), and the removal of this organic matter through fire may delay or even set-back this process during the early and possibly intermediate stages of ecosystem establishment. Burning may also cause losses of nutrients, particularly nitrogen through atmospheric transfers and erosion of deposited ash (Cook 2021).

5.4.4.6 Burns on the TLF

A weed control burn was conducted in 2016 in laterite mix sections 2 and 3 of the TLF to reduce the cover of weedy species (Wright 2019a). Key findings from this report were that trees greater than 2.5 m height and 4 cm DBH are more likely to survive fire and other natural threats (Figure 5-137 and Figure 5-138). Further, planted species *E. tetrodonta, W. saligna* and *A. hemignosta* observed high rates of recruitment following fire. Density of *A. holosericea* was particularly documented to be impacted by fire, however left unmanaged rapidly bounced back.

A second controlled burn was planned and executed in June 2019, to again reduce weed loads. The burn was preceded by a thorough application of herbicide to initially reduce the seed bank and cure existing material. The fuel load prior to burning was visually estimated at 2-3 tonnes per hectare, which in dry season conditions was considered suitable to carry fire without allowing critical damage of larger trees. The burn was conducted under cool conditions and a southeast prevailing wind of 10-15 km/h. It was performed slowly and carefully against the wind to achieve a low, slow burn and concentrate intensity at the ground level.

Data was collected pre-burn and one month post-burn in affected permanent plots for height, DBH, health/condition for each woody stem or tree, as well as ground cover composition and extent. From this data the main findings were:

- Scorch height (height of leaf browning) averaged 2-3 m.
- Except *A. holosericea* (which has a narrow stem and less natural protection from fire) the large majority of trees above 2.5 m height and 4 cm DBH survived and showed signs of regeneration. From over 100 stems, only two large *A. holosericea* shrubs (>3.5 m height) actually showed signs of survival, and these were somewhat protected by fire due to their position on a very rocky area that did not burn (Figure 5-136).
- Weed-dominant groundcover was reduced from 48-98 % to 0-10 %.
- Of all the planted *Acacia* species, those above 2 m survived and many were responding by reshooting.
- Some small *T. ferdinandiana* and *C. fraseri* (<1.3 m) were destroyed.
- A few stunted original *C. disjuncta* and most *E. tetrodonta* and *W. saligna* suckers below 1.4 m were damaged, but showed signs of early regeneration.
- Some slow growing small plants such as *O. vernicosa* and *P. pubescens* (<0.8 m) appeared to be destroyed, however routine monitoring of the TLF has since shown them to have recovered.

It was intended to introduce native understorey in the following wet season, however this opportunity was not capitalised on and early rains contributed to a dense weedy covering by January 2020. The groundcover composition however was changed; pre-burn the ground layer was dominated by Buffalo Clover whereas after it was predominately *Urochloa reptans*, a more manageable weedy native species.

Figure 5-136: *Acacia holosericea* exposed to fire (top) and protected from fire (bottom), four months after 2019 June burn.

Figure 5-137: Recovery of the revegetation from a prescribed burn in May 2016. View of the burnt vegetation on the trial landform 12 days post fire (left) and 6 months post fire (right)

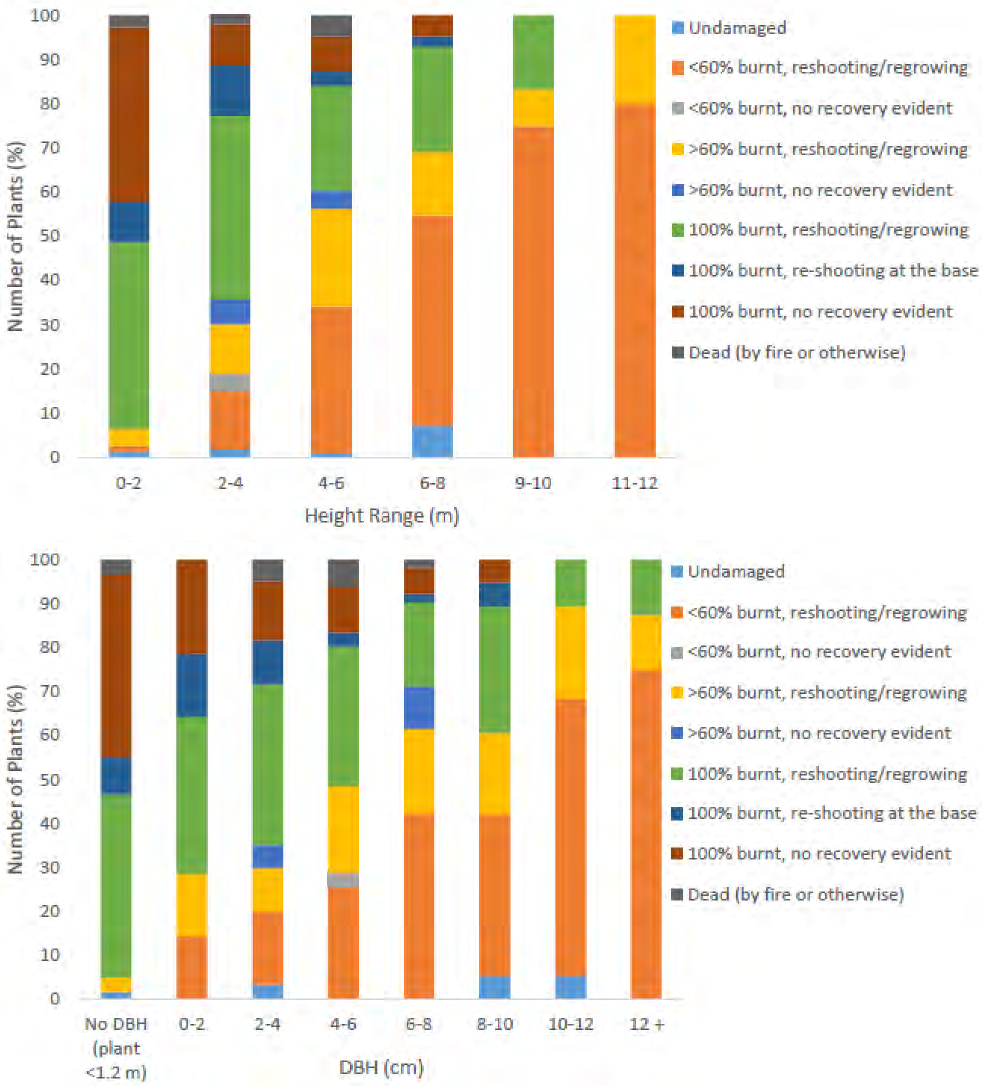


Figure 5-138: Height and DBH ranges and associated health classes after the 2016 burn on laterite mix areas of the TLF (Wright 2019a)

5.4.4.7 Fire implementation on rehabilitated landforms at Ranger

The current strategy for Ranger Mine is to completely exclude fire from developing revegetation areas until, at a very minimum, the majority of individuals from the majority of species have reached a size where survival is likely. Adaptive management trials can be used to help inform when a fire can and should be implemented with consideration of risk management and soil development. In the longer term, a fire regime will gradually be introduced with a focus on purposeful burns and desired burn patterns, rather than on timing exclusively. It is essential that this is undertaken in partnership with Traditional Owners and Traditional Knowledge.

5.4.4.8 Future work on fire resilience and fire implementation on rehabilitated ecosystems

ERA will continue to develop their understanding on how fire on revegetated waste rock landforms may impact key indicators of the ecosystem closure criteria, specifically:

- flora species composition and abundance;
- community structure;
- species flowering, fruiting and recruitment;
- nutrient cycling and soil development; and
- fauna colonisation.

This will help inform and develop the ERA Fire Implementation Plan. ERA will also investigate fire, the risk of deviated states and fire management actions to redirect ecosystems onto a desired development trajectory. This will be achieved though ongoing expert elicitation, stakeholder engagement and ongoing, targeted, adaptive management trial burns.

5.4.5 ESR4 Incidence and abundance of introduced species (flora and fauna)

KKN title	Question
ESR4. Incidence and abundance of introduced species (flora and fauna)	ESR4A What is the incidence and abundance of introduced animals and weeds in areas adjacent to the mine site, and what are the factors that will inform effective management of introduced species on the rehabilitated mine site?

5.4.5.1 Background

A weed is an exotic or native species that colonises and persists in an ecosystem in which it did not previously exist. These invasive plants typically produce large numbers of seeds and are excellent at surviving and reproducing in disturbed environments. Weeds potentially reduce biodiversity by competing with or displacing endemic species and may also affect natural processes such as fire intensity and stream flows. The restriction to recreational movement of people may also result from weed infestations.

One of the most significant threats to the natural and cultural values of the Kakadu NP is weeds (Director of National Parks 2016). Compared to other national parks in the region, Kakadu NP has a low proportion of weeds. However, there are still significant impacts by invasive weeds to some of the landscapes within the national park.

The RPA has been surveyed by ERA annually for weeds since 2003, and approximately 80 species have been recorded during this time. Weeds of National Significance (WoNS) are categorised under the Federal *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act).* Gamba Grass (*Andropogon gayanus*) is the only WoNS previously recorded in the RPA with the recorded presence historically restricted to isolated plants on roadsides, in the vicinity of the Jabiru Airport. In 2022 there was a suspected sighting of one individual plant on a ramp entering Pit 1 from the mine, which was immediately removed and reported to stakeholders. It is possible that the seed was brought in on a vehicle as there are no known sources of gamba grass in the immediate surrounding areas. There are significant sources of gamba grass along the Arnhem highway, so good weed hygiene (including vehicle wash-downs and inspections) and continued weed awareness is required to ensure no populations develop on the RPA. There are five grass species listed as Key Threatening Processes to Australia's biodiversity also under the *EPBC Act*. Gamba Grass is one of these, whilst the other four species have not been recorded on the Ranger Mine.

The Northern Australia Quarantine Strategy (NAQS) was established in 1989 to manage the risks of biosecurity particular to northern Australia due to the proximity to neighbouring countries. The NAQS is administered by the Federal Department of Agriculture. No weeds listed within the NAQS have been recorded within the RPA. There are also six weed species listed under the Tropical Weeds Eradication Program (DAF 2019) which, to date, have not been recorded on the RPA.

In the NT, the *Weeds Management Act 2001* is administered by the Department of Environment and Natural Resources. Six species listed under this legislation as Class A/B/C (eradicate/growth and spread to be/not to be introduced into the NT) have been recorded within the RPA. In addition, there are a further nine weed species that have been identified by ERA as requiring active treatment and/or removal when detected on the RPA (Table 5-55).

An un-identified plant was observed on the RPA in 2019. A sample was submitted to the NT Herbarium for identification, and it was identified on 17 April 2019 as *Spigelia anthelmia* (Indian Pinkroot). The identification of *Spigelia* at the Ranger Mine is the first known occurrence of this weed in Australia. External stakeholders were notified. *Spigelia* is native to the tropical and sub-tropical Americas and is known to have spread to parts of Africa and South East Asia (including Thailand, the Philippines and Papua New Guinea). Since identification the RPA has been comprehensively surveyed. *Spigelia* was detected in a number of locations and all located plants were treated. ERA aims to eradicate the *Spigelia* infestation. A timeframe to achieve eradication is 5-6 years given that *Spigelia* seed may remain viable for at least 3 years.

Twelve introduced fauna species have been recorded in the RPA, the most recently being the browsing ant (*Lepisiota frauenfeldi*), and an additional eight species have been recorded in Kakadu NP

Table 5-56). Three species recorded in both the RPA and Kakadu NP (pig, cat and cane toad) are listed under the *EPBC Act* as key threatening processes to environmental, natural heritage and cultural heritage values.

Table 5-55: Actively Managed Weeds in the surrounding RPA

Scientific name	Common name	***Weeds Act 2001* (NT) listing**
Andropogan gayanus	Gamba Grass	Class A, Class C and Weed of National Significance
Calopogonium mucunoides	Calopo	–
Cenchrus pedicellatus	Annual Pennisetum	–
Cenchrus polystachios	Mission Grass	Class B, Class C
Chamaecrista rotundifolia	Wynn's Cassia	–
Crotalaria goreensis	Rattlepod	–
Hyptis suaveolens	Hyptis	Class B, Class C
Ipomoea quamoclit	Cupid's Flower	–
Macroptilium atropurpureum	Siratro	–
Senna obtusifolia	Sicklepod	Class B, Class C
Sesamum indicum	Sesame	–
Sida acuta	Spinyhead Sida	Class B, Class C
Sida cordifolia	Flannel Weed	–
Spigelia anthelmia	Indian Pinkroot	–
Themeda quadrivalvis	Grader Grass	Class B, Class C

Table 5-56: Feral fauna species known to occur in Kakadu NP and the RPA

Type	Common name	Scientific name	RPA	Kakadu NP
Mammal	Dog	*Canis lupus familiaris*	Y	Y
Mammal	Banteng	*Bos javanicus*		Y
Mammal	Buffalo	*Bubalus bubalis*	Y	Y
Mammal	Cattle	*Bos taurus*		Y
Mammal	Cat	*Felis catus*	Y	Y
Mammal	Donkey	*Equus asinus*		Y

Type	Common name	Scientific name	RPA	Kakadu NP
Mammal	Goat	*Capra hircus*		Y
Mammal	Horse	*Equus caballus*		Y
Mammal	Black rat	*Rattus rattus*	Y	Y
Mammal	House mouse	*Mus domesticus*	Y	Y
Mammal	Pig	*Sus scrofa*	Y	Y
Mammal	Rusa Deer	*Cervus timorensis*		Y
Mammal	Sambar Deer	*Cervus unicolour*		Y
Bird	Rock pigeon	*Columbia livia*		Y
Fish	Mosquito fish	*Gambusia holbrooki*		Y
Insect	Ginger ant	*Solenopsis geminata*		Y
Insect	Pharaoh's ant	*Monomorium pharaonis*		Y
Insect	Singapore ant	*Monomorium destructor*		Y
Insect	Ghost ant	*Tapinoma melanocephalum*		Y
Insect	Big-headed ant	*Pheidole megacephala*		Y
Insect	Browsing ant	*Lepisiota frauenfeldi*	Y	
Insect	Black crazy ant	*Pratrechina longicornis*		Y
Insect	Tropical fire ant	*Solenopsis geminate*		Y
Insect	Yellow crazy ant	*Anoplolepis gracilipes*		Y
Insect	Cockroach	*Periplaneta spp.*	Y	Y
Insect	European honey bee	*Apis mellifera*	Y	Y
Insect	Salvina weevil	*Crytobagous salviniae*		Y
Insect	Sida Beetle	*Calligrapha sp.*		Y
Amphibian	Cane toad	*Rhinella marina*	Y	Y
Reptile	Flower-pot snake	*Ramphotyphlops braminus*	Y	Y
Reptile	House gecko	*Hemidactylus frenatus*	Y	Y

5.4.5.2 Exotic and weed species in revegetation areas

Weeds have been an ongoing issue on the TLF. In May 2009, the waste rock/laterite mix section had a weed density of 7,083 +/- 1,828 weeds/ha, whereas no weeds were identified in the waste rock only areas (Daws & Poole 2010). Daws and Poole (2010) concluded that a substantial weed seed bank was introduced with the laterite material used in constructing the landform. In addition, the waste rock only substrate was quite hostile to self-colonisation by weed species. There was still minimal weed cover on the waste rock areas in 2020, however, species have slowly begun colonised from the laterite mix areas into 1B and 1A in recent years. Paradoxically, the high ground cover contributed to higher early landscape function analysis indices on the laterite mix area, albeit confounded due to the high presence of weedy understorey (Gellert & Lu 2015).

Nineteen exotic /weedy species have been observed on the TLF since September 2018. Most of the species present today were growing in the laterite mix areas within two years after the TLF was constructed (Daws & Gellert 2010, 2011; Daws & Poole 2010). Although the number of exotic and weedy species on the TLF is similar across the four sections, the cover is significantly different. Sections 2 and 3 have recurringly dense, groundcovers of weed, whereas 1A and 1B have sparsely scattered weeds with very few dense patches.

Acacia holosericea is generally considered a native/naturalised species in the NT. However, due to their aggressive colonisation and dominance of disturbed areas it is considered a weed on the TLF and across the RPA. Within two years of the TLF construction, *A. holosericea* had germinated, grown, set seed (Gellert 2012), and were cut back at the end of 2010 to manage their spread (Daws & Gellert 2011). The cool burn performed in the laterite mix areas in July 2019 has proven to be a successful management tool for controlling *A. holosericea* and changing the composition of weedy groundcover (as discussed in ESR8).

Stage 13.1 was finished to final level early 2020 with very little weed presence observable. Application of pre-emergent herbicide prior to planting was not prioritised for areas A and B, and due to ongoing disturbance, subsequent earthworks and rainwater run-on from upstream weed sources, weeds began colonising the area by November 2020, particularly *Chloris barbata* (Rhodes Grass) and *Echinochloa colona* (Barnyard Grass). Area C was treated with pre-emergent herbicide four weeks prior to planting in August 2021.

During the two years since planting began on Stage 13.1, fourteen exotic flora species have been observed across the area. There was a targeted effort to reduce weed loads on Stage 13.1 during the 2020-2021 and 2021-2022 weed seasons. Weed status in the area has improved, particularly in 2022, with chemical treatment and physical removal being the main forms of control. There are still ongoing challenges with Rhodes Grass, which is relatively resilient against various herbicides, and *C. pedicellatus* (annual Mission Grass), which has been successfully controlled but continues to be reintroduced due to weed sources in the mine area blowing into Stage 13.1. A multi-year management plan for weeds in the mining area is currently under development and will be executed in the upcoming weed season.

Minimal weeds were observed growing on the Pit 1 surface in the 2020/2021 wet season following completion of backfill, with just relatively small numbers of *A. holosericea*, *Alysicarpus vaginalis* (Buffalo Clover) and annual Mission Grass. These were treated at the end of the wet season, and each planting section was again treated with pre-emergent and knockdown herbicides at least 2 - 4 weeks prior to planting. Learning from the difficulties experience in previous areas, there was significant focus on Pit 1 weed management during the 2021 – 2022 weed season. Current weed status on Pit 1 is promising, especially considering the size of the area (approx. 40 ha). If there is continued effort and resources spent managing weeds on the landform in the upcoming years while trees and shrubs establish and native understorey cover increases, a weed legacy issue is unlikely. Like Stage 13.1, Rhodes grass has been the most difficult to manage due to it's herbicide resilience. Physical removal of individuals is effective, however it is laborious and time consuming.

5.4.5.3 Future work on introduced flora and fauna

ESR4 is a SSB-only KKN, and as such, ERA do not have any specific research programs regarding introduced flora and fauna. However, ERA will continue to:

- comprehensively monitor weeds and exotic fauna throughout the closure period (Section 10); and
- develop their knowledge and experience on weed management options, particularly for revegetation areas.

5.4.6 ESR2 Determining the requirements and characteristics of a terrestrial faunal community similar to natural ecosystems adjacent to the mine site, including Kakadu National Park

KKN title	Question
ESR2. Determining the requirements and characteristics of a terrestrial faunal community similar to natural ecosystems adjacent to the minesite, including Kakadu National Park	ESR2A *What faunal community structure (composition, relative abundance, functional groups) is present in natural ecosystems adjacent to the mine site, and what factors influence variation in these community parameters?*
	ESR2B *What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?*
	ESR2C *What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?*

5.4.6.1 Species of conservational significance in the region

Kakadu NP contains over one third of Australia's bird species (271), one quarter of Australia's land mammals (77), 132 reptile species, 27 frog species and over 246 fish species recorded in tidal and freshwater areas (Director of National Parks 2016). A significant decline in the abundance of ten small mammal species has been recorded in Kakadu NP since the 1990s, including Northern Brown Bandicoot (*Isoodon macrourus*), Fawn Antechinus (*Antechinus bellus*), Common Brushtail Possum (*Trichosurus vulpecula*), Pale Field-Rat (*Rattus tunneyi*), and Northern Quoll (*Dasyurus hallucatus*). The decline has been attributed to a high fire frequency, feral cats and cane toads (Woinarski *et al*. 2010). The Northern Quoll population particularly has undergone dramatic declines due to ingestion of the toxic cane toad and in many areas of the mainland, such as Kakadu NP, it has become almost extinct.

Many *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) and/or *Territory Parks and Wildlife Conservation Act 1976* (TPWC) listed conservation species have been recorded historically on the RPA and/or in surrounds (Table 5-57). This includes numerous bird species listed under various migratory agreements that are seasonally common and widespread throughout Kakadu NP. A recent analysis of four savanna woodland surveys conducted post-2012 found that the only legislated threatened species recorded in the region across 35 survey sites were Partridge Pigeon (*Geophaps smithii smithii*), Black-footed tree-rat (*Mesembriomys gouldii*), Fawn Antechinus, Northern Brown Bandicoot and Northern Quoll (SLR Consulting 2021).

Table 5-57: Conservation listed species known to occur on the RPA (adapted from Firth 2012)

Common name	Scientific name	*EPBC Act* (Cth) status	*TPWC Act* (NT) status	Preferred habitat
MAMMALS				
Black-footed Tree-rat	*Mesembriomys gouldii*	Endangered	Vulnerable	Tropical woodlands and open forests in coastal areas
Brush-tailed Rabbit-rat	*Conilurus penicillatus*	Vulnerable	Endangered	Tropical woodlands; declined to near extinction since the 1980s
Fawn Antechinus	*Antechinus bellus*	Vulnerable	Endangered	Savanna woodland; tall open forest
Northern Brown Bandicoot	*Isoodon macrourus*	Not listed	Near threatened	Tall grassland, shrubland, savanna and open forest
Northern Quoll	*Dasyurus hallucatus*	Endangered	Critically Endangered	Eucalypt open forests; rocky areas
Pale Field-rat	*Rattus tunneyi*	Not listed	Vulnerable	Found in in the higher rainfall areas of the Top End of the Northern Territory
BIRDS				
Black-tailed Godwit[1-4]	*Limosa limosa*	Marine, migratory	Not listed	Coastal regions
Black-winged Stilt	*Himantopus himantopus*	Marine	Not listed	Freshwater and saltwater marshes, mudflats and the shallow edges of lakes and rivers
Broad-billed Sandpiper[1-4]	*Limicola falcinellus*	Migratory	Not listed	Sheltered coastal, intertidal mudflats
Caspian Tern[3]	*Hydroprogne caspia*	Migratory	Not listed	Coastal sheltered estuaries, inlets and bays
Cattle Egret	*Ardea ibis*	Marine	Not listed	Wet grasslands, wetlands, mudflats
Common Greenshank[1-4]	*Tringa nebularia*	Marine, migratory	Not listed	Coastal and inland wetlands
Common Sandpiper[1-4]	*Actitis hypoleucos*	Marine, migratory	Not listed	Coastal and inland wetlands, billabongs

Common name	Scientific name	*EPBC Act* (Cth) status	*TPWC Act* (NT) status	Preferred habitat
Curlew Sandpiper[1-4]	*Calidris ferruginea*	Critically Endangered, marine, migratory	Vulnerable	Coastal areas, non-tidal swamps, lakes and lagoons, inland ephemeral and permanent lakes, dams
Eastern Great Egret	*Ardea alba modesta*	Marine	Not listed	Range of wetlands, from lakes, rivers and swamps to estuaries, saltmarsh and intertidal mudflats
Glossy Ibis[1]	*Plegadis falcinellus*	Marine, migratory	Not listed	Swamps, flood waters
Great Egret	*Ardea alba*	Marine	Not listed	Wetlands, mudflats, mangroves
Greater Sand Plover[1-4]	*Charadrius leschenaultii*	Vulnerable, marine, migratory	Vulnerable	Sheltered beaches, intertidal mudflats or sandbanks, sandy estuarine lagoons
Green Pigmy Goose	*Nettapus pulchellus*	Marine	Not listed	Coast, tropical freshwater lagoons
Grey Plover[1-4]	*Pluvialis squatarola*	Marine, migratory	Not listed	Coast, inland wetlands
Grey-tailed Tattler[1-4]	*Tringa brevipes*	Marine, migratory	Not listed	Coastal intertidal pools, mudflats and rock ledges
Lesser Sand Plover[1-4]	*Charadrius mongolus*	Endangered, marine, migratory	Vulnerable	Intertidal sandflats and mudflats, beaches, estuary mudflats
Little Ringed Plover[2-4]	*Charadrius dubius*	Marine, migratory	Not listed	Lowland habitats with shallow standing freshwater
Long-toed Stint[1-4]	*Calidris subminuta*	Marine, migratory	Not listed	Shallow freshwater or brackish wetlands
Magpie goose	*Anseranas semipalmata*	Marine	Not listed	Coastal and inland wetlands, billabongs
Marsh Sandpiper/ Little Greenshank[1-4]	*Tringa stagnatilis*	Marine, migratory	Not listed	Coastal and inland wetlands, estuarine and mangrove mudflats
Pacific Golden Plover	*Pluvialis fulva*	Marine	Not listed	Wetlands, shores, paddocks, saltmarsh, coastal golf courses, estuaries and lagoons
Partridge Pigeon	*Geophaps smithii smithii*	Vulnerable	Vulnerable	Lowland woodland
Radjah Shelduck	*Tadorna radjah*	Marine	Not listed	Mangrove flats, swamps, freshwater swamps, lagoons, billabongs
Rainbow Bee-eater	*Merops ornatus*	Marine	Not listed	Open woodlands and forest, grasslands, widespread distribution and habitats
Red-capped Plover	*Charadrius ruficapillus*	Marine	Not listed	Sandflats or mudflats at the margins of saline, brackish or freshwater wetlands

Common name	Scientific name	*EPBC Act* (Cth) status	*TPWC Act* (NT) status	Preferred habitat
Red-necked Stint[1-4]	*Calidris ruficollis*	Marine, migratory	Not listed	Sheltered inlets, bays, lagoons, estuaries, intertidal mudflats and protected sandy or coralline shores
Ruddy Turnstone[1-4]	*Arenaria interpres*	Marine, migratory	Not listed	Coasts including mudflats
Sharp-tailed Sandpiper[1-4]	*Calidris acuminata*	Marine, migratory	Not listed	Fresh or saltwater wetlands
Swinhoe's Snipe[1-4]	*Gallinago megala*	Marine, migratory	Not listed	Coasts, floodplains, rivers
Terek Sandpiper[1-4]	*Xenus cinereus*	Marine, migratory	Not listed	Sheltered coastal mudflats, mangrove swamps
Wandering Whistling Duck	*Dendrocygna arcuata*	Marine	Not listed	Rivers, billabongs, pools and lakes
White-bellied Sea-eagle	*Haliaeetus leucogaster*	Marine	Not listed	Coasts, floodplains, rivers
Whimbrel[1-4]	*Numenius phaeopus*	Marine, migratory	Not listed	Primarily coastal distribution
Wood Sandpiper[1-4]	*Tringa glareola*	Marine, migratory	Not listed	Coasts, floodplains, rivers
		REPTILES		
Estuarine Crocodile[1]	*Crocodylus porosus*	Marine, migratory	Not listed	Marine, freshwater
Merten's Water Monitor	*Varanus mertensi*	Not listed	Vulnerable	Creeks and billabongs

[1]Bonn; [2]China Australia Migratory Bird Agreement; [3]Japan Australia Migratory Bird Agreement; [4]Republic of Korea-Australia Migratory Bird Agreement

Although they are not listed in conservation acts, frugivorous and nectivorous birds as a functional group are also recognised by ERA as important for rehabilitation and ecosystem establishment due to their role in pollination and flora species dispersal (Caves et al 2013, Frick et al 2014). Due to these critical ecosystem services, they have been included under external exchanges closure criteria (refer *Section 8*). The frugivorous and nectivorous birds that will potentially occur within the rehabilitated Ranger mine site identified by Dr John Woinarski are listed in Table 5-58.

Table 5-58: Frugivorous and nectivorous bird species that may occur within the rehabilitated Ranger Mine site

Common Name	Scientific name	Importance of fruit*	Importance of nectar*
Australasian Figbird	*Sphecotheres vieilloti*	1	
Banded Honeyeater	*Cissomela pectoralis*		1

Common Name	Scientific name	Importance of fruit*	Importance of nectar*
Bar-Shouldered Dove	*Geopelia humeralis*	2	
Blue-Faced Honeyeater	*Entomyzon cyanotis*	2	1
Brown Honeyeater	*Lichmera indistincta*		1
Channel-Billed Cuckoo	*Scythrops novaehollandiae*	1	
Dusky Honey-Eater	*Myzomela obscura*		1
Eastern Koel	*Eudynamys orientalis*	1	
Great Bowerbird	*Phalacrocorax carbo*	2	
Helmeted Friarbird	*Philemon buceroides*	2	1
Little Friarbird	*Philemon citreogularis*	2	1
Little Shrike-Thrush	*Colluricincla megarhyncha*	2	
Mistletoebird	*Dicaeum hirundinaceum*	1	
Northern Rosella	*Platycercus venustus*	2	
Olive-Backed Oriole	*Oriolus sagittatus*	2	
Red-Collared Lorikeet	*Trichoglossus haematodus*	2	1
Red-Winged Parrot	*Aprosmictus erythropterus*	2	2
Rose-Crowned Fruit-Dove	*Ptilinopus regina*	1	
Rufous-Banded Honeyeater	*Conopophila albogularis*		1
Rufous-Throated Honeyeater	*Conopophila rufogularis*		1
Silver-Crowned Friarbird	*Philemon argenticeps*	2	1
Spangled Drongo	*Dicrurus bracteatus*	2	
Torresian Imperial Pigeon	*Ducula bicolor*	1	
Varied Lorikeet	*Psitteuteles versicolor*		1
White-Bellied Cuckoo-Shrike	*Coracina papuensis*	2	
White-Gaped	*Lichenostomus*	2	1

Common Name	Scientific name	Importance of fruit*	Importance of nectar*
Honeyeater	*unicolor*		
White-Throated Honeyeater	*Melithreptus albogularis*		1
Yellow Oriole	*Oriolus flavocinctus*	1	
Yellow-Throated Miner	*Manorina flavigula*		2

*A value of 1 indicates that most of the diet is fruit, or nectar. A value of 2 indicates that fruit, or nectar is important, but other dietary items are more important.

5.4.6.2 Reference vertebrate monitoring on the RPA and surrounding Kakadu NP

Recolonisation of fauna into rehabilitated areas, in part, depends on the proximity to sources of fauna in surrounding areas. The Ranger FLF will be surrounded by relatively healthy woodland and is therefore close to sources of native fauna.

A variety of fauna surveys in the RPA and surrounds were conducted historically for purposes not specifically related to mine closure. Fauna surveys performed prior to 2010 were reviewed by ENV Australia Pty Ltd (Firth 2012) during the pre-feasibility study for the Ranger 3 Deeps mine development. The literature review synthesised 26 reports that presented results of vertebrate and invertebrate fauna surveys from 1993 – 2010, in addition to flora and aquatic ecosystem surveys (Firth 2012). Although these surveys contain valuable historical baseline data, they no longer represent the current status of fauna in Kakadu NP, particularly in regard to declining small mammal populations. Therefore, these early surveys have not been included in recent considerations for fauna species that have the potential to recolonise the rehabilitated Ranger mine (SLR Consulting 2021).

In 2020, SLR Consulting Australia Pty Ltd. (SLR) were engaged to provide an updated native vertebrate fauna species list for ERA, based on survey data from suitable savanna woodland sites geographically close to the RPA (SLR Consulting 2021). The species list and spatial database was based on four monitoring programs undertaken post-2012 (Eco Logical Australia 2013, Eco Logical Australia 2016b, SLR Consulting 2019, Einoder et al. 2019) (Table 5-59, Figure 5-139). The report identified a total of 177 native vertebrate species across 35 survey sites, including 15 amphibians, 104 birds, 15 mammals and 38 reptiles. These species could be expected to occur on the rehabilitated Ranger FLF. The full list of species is presented in Appendix 5.6.

Table 5-59: Summary of surveys used for SLR Consulting 2021 analysis

Reference	Survey area	Survey techniques
ELA 2014	Within the Ranger Project Area (RPA) between the mine footprint and Magela Creek.	Elliott, cage, cameras and funnel traps, bird census, nocturnal active searches
ELA 2016	Within the RPA, and Kakadu National Park (KNP) up to 11 km from the mine footprint.	Funnel and camera traps, bird census
SLR 2019	Within the RPA up to 5.5 km from the mine footprint, includes sites on the trial landform.	Cage, Elliott, funnel, pitfall and camera traps, nocturnal and diurnal active searches
Einoder et al. 2019	KNP up to approximately 45 km from the mine footprint.	Cage, Elliott and pitfall trap, instantaneous bird census, nocturnal and diurnal active searches

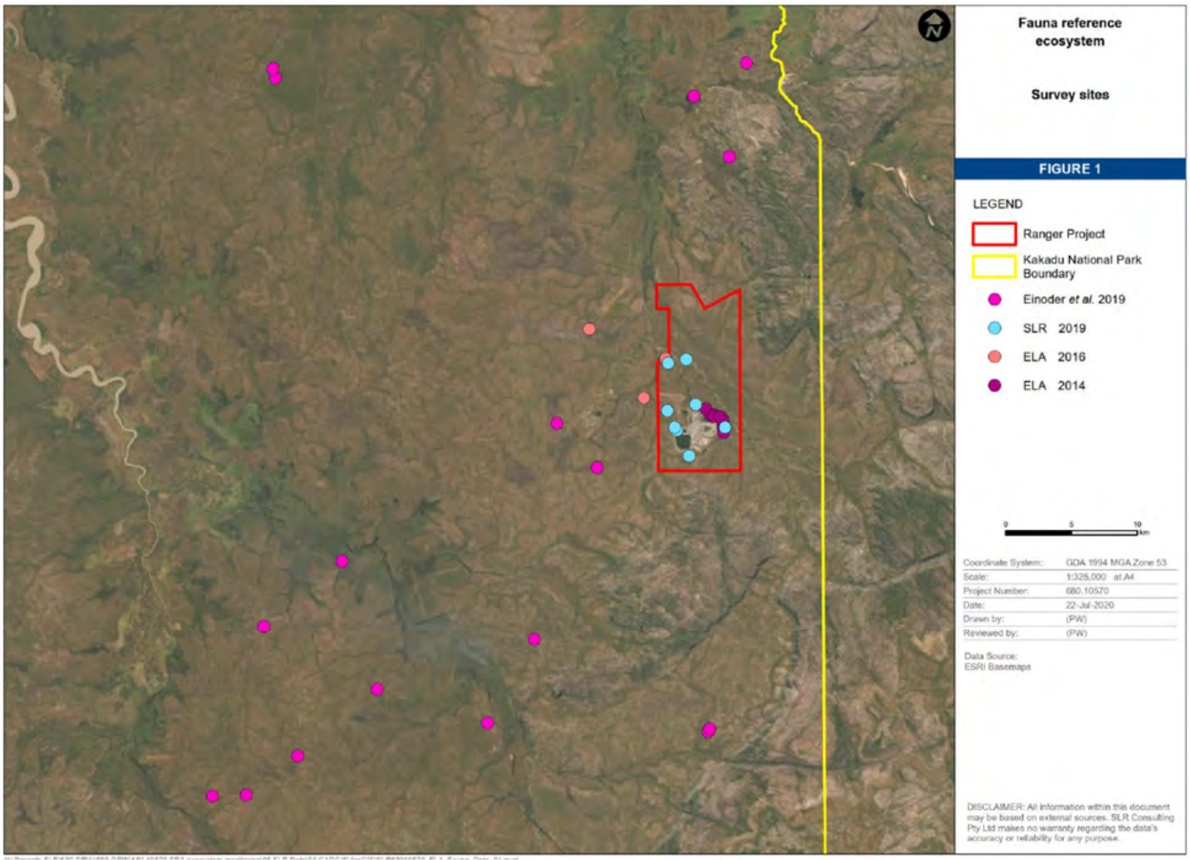


Figure 5-139: Fauna survey site locations across RPA and Kakadu NP (SLR Consulting 2021)

5.4.6.3 Vertebrate colonisation on revegetated waste rock landforms

Extensive fauna studies on historical revegetation trial areas on waste rock dumps in the RPA demonstrated that the array of vertebrate fauna living on the revegetated waste rock dumps was typical to that found in similar habitats of Kakadu NP (Corbett 1999) . One notable exception was the absence of possums and other arboreal groups, which was likely due to the absence of extensive stands of mature trees with hollows (discussed further in later sections). It was hypothesised that one of the major reasons for the relatively high fauna density on the waste rock dump was "… good feral animal control to minimise predator impacts on founder populations" (Corbett 1999).

There were many incidental sightings of fauna on the TLF within the first few years, including visiting dingoes and Agile Wallabies (Macropus agilis). Lizards, frogs and many birds were also observed. Small mammal trapping also found the Common Rock-Rat (Zyzomys argurus) inhabiting the landform (Collier & Hooke 2011). Although the individuals weren't directly observed, Bandicoot tracks/scratchings started appearing after three years. Birds began recolonising and nesting on the TLF in 2013 (Gellert 2014), and excitingly, Partridge Pigeons nested and had offspring in the waste rock only sections in 2015 and 2016 (Figure 5-140). A community of Bush Stone Curlew (Burhinus grallarius) also took up residence for a few years in the laterite mix sections from approximately 2014 - 2017. More regular snake sightings began around this time, particularly in the footage captured from the erosion plot monitoring.

The two tubestock-only sections of the TLF were monitored for vertebrate fauna as part of a larger survey conducted in late wet season 2019 (SLR 2019). The waste rock only site (1A) had 16 native fauna recorded, including 8 birds, 1 mammal and 7 reptiles, and the laterite mix section (3) had 14 native fauna recorded, including 8 birds, 1 mammal and 5 reptiles. Some of the species observed included Common Rock-Rat, Black-Necked Snake-Lizard (*Delma tincta*), Bynoe's Gecko (*Heteronotia binoei*), and Northern Brown Snake (*Pseudonaja nuchalis*). The TLF sites had similar species richness of reptiles and mammals compared to the other RPA sites, but bird richness was lower. No amphibians were observed at the rehabilitated sites during this survey; however, amphibian presence was variable across all the RPA sites (0 – 10 species).


Figure 5-140: Partridge Pigeon on waste rock section of the TLF

5.4.6.4 Invertebrate colonisation on revegetated waste rock landforms

Invertebrates are critically important for a sustainable and functioning rehabilitated ecosystem, as they mediate key ecological processes and are an important food source.

The historical revegetation trials established on waste rock at Ranger Mine in the 1980s were surveyed for ants, in addition to unmined control sites (Andersen 1993). The revegetated sites were first colonised by species of *Iridomyrmex*, with a broad range of species colonising the sites over the initial vegetation establishment phase; however, ant species succession soon stalled due to the dominance of fast-growing Acacias which resulted in heavy litter and considerable shade (Andersen 1993). After eight years, the revegetated sites had roughly a third of ant species compared to the unmined sites (12 compared to 33-35), with the most abundant species being an exotic. Fire management to control the Acacias improved ant recolonisation into the revegetated areas (Andersen 1993).

Insects were incidentally observed on the TLF soon after revegetation. When the ecosystem was nine years old in 2018, invertebrate surveys were performed on the TLF and in natural reference sites surrounding Ranger Mine in the dry season (Andersen & Oberprieler 2019) (Figure 5-141). Species richness was far higher at reference sites compared with the TLF. Surveys from the reference sites yielded 105 ant species from 25 genera, whereas the TLF sites yielded 31 species from 16 genera; the reference sites also collected 37 species of beetle, mutillid wasps and zodariid spiders compared to only 10 at the TLF sites (Andersen & Oberprieler 2019). Species composition was also highly dissimilar. This is to be expected considering the TLF's early stage of revegetation (Andersen & Oberprieler 2019), and encouragingly, the overall ant abundance was similarly high at the reference and TLF sites, with *Iridomyrmex* ants among the most abundant.

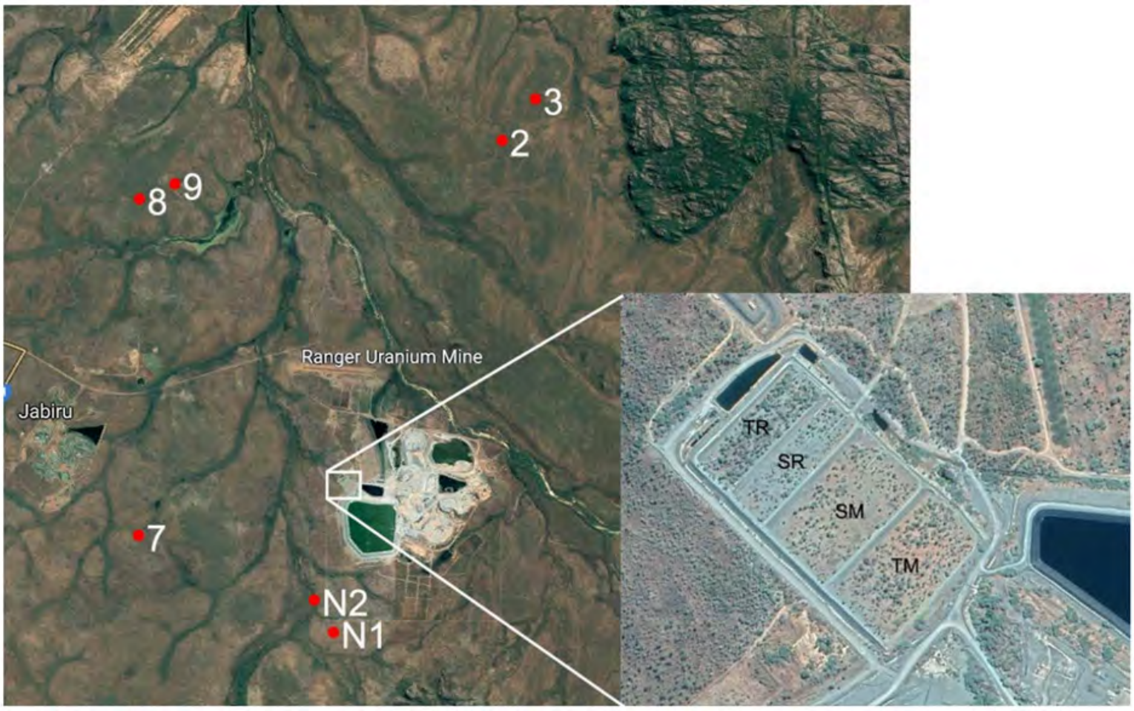


Figure 5-141: Location of the 2018 invertebrate study, with four TLF revegetation sites and seven natural reference sites (Andersen & Oberprieler 2019)

5.4.6.5 Fauna habitat creation

In addition to proximity to sources of fauna, successful fauna recolonisation primarily depends on the presence of suitable habitat for species, with the development of mature vegetation communities correlating with increased species diversity across numerous taxa. The presence of vegetation communities is often used as an indicator of vertebrate recolonisation in mine closure (Cross et al., 2019, Cristescu et al., 2012), although invertebrate recolonisation is typically addressed directly (King et al. 1998, Andersen et al. 2002, Hoffmann and Andersen 2003, Lawes et al. 2017). Important fauna habitat features within vegetation communities include tree hollows, rocks of various sizes, leaf litter, coarse woody debris, and even bushy grasses and palms. Other key considerations are the presence of energy sources (flowers, seed, fruit, leaves, insects etc.) and perching branches for birds. Certain habitat features need to be carefully planned and engineered during the landform construction phase (eg. rocky habitats, discussed in *Section 9*), whereas many other features will develop naturally during the early stages of ecosystem establishment as long as appropriate flora species are introduced.

Tree hollows provide important habitat for various taxa, which include many species that are hollow-dependent (Taylor *et al.* 2003, Goldingay 2009, Goldingay 2011, Lindenmayer *et al.* 2014). Many hollow-forming NT eucalypt woodland tree species/genera (Woolley et al. 2018) are included in the current Ranger revegetation species list (Appendix 5.5). However, hollows can take over a century to form, therefore recolonisation of hollow-dependent species into rehabilitated landscapes is considerably slower than other fauna groups.

ERA began exploring the use of nest boxes in rehabilitated ecosystems in 2019, with the construction of five designs targeting different fauna groups (Table 5-60). The nest box designs were based on advice from Dr John Woinarski and Dr Leigh-Ann Woolley (CDU), as well as Palmerstone Men's Shed. It is recognised that nest boxes cannot replace all the attributes provided by natural hollows; however, they may still provide valuable habitat in rehabilitated areas where no natural hollows are available (SLR 2022a). They can also be used to demonstrate that, with time, rehabilitation areas will become suitable for hollow-dependent species.

In 2021, SLR were engaged to advise on a nest box trial design and implementation plan (SLR 2022a) which was endorsed by stakeholders at the May 2022 ARRTC. The trial will investigate the use of the five nest box designs in three types of sites across the RPA; rehabilitated (on the TLF), modified/disturbed (in the LAAs) and control (in undisturbed woodlands) (Figure 5-142). There will also be 'natural' woodland sites which will only have fauna cameras recording natural hollows as a control for the nest box sites. A ground-truthing, 'reconnaissance' week in June 2022 identified suitable sites and individual trees for camera and nest box installation (SLR 2022b). Construction of additional nest box replicates for the trial is underway and should be completed by October 2022 for installation.

Table 5-60: Nest box design and rationale

Nest Box Type and Rationale	Design
Small arboreal mammal Designed for attracting threatened species such as the Black-footed Tree Rat (*Mesembriomys gouldii*).	
Large arboreal mammal Designed for possums and gliders but may also attract large climbing lizards such as goannas.	

Nest Box Type and Rationale	Design
Small bird Designed for small birds such as finches, particularly if a good ground cover of suitable local native grasses can be established.	
Medium bird Designed for medium size parrots such as the Red-winged Parrot (*Aprosmictus erythropterus*) and Red-Collared Lorikeet (*Trichoglossus haematodus*).	
Microbat Designed to imitate narrow crevices for microbat roosts.	

Figure 5-142: Next box trial site locations (from SLR 2022b)

5.4.6.6 Future work on native fauna

- Full installation of the nest box trial is aimed to be completed before the end of 2022, with ongoing monitoring of the boxes and hollows for at least one year.
- ERA will continue to develop their understanding of habitat requirements for fauna recolonisation of rehabilitated landforms, and potentially undergo more ad hoc, opportunistic trials to encourage faunal establishment.
- Continue to monitor fauna recolonisation into rehabilitated areas, and develop monitoring methods and metrics for closure criteria.

5.4.7 ESR5 Develop a restoration trajectory for Ranger Mine

KKN title	Question
ESR5. Develop a restoration trajectory for Ranger Mine	ESR5A. *What are the key sustainability indicators that should be used to measure restoration success?*
	ESR5B. *What are possible/agreed restoration trajectories (flora and fauna) across the Ranger mine site; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the mine site, including Kakadu National Park?*

5.4.7.1 Background

State and transition (S&T) models are non-linear conceptual models (that can include quantitative information), which organise information about ecosystem change (Bestelmeyer et al. 2017). A S&T model describing desirable and undesirable transitions along possible rehabilitation trajectories at Ranger mine was developed by scientific, industry and local ecology experts at a workshop in April 2019 (CSIRO, 2020). The development of a S&T model that articulates possible rehabilitation trajectories should lead to better predictions of when rehabilitated sites will move to sustainable ecosystems that no longer require additional management intervention, including articulation of points along the desired trajectory that represent milestones linked to closure criteria (Section 8).

Another key element of S&T models is the development of adaptive management plans for ecosystem rehabilitation that is linked to and guides monitoring and maintenance activities. For ERA these will be detailed within a series of Trigger Action Response Plans (TARPs, discussed in Section 10) (Figure 5-143).

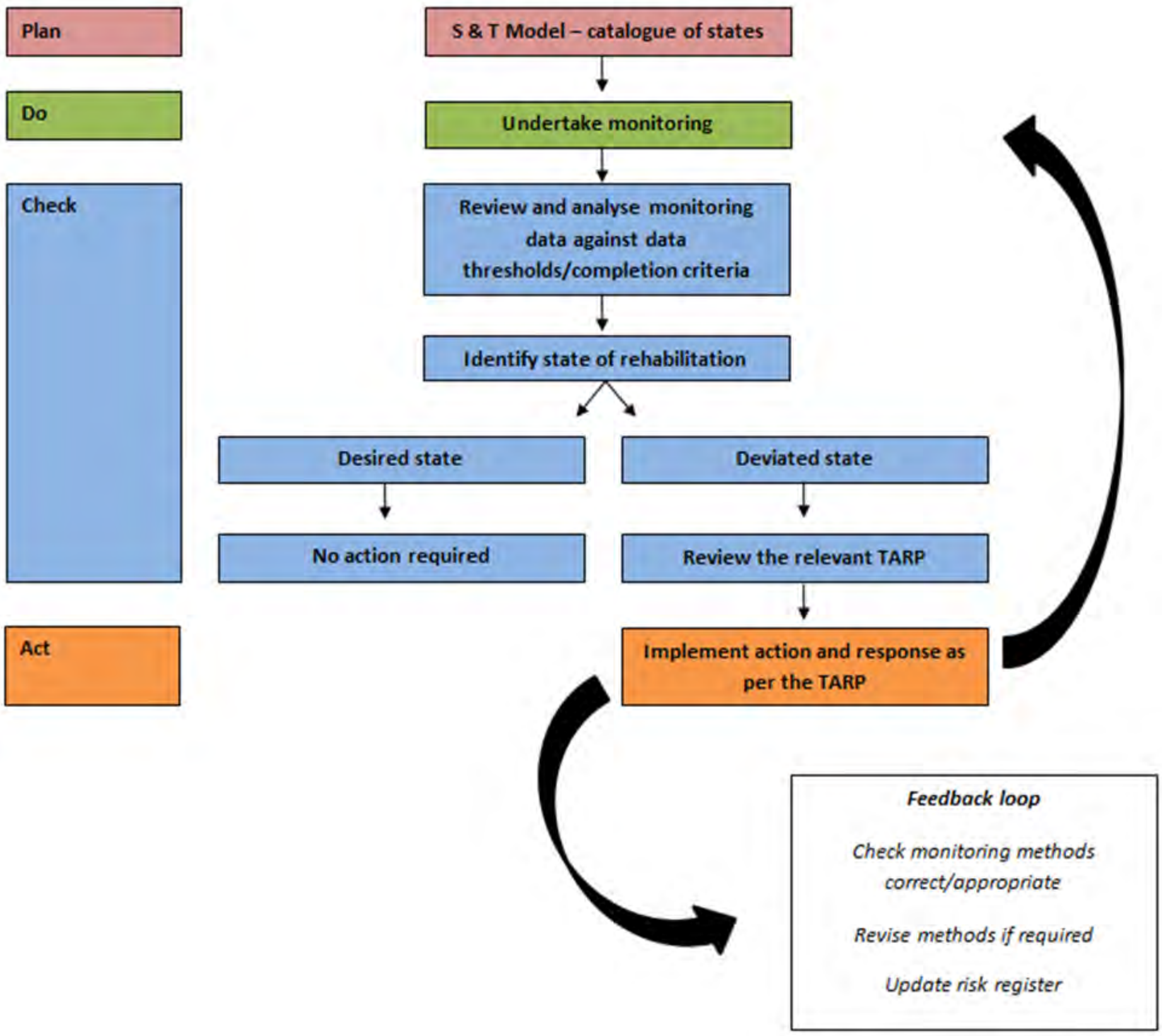


Figure 5-143: Flowchart showing relationship between S&T model and TARPs

5.4.7.2 CSIRO Trajectories Project

As part of the S&T model development process, workshop participants described candidate end states in detail, using the archetype reference dynamic ecosystem model for a wet-dry tropical Eucalypt woodland from the AusEcoModels project as a guide (Figure 5-143). The model was refined and quantified during the workshop. Detailed descriptions of the ecosystem attributes of the five reference ecosystem expressions in the archetype model in Figure 5-144 were developed for the Ranger mine site (CSIRO, 2020). A summary of the S&T model for Ranger mine rehabilitation is shown on Figure 5-145. The axes labels represent qualitative indication of increasing complexity of state attributes over developmental time (ie through the establishment, intermediate and end phases).

The detailed descriptions include descriptions of the three desired end states in the Ranger S&T model (refer to Figure 5-145):

- S1 (Ideal).

- S2 (Ideal_dry).
- S3 (Ideal_function).

Each rehabilitation state is described in CSIRO (2020) using ecosystem attributes related to structure, composition, function, abiotic and landscape characteristics. Each desired and deviated rehabilitation state has been individually modelled to show the potential transitions it could undergo and the resulting states (CSIRO 2020).

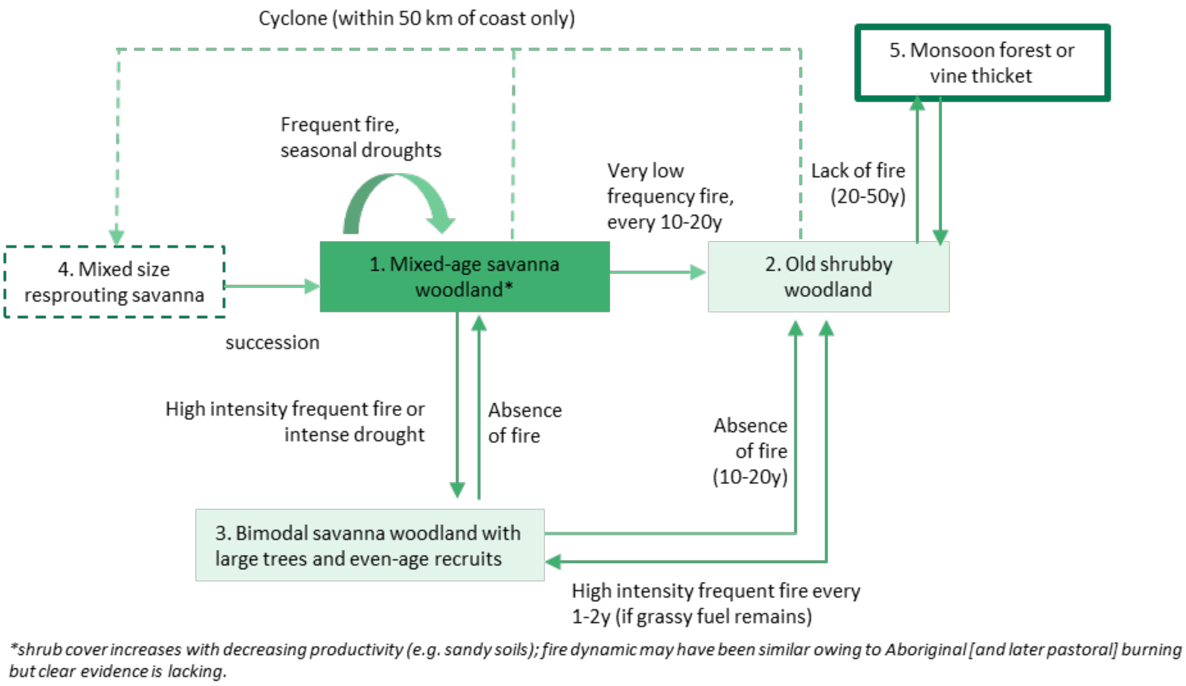


Figure 5-144: Wet-dry tropical woodland archetype reference dynamic ecosystem model (diagram from CSIRO 2020)

The threats (or drivers) of change in rehabilitation state, and management interventions that could be implemented to return rehabilitation states to a desirable trajectory, were identified in the workshop. All possible transitions between rehabilitation states (informed by the list of threats and management interventions), the indicative timeframe for transition to occur, and any pre-conditions (often climate or landscape processes external to the site) were also identified in the workshop (CSIRO, 2020). Transitions are defined as a shift to another state which is not reversible without active management intervention, an extreme event or unacceptably long timeframe.

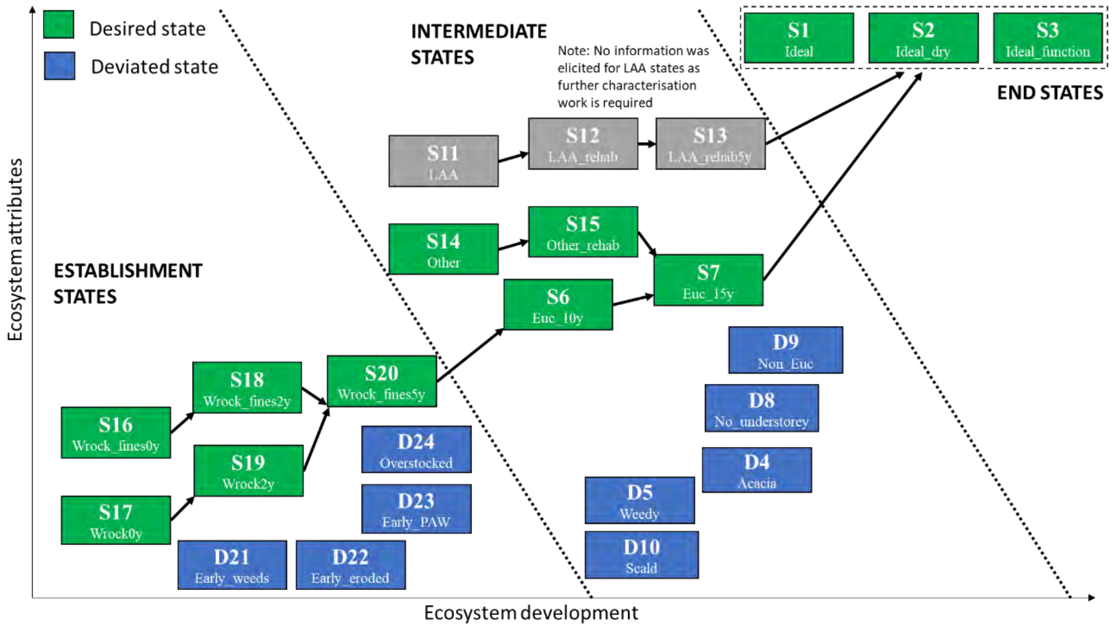


Figure 5-145: Pictorial summary of an S&T model for Ranger mine rehabilitation (diagram from CSIRO 2020)

5.4.7.3 Development of the ERA S&T Model

A first draft of the ERA S&T model report, which builds on the CSIRO (2020) model, was completed April 2021. It included Ranger-specific quantitative and qualitative data derived from previous research and experience on initial and intermediate phase rehabilitated landforms. Themes included: substrate physical, chemical and microbial characteristics (Section ESR7); flora species composition, vegetation community structure, reproduction and recruitment (Section ESR3); and ecosystem resilience (Section ESR8). Unearthed Environment Services Pty Ltd (UES) were then engaged by ERA to critically review and revise the 2021 report. Some key initial observations were (Grant & Grant 2022):

- The form of the S&T model had too many components to meet the ultimate purpose of the model, which is to identify desired and deviated states, aligned to agreed closure criteria to drive maintenance and management activities to facilitate relinquishment.
- Suggest that the model only contains a simplified version of the TARPs, which would reduce the complexity of the model by more than 50% and make it more aligned with the identified purpose.
- That LAAs and ‘other disturbed’ states be removed from the main S&T model, so that focus can be on waste rock landform rehabilitation. If needed, separate models can be created for the other scenarios.
- Focus on the wholistic characteristics of each state and not the individual abiotic and biotic factors as they were represented in the 2021 report.

- That the short-term focus of the model should be on the ecosystem establishment techniques and identifying early deviated states and the required management activities to bring these back onto the desired successional trajectory. A particular focus should be on early intervention (e.g. monitoring of keystone ecosystem elements at 1-2 years of age).
- There are many more desired states on the desired trajectory, but the focus is on identifiable ecosystem states related to the potential crossing of a management threshold to a deviated state through an undesirable transition.
- That the S&T model development needs to be an iterative process, and revised as more data becomes available over times, particularly for intermediate states. Importantly, the model needs to 'live' through implementation of ecosystem establishment techniques and monitoring and management activities, followed by incorporation of learnings into the S&T model.
- Further data is required to be fitted into the proposed (and agreed) S&T model, which will help to identify knowledge gaps and associated actions to address these.

From this review, UES were reengaged in February 2022 to facilitate the further work required to rapidly develop a 'fit-for-purpose' S&T model, which could be used as a practical management tool to help drive rehabilitated areas along the desired successional trajectory towards the identified end state. A report on the proposed new framework of the S&T model was delivered and presented to stakeholders at ARRTC #50 in May 2022 (Grant & Grant 2022), then feedback was incorporated into a new model framework (Figure 5-146).

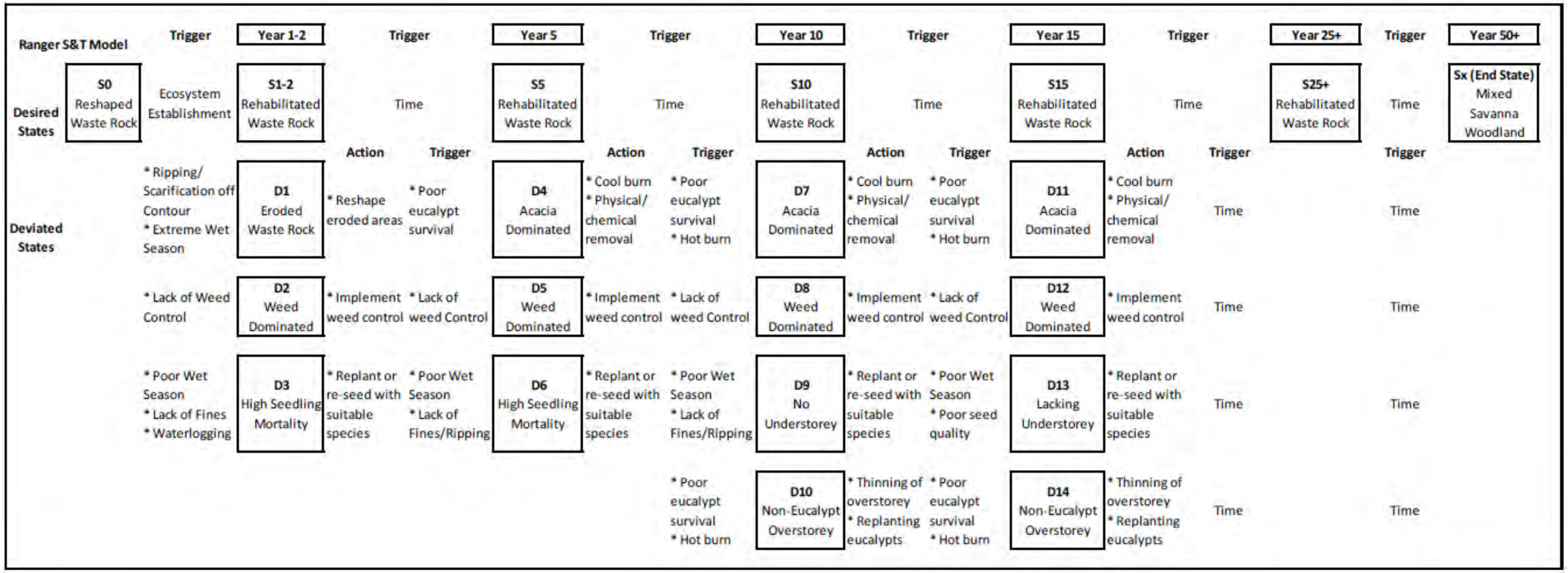


Figure 5-146: Diagram summarizing the updated model for Ranger Mine waste rock rehabilitation

The simplified and more concise version of the Ranger S&T model was developed following the below principles (Grant & Grant 2022):

- Removal of desired and deviated states related to utilization of fines (i.e. laterite) material as this is not a viable broad scale ecosystem establishment technique at Ranger.
- Re-numbering of desired states to reflect the age of the rehabilitated areas (e.g. desired state at year ten is called S10), leaving seven desired states remaining in the model with high level definition of abiotic and biotic characteristics (where available).
- Simplification of a single desired end state of mixed savanna woodland, instead of the five ecosystem types and three climate scenarios previously identified (CSIRO 2020).
- Identification of deviated states for each key time category (i.e. Year 1-2, 5, 10 and 15, 25+ yet to be determined), leaving 14 deviated states in the model with high level definition of abiotic and biotic characteristics.
- Duplication of key relevant deviated states across the time categories (e.g. weed dominated for all key time categories except the end state) and removal of deviated states identified at the 2019 workshop which will not realistically occur on the Ranger Min rehabilitation.
- Identification of key triggers and actions for desirable and undesirable deviations based on the developed TARPs, with further detail provided in an associated spreadsheet.

Some key abiotic and biotic characteristics of the 6 identified desired states and 14 deviated states were populated in the report and associated spreadsheet (Grant & Grant 2022). However, additional sourcing of data was necessary to incorporate into the model to address gaps and uncertainties in the expected trajectories. A week-long ‘S&T model intensive’ was conducted in August 2022 to source additional data from archives and relevant people. As well as considerable data and report sourcing, the week involved over 15 interviews with various people that currently and/or historically have been involved in rehabilitation research, execution, monitoring and/or management at Ranger mine, the Alligator Rivers Region, and northern Australian.

5.4.7.4 Future Work on the ERA S&T Model

Immediate future development of the ERA S&T model will be focussed on:

- Consolidating and synthesising collected data on abiotic/biotic characteristics of desired and deviated states, and successful management actions, so that they can be populated into model.
- Identify existing gaps and develop standardised monitoring program to fill gaps (where possible).

- Identify any additional sources that may have relevant information where gaps cannot be directly filled with further monitoring.
- Develop a spatial information system (e.g. ArcGIS) to store monitoring data relating to the achievement of identified closure criteria and facilitate identification of required management activities.
- Review and update ecosystem rehabilitation TARPS (Section 10).
- Continued development of the adaptive management plan, including outlining critical uncertainties for key measurable thresholds and deviated state mitigation or reversal scenarios.
- Consider development of separate S&T model for the LAA and other disturbed areas.

5.5 Cross theme

5.5.1 CT1 Assessing the cumulative risks of rehabilitation on-site and to the protection of the off-site environment

KKN title	Question
CT1. Assessing the cumulative risks of rehabilitation on-site and to the protection of the off-site environment	CT1A. *What are the cumulative risks to the success of rehabilitation on-site and to the off-site environment?*

The Phase 1 *Ranger rehabilitation and closure risk assessment* was the problem formulation phase for rehabilitation/closure, an ecological risk assessment for the mine site as well as a landscape scale risk assessment and how the two assessments can be linked. A workshop was conducted for the problem formulation phase to develop initial conceptual models (CM) of potential stressors and pathways around four themes; aquatic ecosystems; terrestrial ecosystems on the RPA; terrestrial ecosystems in the landscape; and people (Pollino *et al.* 2013). The workshop focus included defining endpoints; sources, stressors and values associated with mine closure; developing conceptual models and identifying key knowledge gaps. A report was produced by Pollino *et al.* (2013) which details background material, and the values and draft conceptual models produced during the workshop. The report also recommended adopting the AS/NZS ISO 31000:2009 generic framework to ensure outputs of risk assessments are best practice.

Phase 1 developed CMs identifying potential stressors and consequences to a set of aquatic, terrestrial and human endpoints (Bartolo *et al.* 2013). For the people theme, two conceptual models were developed for cultural landscape and human health. The human health model was considered outside the scope of the workshop to be considered at a later date. For the CMs that remained in scope, close to 100 potential hazards were identified. Whilst many of the hazards were considered important, they were not mine related and/or subject to management through the mine closure process. Some have very low likelihoods of occurrence or insignificant consequences if they were to occur.

Phase 2 was the risk screening phase for rehabilitation and closure. The screening methodology employed used input from 16 key experts and was consistent with ISO risk standards to ensure it defensible and transparent (Pollino 2014). Preliminary screening prioritised efforts for the risk analysis phase, providing spatial context and focus on aquatic and terrestrial systems and human health. Likelihoods were expressed as either probability for long-term (chronic) impacts, or event frequencies with a recurrence interval (Pollino 2014).

Hazard rankings were highest in the RPA, with weeds and feral animals being the highest ranked hazards, followed by sediment and radionuclides. Solutes and metals ranked lower and overall hazards to humans received a low ranking. Risk rankings were also highest in the RPA, with weeds and feral animals again ranked highest, followed by sediment and impacts of vegetation from fire and waste rock. As with hazards, solutes and metals were ranked lower and overall, risks to humans also received a low ranking.

A KKN CT1 project identified weeds as the most significant non-mining threat to the Kakadu landscape and wetlands (Waldon & Bayliss, 2003). This project describes the wetland risk assessment for three weed species, Mimosa (*Mimosa pigra*), Salvinia (*Salvinia molesta*) and Para Grass (*Urochloa mutica*).

Most Kakadu National Park floodplain habitats, including the Magela catchment, are susceptible to extensive mimosa invasion. Salvinia will never be eradicated and is considered a permanent component of Kakadu's flora (Waldon *et al.* 2012). There are 35 para grass infestations on the Magela floodplain. A significant proportion of the Magela floodplain (~35–50%) could potentially be invaded by para grass in the future. The overall findings of the landscape environmental risk assessment imply that non-mining landscape-scale risks to Magela floodplain should receive the same level of scrutiny as uranium mining risks, including assessing what is needed to manage these risks. Diffuse landscape scale risks are currently several orders of magnitude greater than point source risks to Magela surface waters from the Ranger Uranium Mine, with para grass contributing most to the overall landscape risk.

Compared to climate change timeframes, management and monitoring for the closure prior to site stabilisation and close out has been achieved, found the risk profile for the mine closure was fairly low for climate related risks. A number of impacts are associated with the risks are scenarios beyond 2050 outside of the influence of closure. Risks considered include increased temperatures, and subsequent evaporation impacts on flora and fauna, rising sea levels, erosion and runoff, bushfires. Further detail on these risks is presented in section 5.6.

Climate change implications for mine closure will be actively managed, predominantly related to the revegetation and soil management on site ensuring the site will be in suitable condition for reliquishment. In the longer term, most climate change risks are landscape in nature and will affect the entire park. These risks will require management through local land management practices. Further detail on potential mitigation measures for future climatic conditions is presented in section 5.6.

A cumulative risk assessment (RES-2017-032) combining both Phase 2 (aquatic pathways) as well as qualitative modelling of Phase 1 (on-site risks) is being reviewed (Harford, 2021). Terrestrial and aquatic qualitative models were developed for the Ranger mine-site rehabilitation. Fire and weeds are primary factors that could significantly affect the success of terrestrial ecosystem rehabilitation where effective weed management would offer the greatest benefit. In aquatic ecosystems, higher trophic levels are supported by key aquatic taxonomic groups, indicators that can measure ecosystem health.

Qualitative modelling adds value to current and future risk assessment approaches by confirming importance of identified high risks, reducing system complexity enabling focus on key risks, predicting outcomes of risk interactions, and identifying where mitigations would be most effective.

5.5.1.1 Aquatic ecosystem assessment & framework development

Commonwealth ERs specific to the protection of water quality and the closure of Ranger Mine specify different objectives for waters leaving the RPA and those on the RPA:

- *Waters leaving the RPA do not compromise the achievement of the primary environmental objectives (ER 3.1) related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds (ER 1 and 2).*
- *Impacts on the RPA are ALARA (ER 1.2e).*

The SSB has recommended rehabilitation standards for concentrations of COPC leaving the RPA to protect biodiversity. These are based on ecotoxicity testing of local species, mesocosm studies, field macroinvertebrate and fish studies and are designed to protect 99% of species. Recent studies (Trenfield *et al* 2021) have shown that the individual guideline values for 99% species protection will adequately be protective for downstream ecosystems where there is a potential for exposure mixtures of the contaminants of concern. These apply at the RPA lease boundary to protect biodiversity. Closure criteria for water quality on the RPA is to be based on impacts that are ALARA as described in Sections 6.3 and 8.3.

An understanding of the potential impacts of different concentrations of mine-related COPC on aquatic biodiversity, and the endpoints representing the other primary environmental objectives, ie, ecosystem processes, Kakadu NP World Heritage values (including culturally sensitive species) and Ramsar values is required. This will help to understand what the impacts are and inform an assessment of whether they are ALARA.

ERA contracted BMT Ltd. to develop a practical and transparent framework to assess effects of COPCs on receiving environments within the RPA during the closure phase, with an initial focus on magnesium (Mg). BMT has been working with ERA and stakeholders since 2017 on this three-phase project. The project builds on best practice frameworks for protection of key ecological and community values (CVs), most notably ANZG (2018) and the *National framework and guidance for describing the ecological character of Australian Ramsar wetlands* (DEWHA 2008). The tasks for each of the Project phases are shown in The project phases are shown in Figure 5-147.

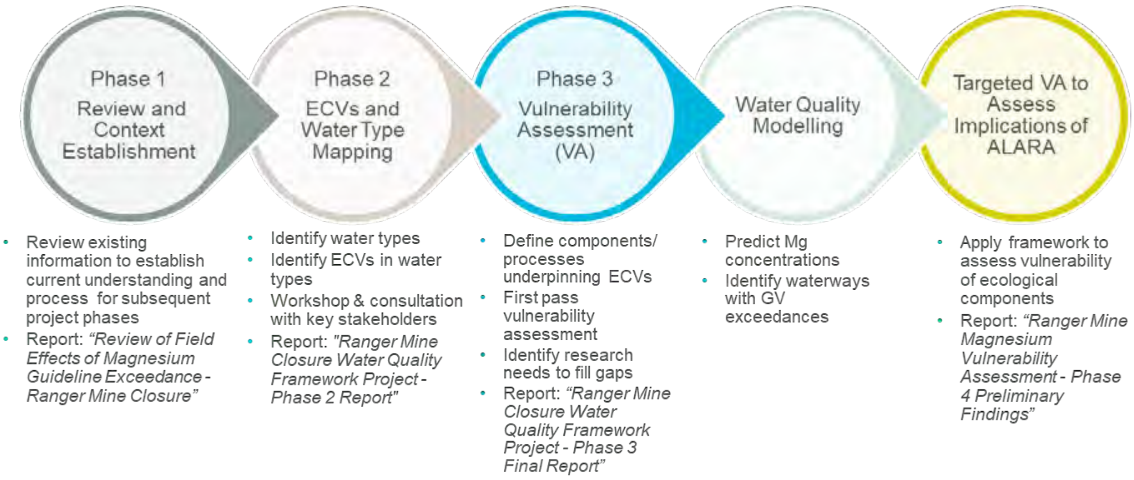


Figure 5-147: Ranger Mine Closure Water Quality Framework Project phases

The Project phases are described in the following sections:

5.5.1.2 Phase 1 (BMT WBM 2017)

This phase provided a review of spatial and temporal patterns in Mg concentrations and aquatic fauna within the waterways of RPA and downstream receiving environments. This Phase provided recommendations on the development of the water quality management framework for mine closure, with consideration given to legislative and policy requirements. Stakeholder feedback on the recommendations helped clarify the scope and role of third phase of the project and its application for future assessments.

5.5.1.3 Phase 2 (BMT 2018)

This phase steps through the initial stages of the ANZECC/ARMCANZ (2000) and ANZG (2018) water quality management frameworks to map and classify waterbody types on and off the RPA and identify CVs relevant to each waterbody type.

5.5.1.4 Phase 3 (BMT 2021)

This final development phase produced the framework to assess the vulnerability of aquatic ecological components underpinning CVs in the RPA to changes in Mg concentrations, and critical periods (i.e. reproduction, migrations, periods of stress) that are important to the maintenance of aquatic ecosystems in the RPA.

Aquatic ecosystems at and adjacent to the RPA support a wide range of biodiversity and cultural values (see BMT WBM 2010; 2017). Biodiversity values, and cultural values that are linked to biodiversity values[11], are composed of a variety of ecological features at different

[11] Note that cultural values not directly linked to biodiversity elements are not included in the scope of this project.

hierarchical levels (i.e. species, assemblages, habitats, ecosystems). These features vary in terms of their sensitivities to stressors such as Mg.

To understand vulnerabilities, there is a need to consider not only sensitivity at the individual organism level, but also how this translates to vulnerability at higher organisation levels – namely the local species population, assemblage, community/habitat and/or ecosystem level – and the capacity of biota to recover.

Vulnerability is based on the consideration of following elements (De Lange *et al.* 2010, Weißhuhn *et al*. 2018), depicted in Figure 5-148:

- level of exposure to stressors – which will be predicted by the surface water modelling project (discussed in next project phase below)
- sensitivities to stressors such as Mg, both in terms of direct effects and indirect flow-on effects to habitat and or food resources. This requires consideration of the biological traits of biota, and the structural and functional relationships between the organisms, and the abiotic environment
- capacity to avoid exposure or recover following a perturbation, such as exposure to a contaminant. This is also known as resilience or adaptive capacity

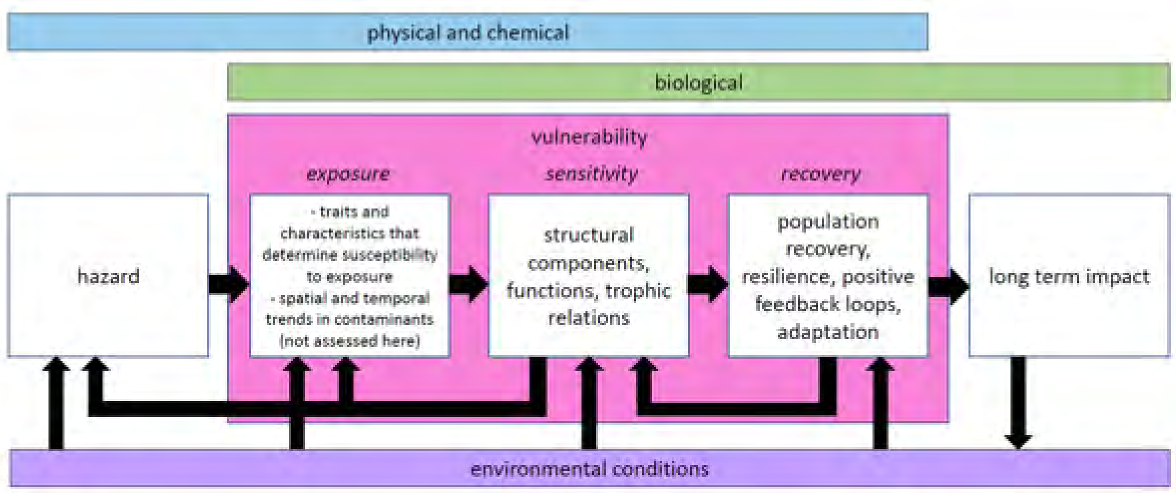


Figure 5-148: Modified version of the generalised ecological vulnerability assessment framework of De Lange et al. (2010)

Ecological vulnerability assessment fills the knowledge gap that exists between laboratory and field effects experiments on a sub-set of species or assemblages (i.e. the information underpinning the recommended SSB Rehabilitation Standards) to understanding risks to higher levels of organisation and/or to other species and species groups (De Lange *et al.* 2010). Ecological vulnerability assessment considers not only the direct sensitivity of organisms to a stressor, but also trophic and habitat relationships and therefore the potential for indirect flow-on effects.

This phase involved the development of a Vulnerability Assessment Framework (VAF) to aid the interpretation of modelling results, with a focus on the potential effects of Mg on CVs of the mine area. The specific objectives of this third phase were to:

- Describe the key processes underpinning the CVs of the RPA and surrounds, and how these change over seasonal time scales.
- Define the key ecological components [12] underpinning the CVs of the RPA and surrounds, and interactions with underpinning processes.
- Document the salinity (a proxy of Mg) concentrations for which key ecological components have been recorded and undertake a first assessment of the sensitivity of these components to Mg, as inferred from field observations and laboratory studies.
- Determine the sensitivity of key ecological components to changes in habitat and food resources, based on their specificity and the availability of habitat and food resources.
- Assess the capacity of key ecological components to avoid contamination exposure and recover following disturbance (both directly and indirectly from Mg) based on their life history traits.

Then, based on the above:

- undertake a first pass assessment of the vulnerability of ecological components to changes in Mg, and factors affecting vulnerability over time.
- Identify gaps in the knowledge based on aquatic ecological component vulnerability to Mg, and further research needs to fill these gaps.

A large literature review (~200 reports) was undertaken, and scoring matrices developed and tested to assess vulnerability of ecosystem components. This was done with input from a committee of subject matter experts comprised of representatives from ERA, the SSB, BMT and several external specialists. Learnings from this initial assessment (BMT 2019) were used to improve the assessment framework and process. Additional literature and lines of evidence were reviewed, scoring matrices updated and decision trees developed to understand vulnerability based on nine traits concerning exposure, sensitivity, and adaptive capacity. The nine traits are comprised of:

Direct Sensitivity – (1) Direct sensitivity of key species; (2) Sensitivity of species groups (assemblage structure). These attributes consider the Mg sensitivity of ecological components.

Distribution and Habitats – (3) Geographic range; (4) Habitat breadth; (5) Dependency on sensitive bio-physical micro-habitats (macrophytes, riparian vegetation). These attributes consider the resilience of populations and species to perturbations. Species that are range

[12] In the context of this Project, the term ‘ecological components’ is the collective term for key species (those with a high biodiversity and cultural significance) and species groups.

restricted, or are habitat specialists that rely on sensitive habitat resources, have poor resilience.

Movement Capacity – (6) Dispersal traits (recolonisation); (7) Dispersal traits (avoidance). The first of these attributes considers traits that enable rapid recolonisation following perturbation, which should be considered in the context of Reproductive Capacity attribute. The second attribute considers traits that enable organisms to evade sub-optimal water quality conditions, and the potential for avoidance behaviour to impact on the fitness of local populations or species.

Reproductive Capacity – (8) Generation Time/Fecundity. This attribute considers generation time (the average amount of time between two consecutive generations) and number of offspring. Species with short generation times that produce higher numbers of offspring are more likely to produce more genetic variant individuals to trigger adaptation. There are other traits that can influence reproductive capacity including offspring survival, life span and parental care that were also broadly considered if adequate data was available.

Dietary Flexibility – (9) Diet breadth. This attribute considers dietary specialisation. Dietary specialists are more likely to be affected by food resource limitation than dietary generalists.

This phase provided a first pass vulnerability assessment in the absence of water quality modelling to determine ‘exposure’ and also identified key information gaps regarding the vulnerability of biodiversity elements underpinning CVs.

5.5.1.5 Water quality modelling (WS3)

Solute transport modelling predicting the concentrations of COPCs on, and downstream of, the RPA following closure is completed (see WS3). The surface water modelling (WS3) produce predictive estimates of Mg concentrations in receiving environments during post-closure conditions and the vulnerability assessment (Phase 3) provides the tool to interpret the water quality modelling results, i.e. vulnerability of different environmental values should Mg exceed the guideline value. See section WS3 for more information about the water quality monitoring undertaken at Ranger.

5.5.1.6 Targeted Vulnerability Assessment (BMT 2022)

The vulnerability assessment framework (VAF) produced in phase 3 is a tool to understand what type of ecological change might occur at the different contaminant concentrations predicted by the water quality modelling. The first targeted vulnerability assessment was completed in 2021/2022 with a focus on contaminant concentrations as a result of the Pit 3 closure activity (Pit 3 related sources).

An interactive workshop was held in 2021 with key internal and external stakeholders and subject matter experts to:

- Identify target waterbodies and confirm ecological values to be assessed
- Seek feedback and agree on assessment criteria and data quality criteria

- Undertake scoring of geographic range and habitat breadth attributes to derive a refined list of ecological components

- Seek feedback and refine vulnerability scores and data quality scores

- Identify key knowledge gaps

The targeted VAF undertaken in 2021/2022 focussed on the following subject waterbodies: Coonjimba Billabong, Georgetown Billabong, Georgetown Creek and Magela Creek (end of RPA reporting point).

For the purposes of assessing vulnerability, predicted closure phase Mg concentrations for P10, P50 and P90 loads presented in the surface water modelling and worst-case scenario values were selected. Median (50%), 10% and 1% exceedance values were also provided (BMT 2022).

The operational water quality data as well as seasonal patterns were provided for context and on whether simulated Mg during closure is within or outside the range of operational phase values. Summary statistics (50^{th} , 90^{th} and 99^{th} percentile values) were provided for the period 2006/8 to 2014/18. The metrics were derived from ERA monthly electrical conductivity data converted to Mg based on the equation in Turner et al. (2015).

Seasonal water quality periods were taken into consideration i.e., full flow vs recessional flow. This provides context for evaluating whether the timing of Mg exposure is consistent year-round or is restricted to the recessional period when many important ecological processes occur (BMT 2021).

The species protection levels used in the assessment were based on laboratory ecotoxicity testing conducted by SSB.

Outcomes and further work

The targeted VAF (BMT 2022) reported that At Magela Creek, Georgetown Billabong and Georgetown Creek:

- Sensitive algae and invertebrates may be intermittently affected by Mg (concentrations slightly greater than the 99% water quality guideline value (WQGV)). These groups have high resilience and are expected to recover during periods of lower Mg. These components are considered to have moderate vulnerability.

- All other ecological components, including key species, vertebrate and vegetation assemblages, are considered to have low vulnerability at the individual organism level (and by extension local population level)

- This upper predicted Mg concentration in shallow groundwater at Magela Creek (Djalkmarra Sands location) is close to (but exceeds) the highest concentration tested by Hutley et al. (2001) for which no significant decline in riparian vegetation biomass occurred. The predicted Mg concentration in shallow groundwater at Magela Creek at the end RPA reporting site was 1-10 mg/L, which is well within the tolerance limits of the tested riparian tree species.

At Coonjimba Billabong (BMT 2022):

- Many algae and invertebrates, and some fish species (including some key species), would be affected by long-term, chronic exposure to Mg concentrations well above the 99% WQGV. While most ecological components have traits that allow rapid recovery from perturbations, ongoing exposure is likely to prevent this. These components are considered to have high vulnerability.

- There is a high degree of uncertainty regarding the response of aquatic macrophytes to Mg concentrations predicted to occur at Coonjimba Billabong. Many aquatic macrophytes species have EC_{MRF} (Maximum recorded field electrical conductivity) values less than the predicted Mg concentrations and are therefore potentially sensitive. However aquatic macrophyte monitoring at Coonjimba Billabong has not detected any change in structure (relative to pre-mining), despite having elevated Mg concentrations similar to (or slightly less) than predicted during closure.

- While most vertebrate fauna are not directly sensitive to Mg, any major shift in macrophyte cover /structure or food resources would be expected to have cascading indirect effects to these groups. These groups are tentatively classified as moderate vulnerability, however further work is required to evaluate this.

It should be noted that this targeted assessment did not consider the capacity of biota to acclimate to changes in environmental conditions, as discussed by BMT (2021).

The workshop and targeted VAF also highlighted areas with potential gaps in information and ERA/BMT and SSB undertook a fieldwork program in 2022 with the aim to address these gaps. The different components of field work were successfully undertaken as a collaboration project between ERA/ BMT and SSB. The components of the field program included Macrophyte mapping, Water quality and Phytoplankton Communities sampling, Periphyton Communities sampling, Aquatic Macrophyte Communities sampling, Aquatic Macroinvertebrate Communities sampling and e-DNA Analysis for Fish, Decapods, Vertebrates and Algae.

The results and report of this field program is being developed and will be reviewed by stakeholders prior to finalisation. The results will also initiate a revised targeted vulnerability assessment to confirm scores in the assessment.

The VAF findings will be used to inform risk assessments and the ALARA process (Section 6.3) for assessing the suitability of the mine closure strategy, apprising the need for mitigation activities, and supporting development of the RPA on-site water quality objectives representing impacts that are ALARA. Section 8.3.2.1 discusses how this work is used to support criteria development in Steps 7 and 8 of the national water quality management framework (ANZG 2018).

5.5.2 CT2 Characterising World Heritage values of the Ranger Project Area

KKN title	Question
CT2. Characterising World Heritage Values of the Ranger Project Area	CT2A. *What World Heritage Values are found on the Ranger Project Area, and how might these influence the incorporation of the site into Kakadu National Park and World Heritage Area?*

5.5.2.1 Aboriginal culture and heritage

There is recent evidence of Aboriginal occupancy of the Kakadu region dating back more than 65,000 years.[13] Central to closure planning are the Mirarr people who are the Traditional Owners of the land encompassing the Ranger and Jabiluka mineral leases. In addition to the mineral leases, Mirarr country extends to the town of Jabiru and parts of Kakadu NP, including the wetlands of the Jabiluka billabong country and the sandstone escarpment of Mount Brockman.

Prior to the 19th Century, the Kakadu region had a population of approximately 2,000. However, the population experienced a rapid decline from the late 19th Century to the early decades of the 20th Century (Taylor, 1999). This was, in part, as a result of European missionary activity, which encouraged a dispersal of the population, and large-scale military activities during the Second World War. At the time of initial uranium exploration at the Ranger deposit in the 1970s, only 44 indigenous Australians were counted as residing in the area in the 1976 Australian Bureau of Statistics Census (cited in Taylor, 1999).

The establishment of the town of Jabiru to service the uranium mining industry was, and remains, a significant factor in the increase in population in the region since the late 1970s. The extent to which the indigenous population has varied during this period is difficult to ascertain due to a paucity of reliable data.

The RPA contains several significant Aboriginal sites, including two recorded sacred sites which lie within designated 'restricted work areas'. One site is located approximately five kilometres north of the mine. The second sacred site, Tree Snake Dreaming, is situated north of Pit 3 and access into the vicinity for operational activity is required on very infrequent occasions. Both sites are listed with the Aboriginal Areas Protection Authority and a Site Management Plan is in place to ensure ongoing protection.

A third site of indigenous cultural heritage significance in the RPA is a cemetery where a small number of local Aboriginal people are buried; this was established prior to mining exploration. This is not a gazetted cemetery, and the burials were contemporary for the period rather than being Traditional Aboriginal burials. There are also restricted work areas on the RPA boundary for two sacred sites that occur outside, but adjacent to, the RPA.

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. There are a

[13] ABC News, 20 July 2017: http://www.abc.net.au/news/science/2017-07-20/aboriginal-shelter-pushes-human-history-back-to-65,000-years/8719314

total of 171 recorded places of indigenous cultural heritage significance in the RPA. One such site (R34), is located adjacent to Pit 3 and is protected within a fenced exclusion zone.

5.5.2.2 World heritage listing attributes

The attributes of the Kakadu NP must not be compromised by the closure and rehabilitation of the RPA. The Kakadu NP was listed under the World Heritage Convention for five of a possible ten criteria, incorporating both cultural and natural attributes (UNESCO 2019). Criterion (i) and (iv) related to the cultural attributes.

In June 2013, the World Heritage Committee adopted the retrospective Statements of Outstanding Universal Value for all World Heritage properties inscribed between 1978 and 2006, prior to the launching of the Second Cycle of Periodic reporting in each region (UNESCO 2013). World Heritage criteria that apply to Kakadu NP, include:

World Heritage criterion (i): The Kakadu art sites represent a unique artistic achievement because of the wide range of styles used, the large number and density of sites and the delicate and detailed depiction of a wide range of human figures and identifiable animal species, including animals long extinct.

World Heritage criterion (vi): The rock art and archaeological record is an exceptional source of evidence for social and ritual activities associated with hunting and gathering traditions of Aboriginal people from the Pleistocene era until the present day.

World Heritage criterion (vii): Kakadu NP contains a remarkable contrast between the internationally recognised Ramsar–listed wetlands and the spectacular rocky escarpment and its outliers. The vast expanse of wetlands to the north of the park extends over tens of kilometres and provides habitat for millions of waterbirds. The escarpment consists of vertical and stepped cliff faces up to 330 m high and extends in a jagged and unbroken line for hundreds of kilometres. The plateau areas behind the escarpment are inaccessible by vehicle and contain large areas with no human infrastructure and limited public access. The views from the plateau are breathtaking.

World Heritage criterion (ix): The property incorporates significant elements of four major river systems of tropical Australia. The Kakadu NP ancient escarpment and stone country span more than two billion years of geological history, whereas the floodplains are recent, dynamic environments, shaped by changing sea levels and big floods every wet season. These floodplains illustrate the ecological and geomorphological effects that have accompanied Holocene climate change and sea level rise.

The Kakadu region has had relatively little impact from European settlement, in comparison with much of the Australian continent. With extensive and relatively unmodified natural vegetation and largely intact faunal composition, the Kakadu NP provides a unique opportunity to investigate large-scale evolutionary processes in a relatively intact landscape.

World Heritage criterion (x): The Kakadu NP is unique in protecting almost the entire catchment of a large tropical river and has one of the widest ranges of habitats and greatest number of species documented of any comparable area in tropical northern Australia. The large size, diversity of habitats and limited impact from European settlement of the Kakadu NP has resulted in the protection and conservation of many significant habitats and species.

5.5.2.3 Kakadu National Park

The area of Kakadu was established as a national park in April 1979, with construction of Ranger Mine commencing in January 1979. Since the original proclamation, the park has been extended to cover an area of almost 20,000 km^2 of the Alligator Rivers Region; the Alligator Rivers Region is as defined in the *Environment Protection (Alligator Rivers Region) Act 1978*). Over half of the Kakadu NP is held by Aboriginal Land Trusts on behalf of the Traditional Owners and has been leased to the Director of Parks Australia North. Kakadu NP is of great significance for its landforms, its variety of fauna and flora and its rich legacy of Aboriginal art.

The park protects an extraordinary number of plant and animal species including over one third of Australia's bird species, one quarter of Australia's land mammals and an exceptionally high number of reptile, frog and fish species. Huge concentrations of waterbirds make seasonal use of the park's extensive coastal floodplains.

5.5.2.4 Ramsar wetlands and sensitive habitat

The entire Kakadu NP is listed as a wetland of international importance under the Ramsar Convention, due to its adherence to the selection of the criteria defining wetlands of international importance (BMT WBM 2010).

Criteria defining Kakadu NP as a site containing Ramsar wetlands of international significance (BMT WBM 2010) are:

- a wetland should be considered internationally important if it contains a representative, rare, or unique example of a natural or near natural wetland type found within the appropriate biogeographic region
- a wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities
- a wetland should be considered internationally important if it supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region
- a wetland should be considered internationally important if it supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions
- a wetland should be considered internationally important if it regularly supports 20 000 or more waterbirds
- a wetland should be considered internationally important if it regularly supports one percent of the individuals in a population of one species or subspecies of waterbird

- a wetland should be considered internationally important if it supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions and/or populations that are representative of wetland benefits and/or values and thereby contributes to global biological diversity
- a wetland should be considered internationally important if it is an important source of food for fishes, spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend
- a wetland should be considered internationally important if it regularly supports one percent of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species

The wetlands of Kakadu NP are also part of an East Asian-Australasian Flyway established to protect areas used by migratory shorebirds (BMT WBM 2010). Due to this international recognition of wetlands in the Kakadu NP these wetlands must not be negatively affected by the closure and rehabilitation of the RPA. However, no environments of special significance (such as significant breeding sites, seasonal habitats or wetlands areas) occur within the RPA or the footprint of the Ranger Mine.

One ecological community in the Alligator Rivers Region is listed as Endangered under the (Commonwealth) *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). However, this Arnhem Plateau Sandstone Shrubland Complex is restricted to stone country and the nearest suitable habitat occurs approximately 1.5 km from the eastern boundary of the RPA.

5.5.2.5 Cataloguing world heritage values

Everett *et al.* (2021) focussed on producing a preliminary catalogue of attributes located within the RPA that would contribute to or complement the natural World Heritage values of Kakadu NP. The three natural criteria contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance; are outstanding examples representing significant ecological and biological processes in the evolution of ecosystems and communities; and contain the most important and significant natural habitats for in-situ conservation of biological diversity. Spatial and other published data sources were collated and analysed to determine the location and extent of attributes associated with each of these criteria for the RPA.

The collation and analyses of data for the broader Kakadu NP and RPA undertaken for this project shows that some attributes representing World Heritage natural values of Kakadu NP are found in the RPA. Where World Heritage natural values in the RPA are found in Kakadu NP, they typically occur more extensively or abundantly in Kakadu NP; and many of the World Heritage natural values of Kakadu NP (threatened, endemic and relict species and ecosystems) are predominantly located in the Stone Country and are not present in the RPA.

In the context of rehabilitation at Ranger mine and long-term ecosystem sustainability, restoration plans should give consideration to maintaining or enhancing values found in

Kakadu NP. This will address the ERs relating to environmental protection of World Heritage values and rehabilitation of the site to a standard such that it could be incorporated in Kakadu NP.

5.6 Future climatic conditions and associated risks

Overall, the state and trend of the environment of Australia are poor and deteriorating as a result of increasing pressures from climate change, habitat loss, invasive species, pollution and resource extraction (Cresswell, Janke & Johnston, 2021). Existing climate patterns affect Australia's environment and communities in regular cycles, with climate change expected to excacerbate the impact of these cycles (Trewin, Morgan-Bulled & Cooper, 2021). Many significant impacts of climate change are due to extreme events (Trewin, Morgan-Bulled & Cooper, 2021). Australian ongoing climate trends include further warming and sea-level rise, more hot days and heatwaves, more rainfall in the north and fewer but more intense tropical cyclones (IPCC, 2022). Climate trends and extreme events have negatively impacted terrestrial and freshwater ecosystems (IPCC, 2022)

Australia's climate varies widely from season to season, year to year, and region to region (Trewin, Morgan-Bulled & Cooper, 2021). Australia currently lacks a framework that delivers holistic environmental management to integrate disconnected legislative and institutionial national, state and territory systems (Cresswell, Janke & Johnston, 2021).

5.6.1 Climate in the Northern Territory

The global climate system is comprised of five interconnected components and their interactions: the atmosphere, the hydrosphere (oceans, lakes, rivers), the cryosphere (ice, snow), the lithosphere (the land) and the biosphere (living things) (NESP ESCC Hub 2020).

The Northern Territory climate is strongly affected by the seasonal migration of the monsoon back and forth across the equator resulting in two distinct climates; a monsoonal wet season typically between October to April followed by a dry season during May to September (Moise *et al.* 2015). The drivers across the Northern Territory which largely influence rainfall include topography, strength (onset, duration and retreat) of the monsoon season, the phase of El Niño Southern Oscillation (ENSO) which influences rainfall, temperatures and tropical cyclones, the occurrence of tropical cyclones, and the strength of the south-eastern trade winds (Moise *et al.* 2015). The timing and strength of the monsoon bursts are further influenced by the Madden-Julian Oscillation (MJO). The Indian Ocean Dipole (IOD) additionally influences rainfall and temperatures (NESP ESCC Hub 2020).

Future climatic conditions globally and in the Northern Territory will be determined by the concentration of greenhouse gases in the atmosphere and how the climate system responds to the change and natural climate variability (NESP ESCC Hub 2020). These future climatic conditions have the potential to influence components of mine closure, particularly given the long-term nature of closure planning.

Potential impacts from climate change within the Northern Territory include:

- Increased exposure of humans and ecosystems to heat stress, disease, extreme rainfall events and flooding,
- Flooding of freshwater wetlands with salty water due to rising sea levels, and
- Less frequent tropical cyclones increasing in proportion of more powerful cyclones, causing more damage to coastal and marine areas.

ERA has completed a number of studies and risk assessments in relation to climate change. In 2012, INTERA facilitated a workshop focussing on Features, Events and Processes (FEPs) that may affect safe storage of tailings in Pit 3. Since 2012, considerable studies have been undertaken by INTERA, refining and revising initial assumptions and updating inputs to the relevant site model (INTERA 2017). A final report identified and evaluated a fully comprehensive list of FEPs that may affect an environmental assessment of a mine facility and associated safety function analysis (INTERA 2017). Climatic processes and effects were identified as a category and evaluated. Potentially deleterious FEPs associated with climatic processes and the risks these present to safety functions were discussed.

ERA have also completed a 'First Pass Climate Change Risk Assessment' to understand how climate change is likely to affect the MCP and determine any additional investigations or actions required to help address identified challenges (BMT 2020). Risk summaries and details of the process undertaken to determine risks are summarised in Chapter 5.2.2.

Climate change is likely to have a significant affect across the entire Kakadu region with most impacts likely to occur beyond 2050. The relatively short period (compared to climate change timeframes) of active onsite management and monitoring for closure expected before the site stabilises and meets close out conditions resulted in a fairly low risk profile for mine closure. In the longer term, most climate change risks are landscape in nature affecting the entire Kakadu region.

5.6.2 Temperature

Climate aspect	Prediction and confidence
Overall temperature	Very high confidence of substantial warming for overall mean, maximum and minimum temperatures
Hot days and prolonged periods of heat	Very high confidence of substantial increase in the temperature reached on the hottest days, the frequency of hot days and the duration of warm spells

Warming temperatures are the clearest manifestation of climate change (Trewin, Morgan-Bulled & Cooper, 2021). Warming of the Australian climate and associated climate system continue unabated, largely driven by increasing concentrations of greenhouse gases in the atmosphere (Trewin, Morgan-Bulled & Cooper, 2021). Emissions that have already occurred will drive futher changes over the coming decades, regardless of the future emissions pathway, where future emissions will have a major effect on the trajectory of climate change in the second half of the 21st Century (Trewin, Morgan-Bulled & Cooper, 2021).

Global surface temperature increases of 1.09 degress Celsius (◦C) in 2011 to 2020 above 1850 to 1900, have at least a greater than 50% likelihood that global warming will reach or exceed 1.5 ◦C in the near term, even for the very low greenhouse gas emissions scenario (IPCC, 2022). Since 1910, mean temperatures have increased in Australia by 1.4 ◦C, over all parts and in all seasons (BOM, 2020; Trewin, Morgan-Bulled & Cooper, 2021) (Figure 5-149).

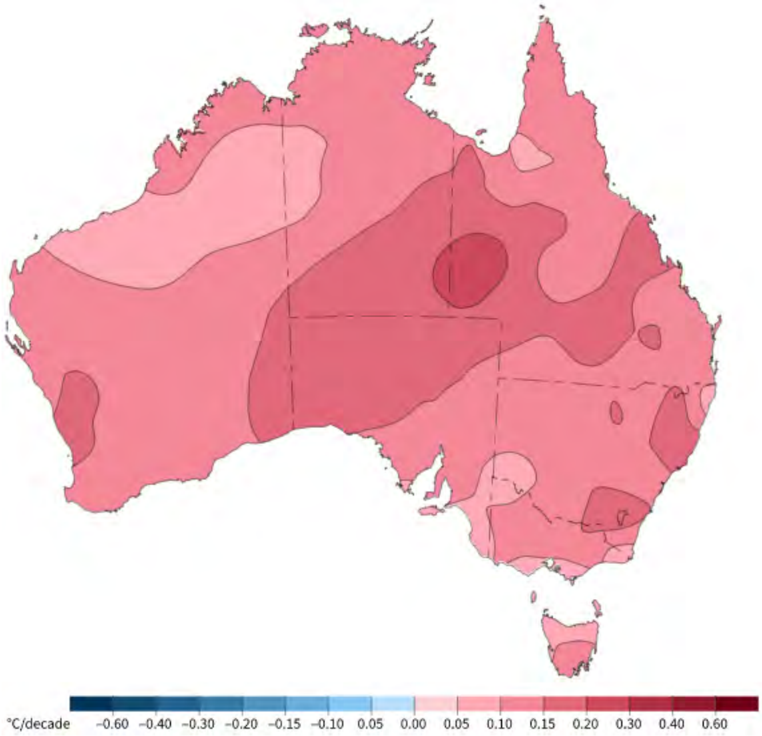


Figure 5-149: Trend in mean temperature, 1910 - 2020 (Source: State of the Environment, 2021)

Indigenous people also experience impacts of rising temperatures leading to extreme cultural change due to biodiversity loss, loss of culture and changed cultural patterns of living and travelling in and across Country (Trewin, Morgan-Bulled & Cooper, 2021). Rising land temperatures can reduce availability and growth of plants used for traditional purposes such as food and medicine, affecting the health of peoples who rely on traditional plants for nutritional and healing properties (Trewin, Morgan-Bulled & Cooper, 2021).

5.6.3 Predictions

Since the middle of last century there has been a clear warming trend with the Northern Territory having warmed by 1.5 °C since 1910 (CSIRO, 2022). Overall, the Northern Territory will continue to get warmer, with the hottest days being hotter and more frequent, and warm spells being longer (NESP ESCC Hub 2020). Future substantial warming for mean, maximum and minimum temperature is projected with very high confidence (NESP ESCC Hub 2020, Moise et al. 2015).

In the Top End of the Northern Territory, the near future (2030) will see warming around 0.5 to 1.4°C compared to the average for the period 1986–2005, with very little difference between emissions scenarios. By mid-century (2050), Darwin is projected to be more like the current climate of Jabiru, with warming ranging from 1.5 to 2.5°C under high emissions with a central estimate of 2.0°C (CSIRO, 2022). Large and sustained reduction in global greenhouse gas emissions reduces the projected warming to around 0.8 to 1.7 °C with a central estimate of 1.1 °C (CSIRO, 2022). Under a high emissions pathway the number of hot days over 35°C will approximately double across various regions of the NT, for example from 86 to 199 days per year in Batchelor (CSIRO, 2022).

5.6.3.1 Risks and possible mitigations

Changes in temperature present the largest risk of impacts to mine closure activities. Increases in frequency and intensity of hot periods could compromise the success of revegetation, present challenges to onsite management activities and impact onsite and receiving waters (BMT 2020). The following potential risks were identified in the Climate Change first pass assessment:

- Increased temperature and long hot and humid conditions may impact health and safety of staff involved in planting, management and maintenance and longer-term monitoring.
- Changing climate may result in conditions unfavourable for target revegetation species and vegetation communities could become unviable.
- Changes to trees species may have flow on effects to fauna. If deciduous trees dominate then following nesting species may be affected by the lower amount of shade that may eventuate.
- Selection of vegetation more tolerant to dry conditions may have flow on consequences e.g. if trees drop leaves to cope with heat stress, ground cover gets impacted by sun and associated heat.
- Temperature and excessive dry weather may affect early survival of revegetation.
- Longer, hotter dry periods impacting understorey growth rates and survival.
- Weed encroachment from the mine site into Kakadu National Park increasing as invasive species have a higher competitive advantage in changing climates.
- Pests or diseases, such as myrtle rust, affecting vegetation of the rehabilitated site.
- Higher temperatures coupled with longer drier periods may impact soil biota and affect nutrient cycling.
- Toxicity of contaminants increasing in higher temperature water.

- Higher temperatures of water bodies may lead to lower levels of dissolved oxygen in the water column which can results in fish kills.
- Increased algal blooms in water ways due to increased rates of production in higher temperatures.
- Longer periods of increased water temperatures can lead to shifting species complexes, favouring thermophiles which are heat tolerant.
- Increased temperatures influencing sex ratios of reptile species such as crocodiles.

Many of the identified risks are not directly linked to mine closure activities, including higher temperatures impacting species complexes and sex ratios. These risks will need to be managed at the landscape scale. A number of potential impacts due to predicted increasing temperature become landscape wide after 2050 and require management in consultation with relevant stakeholders at the landscape scale.

The changing climate was factored into the development of the revegetation plan for the Ranger mine site. Important aspects such as the effect of heat on workers, the selection of vegetation and longer-term management, maintenance and monitoring were considered.

Heat impacts to human health in the context of workers at RPA are not considered a long-term risk because by 2100[14] the period of intense mine closure activities will have passed. Options to manage short to medium-term risk include the use of remote sensing, drones, and other new technology to monitor vegetation, with consideration of night-time planting to reduce heat impacts.

Managing heat impacts on revegetation activities involves a combination of measures undertaken both prior to and after planting has occurred. Climate projections will be monitored over time to ensure that new information is accounted for when selecting plant species for revegetation. Native vegetation that has been removed or partially regrown has reduced ecological integrity (Williams et al, 2021). The extent of ‘remnant’ and ‘regrowth/modified’ native vegetation is not assessed based on its condition; additional information is needed to assess the growth stage and ecological integrity to provide a more comprehensive understanding of the implications for biodiversity and land condition (Williams et al, 2021). The condition of native vegetation is assessed in terms of its integrity or capacity to continue to provide habitat to support Australia’s unique biodiversity (Williams et al, 2021). Condition is quantified by measuring the similarity of a current ecosystem to a historical reference state with high ecological integrity or one that is minimally impacted by people (UNCEEA, 2021).

For savanna overstorey communities to be established at RPA, stakeholders agree that a *Eucalyptus tetrodonta* / *E. miniata* open forest, which dominates the Ranger surrounds, will constitute the community type for establishment. These local species are naturally resilient to high variation in climate variables, ensuring sufficient temperature tolerant plants will be

[14] 2100 is the best available timeframe for long-term projections

planted. Additional factors, such as coarseness of the substrate, will be considered for area-specific revegetation plans. For example, for areas with coarser waste rock, the *E. tetrodonta* / *E. miniata* community may include slightly higher densities of species proven to be well suited to rockier substrate, whereas areas with fine substrate may require slightly more water-logging tolerant species.

Climate change is placing pressure on soils through increased frequency of droughts and extreme weather events, increasing average tempertures which cause soil loss and damage (e.g. Grace et al. 2006, Rabbi et al. 2015, Borrelli et al. 2020, DAWE 2021t). A decline in the amount and health of soil directly affects its ability to provide important ecosystem services that support the natural environment (Williams et al, 2021). Soil rehabilitation may take many decades, and the full range of biodiversity may never be recovered (Williams et al, 2021).

High temperatures combined with drier conditions may result in dieback of establishing and mature plants due to limited water, changes to soil biota and nutrient cycling. Initial plantings will be supported by irrigation measures during the establishment phase. Potential for plant mortality can also be reduced through secondary inductions, with understorey species introduced once the ecosystem has begun to accumulate fines and organic matter, as shade is provided by the initial established species. Further detail on the revegetation implementation is presented in *Section 9 Closure Implementation Chapter 9.3.6*.

5.6.4 Rainfall and evaporation

Climate aspect	Prediction and confidence
Rainfall	Low confidence in models (similar probability of drier and wetter outcomes)
Intensity of heavy rainfall events	High confidence that the intensity of heavy rainfall event will increase
Drought	Low confidence in predictions of the frequency and duration of extreme drought for northern parts of NT
Evaporation	High confidence for increases in evapotranspiration, however despite model agreement there is only medium confidence on the magnitude of these projections
Soil moisture	Medium confidence for overall seasonal decreases in soil moisture
Runoff	Low confidence of a decrease in runoff

Rainfall is generally increasing in the north of Australia (Trewin, Morgan-Bulled & Cooper, 2021). Droughts and periods of extreme fire weather are expected to become common, as are more intense rainfall events (Trewin, Morgan-Bulled & Cooper, 2021). Regional differences may indicate national average rainfall is of limited value as an indicator of climate trend (Trewin, Morgan-Bulled & Cooper, 2021). High levels of decadal variability, particularly in drier parts of Australia, means observed trends in rainfall can be sensitive to start and end dates of the measured trend period (Trewin, Morgan-Bulled & Cooper, 2021).

Extreme rainfall events are projected to become more intense (CSIRO, 2022). High rainfall extremes are expected to increase due to the warmer atmosphere being able to hold more water, with extreme localised events highly variable from year to year, making trends difficult to detect (Trewin, Morgan-Bulled & Cooper, 2021). Increases in both short duration extreme rainfall events and daily totals associated with thunderstorms are most pronounced in Nothern Australia (Trewin, Morgan-Bulled & Cooper, 2021). Heavy rainfall can lead to increased soil runoff, increased risk of landslides and natural hazards, and damage to cultural sites (Trewin, Morgan-Bulled & Cooper, 2021). Inland waterways exposure to these events accelerate bank erosion and over bank flow, movement of sediment into foreign areas and loss of biodiversity in riparian areas, impact cultural heritage sites, as well as affecting level of recovery after an event (Trewin, Morgan-Bulled & Cooper, 2021).

Historical tropical cyclones in the Northern Terriotry include the destruction of much of Darwin during cyclone Tracey in 1974 (Trewin, Morgan-Bulled & Cooper, 2021). The coast is most exposed to damage from wind and storm surges, with heavy rains and flooding extending beyond the cyclone landfall point, with cyclones more common during La Nina years and less common in El Nino years (Trewin, Morgan-Bulled & Cooper, 2021). Cylone numbers have been decreasing in the last 40 years, with studies indicating increases in category (Trewin, Morgan-Bulled & Cooper, 2021).

5.6.4.1 Predictions

As a climatic variable, the projected change in average rainfall for the Northern Territory is unclear, although significant change is possible, where both wetter and drier futures should be considered (CSIRO, 2022). Rainfall can vary a great deal from year to year due to the normal variability of the climate system, and models have high confidence that natural climate variability will remain the major driver of annual mean rainfall changes by 2030 (Moise et al. 2015, NESP ESCC Hub 2020).

For the near future, projections for the dry season in the Top End of the Northern Territory range from 35% drier to 29% wetter than the 1986–2005 average, depending on greenhouse gas concentrations (NESP ESCC 2020). Projected wet season change for the same period ranges from 8% wetter to 7% drier. Towards the end of the century, the projected dry season change ranges from 45% drier to 44% wetter, and for the wet season, the range is 23% drier to 19% wetter (NESP ESCC Hub 2020). Due to the understanding of physical processes, there is high confidence that the intensity of heavy rainfall events will increase, however the magnitude of change, and the time when any change may be evident against natural variability, cannot be reliably projected (Moise *et al.* 2015).

Heavy and extreme rainfall events in the Northern Territory are often the result of tropical cyclones, tropical lows, and long-lived thunderstorms. Tropical cyclones are projected to become less frequent, but with increases in the proportion of the most intense storms due to there being more energy in the climate system (Moise *et al.* 2015, NESP ESCC Hub 2020). As the air becomes warmer it has a greater capacity to hold water vapour, meaning even though changes to average rainfall are unclear, the intensity of heavy rainfall events will increase in the future as a result of increased air temperatures (NESP ESCC Hub 2020).

Similarly, impacts of drought are likely to be more severe in the future due to increasing temperatures (NESP ESCC Hub 2020). The time spent in drought may also increase, with changes seen in both frequency and intensity (NESP ESCC Hub 2020). However, given the relation of drought to rainfall there is low confidence in how the frequency and duration of extreme meteorological drought may change (Moise *et al*. 2015).

Evaporation rates have largely remained unchanged within the Top End, however across the Northern Territory, projections for potential evapotranspiration indicate increases in all seasons (NESP ESCC Hub 2020). In relative terms there are larger increases in the dry season relative to the wet season with the largest absolute rates predicated in the wet season by 2090 (Moise *et al.* 2015, NESP ESCC Hub 2020).

Increases in evaporation rates combined with changes in rainfall can have implications for both soil moisture and runoff. Soil moisture is predicted to have an overall seasonal decrease, predominantly in the dry season due to lower rainfall amounts and high evaporation rates (Moise *et al.* 2015). Runoff is also projected to decrease; however, the projections have low confidence and more detailed hydrological modelling is needed to confidently assess the changes (Moise *et al.* 2015).

5.6.4.2 Risks and possible mitigations

Variability in rainfall patterns and evaporation predominantly present risks to onsite and receiving waters in terms of quantity and quality. The potential for more intense tropical cyclones and droughts can also result in damage to vegetation and landforms (BMT 2020).

The following potential risks were identified in the first pass assessment:

- Cyclone damage to vegetation planted as part of mine rehabilitation.
- Risk that leaf litter may increase as a result of intense winds, increasing bushfire risk and potentially leading to water column deoxygenation if washed into waterways.
- Connectivity of water courses reduced during longer, drier periods and solutes remaining in smaller areas for longer. This could increase exposure of fauna and flora in the water courses which are unable to disperse during periods of little or no connectivity.
- Longer hotter dry periods could dry out billabongs and expose previously unexposed ASS with implications for water quality and release of sediment bound contaminants.
- Increased evaporation leads to an increase in contaminants washed into onsite and receiving water during the first flush. A ‘dry’ wet season could mean greater loads into billabongs which do not then flush out to the ocean.
- Higher evaporation rates may affect shallow billabongs and result in a loss of refuge habitat for species.
- Intense storms damaging the road network.
- Erosion during storm events resulting in minor gullying on land and sedimentation in waterways.

- Increased cyclone damage to riparian zone degrades water quality.

None of these risks are created as a direct result of mining activity. A number of risks will be present across the entirety of the Kakadu NP (for example increased leaf litter from intense storms, loss of refuge from dry out of shallow billabongs) and will require management in consultation with Kakadu NP at the landscape scale. Changes to the waterbodies and hydrology of the system are likely to occur. These will be regional, where local receiving waterways may be affected which may influence the concentrations of received contaminants.

Intense storms and cyclones have the potential to impact directly on mine closure activities, particularly when it comes to revegetation and rehabilitation of areas. Strong winds and heavy rainfall can cause large scale damage to new vegetation. Damage to vegetation can have secondary impacts including increased erosion due to lower revegetation success and potential water quality impacts from increased runoff. Revegetated areas will be monitored with impacts remediated as required during the active management period. The revegetation strategy is tailored to landform elements (e.g. slopes, gullies, etc) to enhance vegetation cover and prevent erosion. The revegetation strategy also involves irrigation to encourage deep root development and subsequent cyclone resistance. Cyclonic activity and a general increase in intense rainfall events can cause significant damage via erosion leading to gullying on land and sedimentation in waterways.

The final landform design and landform evolution modelling will include surface treatments and sediment control features in future iterations. With no steep slopes across the site the potential for gullying on land and risk of flood scour is reduced, where armouring of landform toe-slopes adjacent to Magela Creek is a potential mitigation option. Modelling (Hancock et al. 2017) indicates a high likelihood of gullying across the landscape however not deep enough to expose the buried tailings. A such, whilst the risk of gullying is high the consequence (e.g. exposure of tailings) is low.

Extreme rainfall events are included in the landform evolution models to assess potential tailings exposure over 10,000 years (Lowry 2020). ERA will make minor adjustments to the final constructed landform such that any drainage channels or significant gully formation are mitigated within the shell of the pits. Armoured drainage lines across the pit are also an additional mitigation option. Erosion and gullying that occurs during the management period will be actively managed, with erosion management undertaken by the designated management authority following close-out.

The management of water at RPA makes extensive use of an operational simulation model (OPSIM) to assess the likely change in water inventories over time, taking full account of both climatic and operational influences (Water Solutions 2009). Variations to rainfall patterns are likely to impact both surface water and groundwater on and off-site. The OPSIM is well calibrated and validated, however is application to the task of future forecasts relies on the assumption that historical rainfall is fully representative in future occurrences (Water Solutions 2009). Investigations have been undertaken into methods to assess the likely impacts of changing climatic state on OPSIM based water management techniques used at RPA. The investigation found that specific inclusion of possible changes to rainfall on account of temperature rise was not recommended as there remains uncertainty as to the magnitude of possible changes to rainfall totals and the ‘worst estimate’ impacts are relatively small (Water Solutions 2009). This matter will continue to be investigated as further information becomes available.

A decrease in soil moisture can impact PAW, which is the amount of available water that can be stored in soil and be available for growing plants (within the rooting zone). Water availability on the waste rock final landform cover presents a challenge for ecosystem re-establishment as waste rock growth media often lacks structure or contains large amounts of rock fragments and macropores that reduce their water holding capacity (compared to natural soils). Waste rock PAW depends on the proportion of fines (<2 mm) in the material as well as the total depth available for plant root establishment. Waste rock substrate provides greater rooting depth meaning larger plants will likely be able to access any PAW in this soil and have improved plant-water relations in the late dry season when seasonal stresses (including reductions in soil moisture) are greatest. The construction of the waste rock final landform is carefully designed to optimise PAW as much as possible in the root depth zone.

The Groundwater Uncertainty Analysis (UA) conducted by INTERA incorporates climate variability to the greatest extent possible by treating groundwater recharge rates for surficial HLUs as random parameters to account for uncertainty (INTERA 2021b). The calibration of the UA predictive model was based on 40 years of head change data caused by widely varying rainfalls and consequently, the model appropriately captures the uncertainty in post-closure recharge rates because they reflect the amount of water that can recharge through these materials (INTERA 2021b). If climate change increases rainfall to exceed the observed 40-year span, the physical properties of the materials will likely shed that rainfall as runoff rather than allow it to recharge the groundwater. This means that the wide range of groundwater recharge rates for the landform waste rock used in the model include a wider range than is expected from climate change during the mid to late part of the century when peak loads are expected to occur and likely include all of the recharge rates that may occur from climate change at even later times (INTERA 2021b).

Recent investigations of groundwater and surface water interactions have shown that groundwater discharge does not occur during the last weeks or month of Magela Creek flow, indicating that climate change induced impacts on surface water quality from groundwater will be small (INTERA 2021a). If long term rainfall increased in magnitude or intensity due to climate change, creek flows will increase by a far greater proportion than groundwater recharge (INTERA 2021a). Increase rainfall magnitude and intensity will also likely lead to more rejected recharge when either the subsurface is saturated or the rainfall rate exceeds the infiltration rate. Any excess rainfall as a result of climate change will likely induce greater runoff that effectively decreases COPC surface water concentrations (INTERA 2021a). If future climate change decreases rainfall, then it will also decrease groundwater recharge (INTERA 2021b).

Connectivity of watercourses and provision of associated refuge habitat can be altered by decreases in rainfall combined with increases in evaporation. Assessing the implication and likelihood of reduction in connectivity requires a landscape management approach in order to help understand the issues and process. Long dry and highly evaporative periods may dry out billabongs and expose previously unexposed Potential Acid Sulfate Soils (PASS) and result in the forming of Acid Sulfate Soils (ASS). This has implications if occurring on mine site water bodies and will be a key area of active management during the closure period. It is noted that annual periods of drying are a common and known occurrence in the Northern Territory, which has resulted in local species within and surrounding the RPA adapting to these conditions. A number of projects are currently underway, or have been completed, which assess ASS in and around the RPA.

5.6.5 Fire

Climate aspect	Prediction and confidence
Fire frequency	High confidence of little change to fire frequency

The number of days with higher or above fire danger has generally increased typically from the lengthening of the fire season than from intensification of the peak of the season (Trewin, Morgan-Bulled & Cooper, 2021; Figure 5-150). Increased bushfire events in areas that have not fully recovered will increase nutrient levels in systems, creating unbalanced ecosystems for sustainable biodiversity in both freshwater and coastal regions (Trewin, Morgan-Bulled & Cooper, 2021).

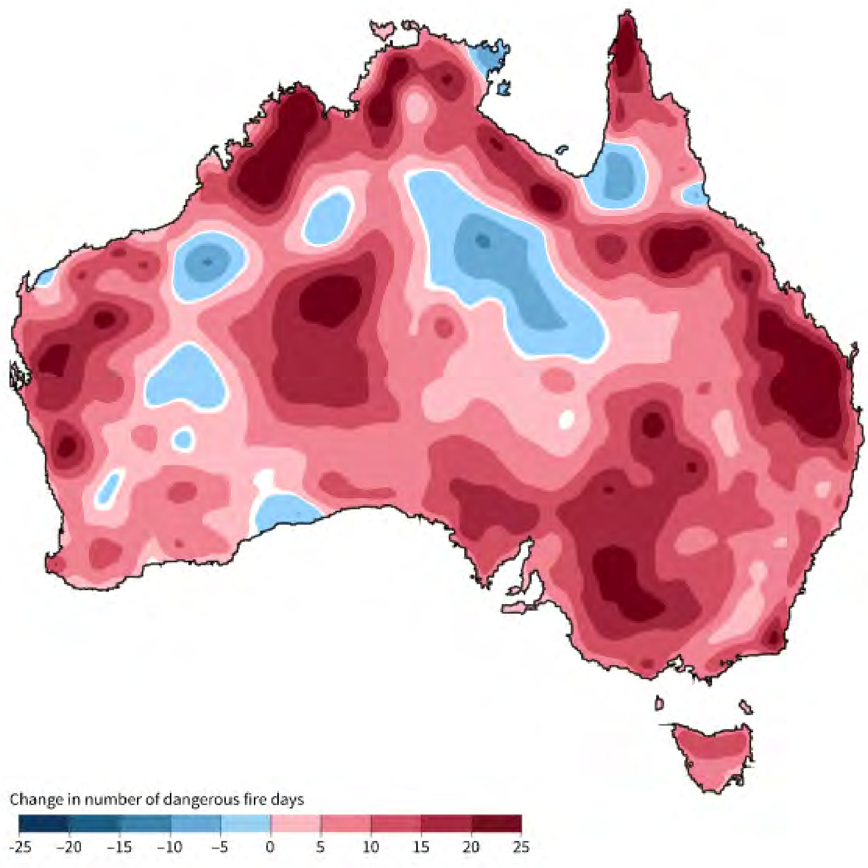


Figure 5-150: Change in number of days with the FFDI above the 90th Percentile, 1950-85 to 1985 - 2020 FFDI – Forest fire danger index (indicator of fire weather in forested or semi-forested areas.

5.6.5.1 Predictions

The occurrence of bushfires is determined by having an ignition source, fuel availability, fuel dryness and suitable fire weather (hot, dry, and windy conditions) (NESP ESCC 2020). Fuel availability in the Northern Territory is largely influenced by rainfall, as abundant rainfall will lead to higher fuel loads (Moise et al 2015). In Northern Australia, the most dangerous fire conditions occur in the dry season when there is an increased fuel load following rainfall from the wet season. Over the past 30 years, the number of days with severe fire weather during the dry season has increased (NESP ESCC 2020).

Rainfall is likely to remain abundant as a result of the monsoonal influence and consequently, there is little change projected to fire frequency within the Northern Territory (NESP ESCC 2020).

5.6.5.2 Risks and possible mitigations

The potential for more extreme fire behaviour presents a significant risk to the success of establishing vegetation across the RPA, both from the risk to humans carrying out activities and the potential for vegetation mortality. The following potential risks were identified in the first pass assessment:

- Climate-driven increased extent of ground cover planted during restoration may increase the fuel load and increase fire risk.
- Exotic grasses may become established following bushfires.
- Vegetation which includes a mix of species better adapted to survival on waste rock sites will be susceptible to fire.
- Length of the potential burning season may decrease as a result of a changing climate which may increase the risk of inappropriate burning regimes or wildfires.
- Fire severity may increase over time as a result of increased heat and evapotranspiration. This may lead to increased tree mortality.
- Severe fires and associated tree mortality may impact faunal communities.
- When active mine closure management ceases after close-out, reduced activity on the mine site may result in increased fire potential because of less active onsite management.
- People living, working or visiting Kakadu may be affected by any increased bushfire.
- Bushfires destroying riparian vegetation and leading to increased bank erosion when the wet season commences.

The risk of large-scale fire destroying immature vegetation is recognised and is captured in the risk assessment presented in *Section 7 Risk assessment and management*. Considerations for managing this risk during the post-closure period and longer-term have been incorporated within the Revegetation Adaptive Management Plan, both in terms of species selection and revegetation techniques, as well as monitoring and management actions during the post-closure period.

The Ranger Mine exists within the Australian savanna biome, where frequent fires dominate and lead to a shared dominance of trees and grasses (Cook 2021). Globally savanna vegetation is marked by a co-dominance of grasses and fire tolerant trees. While the ground stratum of savannas is relatively insensitive to variation in fire regimes at least in the short term, the tree stratum is sensitive to intense fires that more commonly occur late in the dry season (Cook 2021).

Developing ecosystems such as rehabilitation/revegetation areas have a different structure and composition to natural ecosystems. Although the same species may have been planted in rehabilitated landscapes as adjoining natural landscapes, they may take a long time to develop resilience to fire (Cook 2021). The resilience of vegetation to single fires depends on a range of vegetation attributes such as (Cook 2021):

- avoiding heat damage through;
    - thick bark,
    - placement in tall canopy above flame height,
    - placement below ground, and
    - placement in moist bark or leaves,
- the ability to recruit following fires through asexual reproduction or protection of seed.

Surviving one fire does not necessarily mean that a plant can survive multiple fires. Different aspects become important when faced with a fire regime including the ability to restore protections damaged in one fire before the next fire (Cook 2021). Fires within the first year of planting can lead to very high mortality of tree seedlings, with plants become more resilient to fire as they increase in size (Cook 2021). Fire resilience is highest in species of *Eucalyptus*, *Corymbia* and *Syzygium* (Gardener et al. 2007). On the RPA, trees greater than 2.5 m tall and 4 cm Diametre at Breast Height (DBH) were more likely to survive a fire than those with less than this threshold. It was therefore concluded that fires should be avoided in revegetation until most trees were greater than these sizes (Cook 2021).

Establishing a good level of ground cover in the revegetated areas is also a key objective of mine rehabilitation. It is noted that increased ground cover provides additional fuel supply during the bushfire season. Bushfire activity during both the closure and rehabilitation period will be monitored and managed accordingly. Management measures include the delayed introduction and active management of high biomass grasses (e.g. cool season burns), the establishment of fire breaks and access tracks and weed management to control exotic grasses. Ground cover in rocky dry areas will have a slower growth rate and consequently lower fuel loads.

The waste rock surface has a low risk for five to seven years post-planting. Species selected for the waste rock areas will be any climate-adaptable, hardy species from the Kakadu NP area that are generally subject to a similar overall fire regime. The chosen taxa will not increase the risk of bush fire, nor be more susceptible than species from agreed reference ecosystems in revegetated areas.

Having a revegetated ecosystem that is resilient to a suitable fire regime is one of the closure criteria that must be met prior to close-out. The knowledge to manage developing ecosystems in a frequently burnt landscape is limited and needs to be supported by adaptive management to achieve the goal of fire-resilient revegetation (Cook 2021). The Fire Management Plan will be developed and implemented in partnership with Traditional Owners based on Traditional Knowledge. Cool burns will be introduced 5-10 years post planting with a focus on wet season burning to help reduce fuel loads without the increased risk of uncontained wildfire.

The use of prescribed burns will assist in controlling exotic grass species. Following close out, climate-driven increased wild-fire risk will be a boarder landscape management issue. A number of the risks of changing weather (increased burning season, increased fire severity) will be similar across the whole Kakadu NP area requiring a coordinated management approach.

5.6.6 Humidity

Climate aspect	Prediction and confidence
Relative humidity	High confidence in little change in relative humidity by 2030 and medium confidence in. a decrease by 2090

5.6.6.1 Predictions

Relative humidity is the amount of moisture in the air as a percentage of the total amount of moisture the air can hold. The projection of future relative humidity indicates an overall tendency for decrease (Moise *et al.* 2015). In the near future there is little change projected, however, by the end of the century under a high emission pathway, a decrease is predicated for Northern Australia (NESP ESCC Hub 2020). Under a high emissions pathway, relative humidity is projected to decrease up to 10% in the dry season with high confidence (NESP ESCC Hub 2020).

The decrease in relative humidity will be apparent in areas away from the coastline due to an increase in the moisture holding capacity of a warming atmosphere and the greater warming of land compared to the ocean (Moise *et al.* 2015). This general tendency to decrease may be counteracted by a strong increase in rainfall. It is noted that changes in rainfall patterns have a higher level of uncertainty.

5.6.6.2 Risks and possible mitigations

A wide range of climate parameter trends were assessed as part of the first pass risk assessment, with risks fitting into four key areas of onsite activities; revegetation, onsite and receiving water quantity, quality and ecology, and erosion and sediment. The first pass risk assessment did not identify any risks within these categories specifically related to changes in relative humidity.

5.6.7 Sea level rise

Climate aspect	Prediction and confidence
Sea level	Very high confidence that sea level will continue to rise, with only minor level differences in emissions scenarios

Sea level rise increases levels of coastal inundation and erosion, with many regions having sensitive environmental features, infrastructure and development (Trewin, Morgan-Bulled & Cooper, 2021). Global sea level has been rising since the beginning of the 20th century at an accelerating rate (Trewin, Morgan-Bulled & Cooper, 2021). Global mean sea level has been rising at a rate of 3.3 mm per year (mm/yr) increasing by around 9 cm from 1993 to 2020 (Trewin, Morgan-Bulled & Cooper, 2021). In northern Australia, the rate of sea live rise after 1993 has increased in some areas up to 5 mm / yr, a major driver is natural climate variability including from the El Nino – Southern Oscillation (Trewin, Morgan-Bulled & Cooper, 2021).

5.6.7.1 Predictions

Climate change can cause sea level to rise via two mechanisms; thermal expansion where water warms and increases in volume as well as melting ice sheets and glaciers adding more water to oceans. Thermal expansion accounts for approximately one-third of sea level rise observed to date, with the remainder occurring from melting ice (NESP ESCC Hub 2020).

There is a very high confidence that sea levels will continue to rise during the 21st century, with only minor differences in levels between emissions pathways (Moise *et al.* 2015). In the near future, the increase is predicated to be 0.06 to 0.17 m above the 1986-2005 levels, with the difference becoming more pronounced as the century progresses (NESP ESCC Hub 2020). At the end of the century, a medium emissions pathway is predicted to increase levels between 0.28 to 0.64 m while a high emissions pathway gives a rise of 0.38 to 0.85 m (NESP ESCC Hub 2020).

Changes in sea level can occur at many time scales due to a range of factors including tides, storm surges, seasonable changes and the influence of climate divers including El Niño and La Niña (NESP ESCC Hub 2020). Sea levels around the coastline of the Northern Territory have risen at a higher rate compared to much of the rest of Australia due to a combination of natural climate variability and climate change impacts (NESP ESCC Hub 2020). Tides, winds and severe weather systems may cause extreme sea-level events outside of climate induced sea level rise. The Northern Territory is susceptible to extreme storm surges as a result of tropical cyclones (NESP ESCC Hub 2020).

5.6.7.2 Risks and possible mitigations

Rising sea level will exacerbate the impacts of extreme sea-level events, including storm surges, which may cause issues in downstream freshwater sites. The following potential risks were identified in the Ranger Climate Change first pass assessment:

- Sea-level rise may reduce the availability of freshwater refugia downstream of the mine site.
- Wave action from inundated flood plain causing erosion of the mine site.
- Sea-level rise causes floral and faunal species complexes to change, and they may begin to be dominated by saline tolerant (marine) species which may have flow on effects to other important taxa.
- Higher salinity waters may result in the loss of freshwater fauna such as freshwater turtles and amphibians.
- Higher sea-levels and more saline water in receiving waters may affect the ways in which surface water models are interpreted.

Discussions at the 2012 FEPs workshop included large sea level rises, in which the site might progress to a coastal mangrove swamp (INTERA 2017). Such progression may lead to low hydraulic gradients and reducing conditions that may decrease solute releases from the tailings (INTERA 2017). Predicted conditions at the site are considered somewhat speculative under such drastic climate change. The potential for very large sea level rise is considered of low likelihood with uncertain importance. It will be reconsidered at a later time as additional information becomes available (INTERA 2017).

Sea-level rise beyond 2050 is a landscape risk which will affect the entire Kakadu region and is not directly related to Ranger mine closure. Low lying areas of Kakadu NP are likely to be affected, reducing the extent of freshwater billabongs and waterways and the associated floral and faunal communities. Upstream sites will become important refugia and may include freshwater bodies on and adjacent to the mine site not influenced by mine closure. There is potential to consider the opportunity for establishing additional freshwater bodies on the mine site through ecological engineering. Additional management activities for landscape risks are are considered necessary.

5.6.8 Ocean temperature and chemistry

Climate aspect	Prediction and confidence
Sea surface temperature	Very high confidence in a continuation of increases in sea surface temperature
Ocean acidification	Very high confidence that the ocean around Australian will become more acidic High confidence that the rate of ocean acidification will be proportional to carbon dioxide emissions

Sea surface temperatures in the Australian region since 1900 have risen by 1.1 ◦C, slower than increases in land temperatures (Trewin, Morgan-Bulled & Cooper, 2021) (Figure 5-151). The rate of warming is fairly uniform across all seasons but can differ substantially between land and sea temperatures each year (Trewin, Morgan-Bulled & Cooper, 2021). This variation is due to how land and sea temperatures are affected by El Nino-Southern Oscillation and Indian Ocean Dipole, for example La Nina is associated with below average temperatures on land and above average temperatures in Northern Australian Waters (Trewin, Morgan-Bulled & Cooper, 2021).

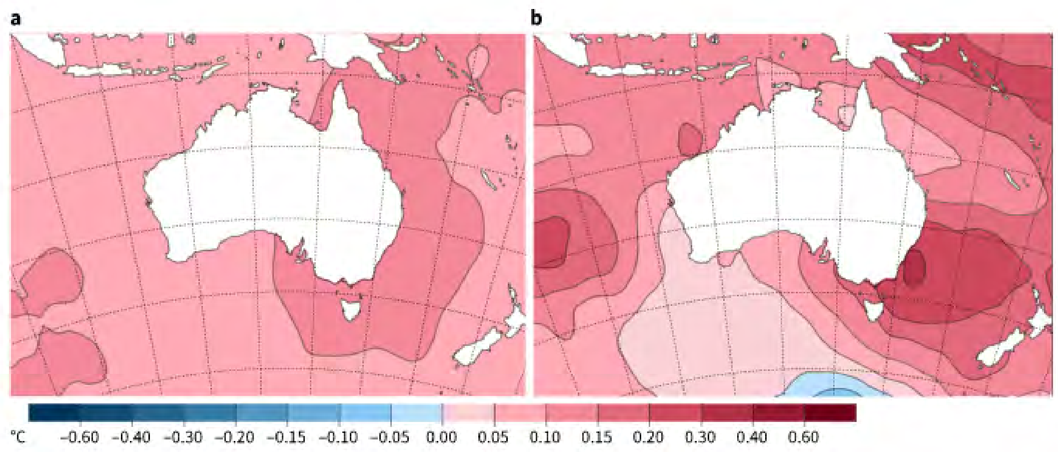


Figure 5-151: Sea surface temperature trends in the Australian region (a) 1910-2020; (b) 1980 - 2020 (State of the environment, 2021 source: BOM, using ERSSTv5 dataset).

High ocean temperatures increase risk of marine heatwaves, resulting in changed marine ecosystems and range of species as well as coral bleaching (Trewin, Morgan-Bulled & Cooper, 2021).

5.6.8.1 Predictions

The general trend for ocean temperature and chemistry is continuing increases in sea surface temperature with the oceans surrounding Australia becoming more acidic (Moise *et al.* 2015). Sea surface temperatures have risen significantly globally over recent decades, with the temperature around the Northern Territory waters increasing by at least 0.5°C since 1950 (NESP ESCC Hub 2020). In the near future sea surface temperature around the Darwin area is predicted to increase between 0.4 to 1.1°C up to 2.2 to 4.1°C under a high emissions pathway by the end of the century (NESP ESCC Hub 2020). Increasing temperature presents a significant risk to the marine environment with associated biological changes in marine species, community structure and increased risk of coral bleaching (Moise *et al.* 2015).

Approximately one-third of the carbon dioxide emitted into the atmosphere over the past 200 years is absorbed by the oceans, decreasing the pH by 0.1 in surface water pH (Moise *et al.* 2015, NESP ESCC Hub 2020). As the carbon dioxide enters the ocean it reacts with seawater causing a decrease in pH and carbonate concentration, a process collectively known as ocean acidification.

In the near future, pH is projected to fall by an additional 0.07 units in the Northern Territory's coastal waters and up to 0.14 under medium emissions, or 0.3 units under a under high emissions pathway projected by the end of the century (NESP ESCC Hub 2020). These values represent a 40 and 100% increase in acidity respectively. The increase in acidity is accompanied by reductions in aragonite saturation state and together with the changes in sea surface temperature will affect all levels of the marine food web and make it harder for calcifying marine organisms to build shells, affecting resilience and viability of marine ecosystems (Moise *et al.* 2015).

5.6.8.2 Risks and possible mitigations

A wide range of climate parameter trends were assessed as part of the first pass risk assessment and did not identify any risks specifically related to changes in ocean temperature and chemistry directly linked to mine site closure.

5.6.9 Future work on climate change risk

The climate change risk assessment undertaken involved a large body of site-specific studies and expert elicitation. A list of recommendations was provided in the report relate to the water and sediment theme and ecosystem rehabilitation theme and have been incorporated into ERA's risk management system and the MCP where relevant.

ERA notes that new information on climate change available in 2022 from the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report has been released. Information from this report is under review for suitability of incorporation into an updated Ranger Uranium Mine Closure Climate Change Risk Assessment. Stakeholder feedback on the 'first-pass' risk assessment will also be considered, as well as recommendations made in the project report.

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APPENDIX 5.1: KEY KNOWLEDGE NEEDS

APPENDIX 5.1 KEY KNOWLEDGE NEEDS (KKNs)

KKN	KNN Title	Question	Responsibility	Status
Landform Theme				
LAN1	Determining baseline erosion and sediment transport characteristics in areas surrounding the RPA	LAN1A. What are the baseline rates of gully formation for areas surrounding the RPA?	SSB	Active
		LAN1B. What are the baseline rates of sediment transport and deposition in creeks and billabongs?	SSB	Active
LAN2	Understanding the landscape-scale processes and extreme events affecting landform stability	LAN2A. What major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate)?	SSB	Active
		LAN2B. How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?	Both	Active
LAN3	Predicting erosion of the rehabilitated landform	LAN3A. What is the optimal landform shape and surface (e.g. rip lines, substrate characteristics) that will minimise erosion?	Both	Active
		LAN3B. Where, when and how much consolidation will occur on the landform?	ERA	Active
		LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?	SSB	Active
		LAN3D. What are the erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of	SSB	Active

		mitigations)?		
		LAN3E. How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?	Both	Active
LAN4	Development of remote sensing methods for monitoring erosion	LAN4A. How do we optimise methods to measure gully formation on the rehabilitated landform?	SSB	Active
LAN5	Development of water quality monitoring methods for assessing landform erosion	LAN5A. How can we use suspended sediment in surface water (or turbidity as a surrogate) as an indicator for erosion on the final landform?	SSB	Active
Water and Sediment Theme				
WS1	Characterising contaminant sources on the RPA	WS1A. What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?	ERA	Active
		WS1B. What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?	ERA	Active
WS2	Predicting transport of contaminants in groundwater	WS2A. What is the nature and extent of groundwater movement, now and over the long-term?	ERA	Completed
		WS2B. What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?	ERA	Active
		WS2C. What are predicted contaminant (including nutrients) concentrations in groundwater over time?	ERA	Completed
WS3	Predicting transport of contaminants in surface	WS3A. What is the nature and extent of surface water movement, now and over the long-term?	ERA	Completed

	water	WS3B. What concentrations of contaminants from the rehabilitated site will aquatic (surface and ground-water dependent) ecosystems be exposed to?	ERA	Completed
		WS3C. What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?	ERA	Completed
		WS3D. Where and when does groundwater discharge to surface water?	Both	Completed
		WS3E. What factors are likely to be present that influence contaminant transport (including nutrients) between groundwater and surface water?	ERA	Completed
		WS3F. What are the predicted concentrations of suspended sediment and contaminants (including nutrients) bound to suspended sediments in surface waters over time?	Both	Active
		WS3H. Where and when will suspended sediments and associated contaminants accumulate downstream?	ERA	Active
WS4	Characterising baseline aquatic biodiversity and ecosystem health	WS4A. What are the nature and extent of baseline surface water, hyporheic and stygofauna communities, as well as other groundwater dependent ecosystems, and their associated environmental conditions?	SSB	Completed
WS5	Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health	WS5A. Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?	Both	Active
WS6	Determining the impact of nutrients in surface water on aquatic biodiversity and	WS6C. Will the total loads of nutrients (N and P) to surface waters cause eutrophication?	ERA	Active

	ecosystem health			
WS7	Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health	WS7B. What is the risk associated with emerging contaminants?	Both	Active
WS9	Optimisation of water quality monitoring programs and assessment methods	WS9A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?	ERA	Active
Health Impacts of Radiation Theme				
RAD1	Radionuclides in the rehabilitated site	RAD1A. What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and land application areas?	ERA	Active
RAD2	Radionuclides in aquatic ecosystems	RAD2A. What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?	ERA	Completed
RAD3	Radon progeny in air	RAD3A. What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?	Both	Completed
RAD4	Radionuclides in dust	RAD4. What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	SSB	Completed
RAD5	Radionuclides in bushfoods	RAD5A. What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?	SSB	Active
RAD6	Radiation dose to wildlife	RAD6A. What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?	ERA	Completed

		RAD6B. What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?	SSB	Active
		RAD6C. What are the tissue to whole organism conversion factors for uranium and actinium series radionuclides for wildlife represented by the representative organism groups?	SSB	Completed
		RAD6E. What is the sensitivity of model parameters on the assessed radiation doses to wildlife?	ERA	Active
RAD7	Radiation dose to the public	RAD7A. What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?	ERA	Active
		RAD7B. What is the sensitivity of model parameters on the assessed doses to the public?	ERA	Active
RAD8	Impacts of contaminants on wildlife	RAD8A. Will contaminant concentrations in surface water (including creeks, billabongs and seeps) pose a risk of chronic or acute impacts to terrestrial wildlife?	ERA	Active
RAD9	Impacts of contaminants on human health	RAD9A. What are the contaminants of potential concern to human health from the rehabilitated site?	ERA	Completed
		RAD9B. What are the concentration factors for contaminants in bush foods?	SSB	Completed
		RAD9C. What are the concentrations of contaminants in drinking water sources?	ERA	Completed
		RAD9D. What is the dietary exposure of, and toxicity risk to, a member of the public associated with all contaminant sources, and is this within relevant Australian and/or international guidelines?	ERA	Active

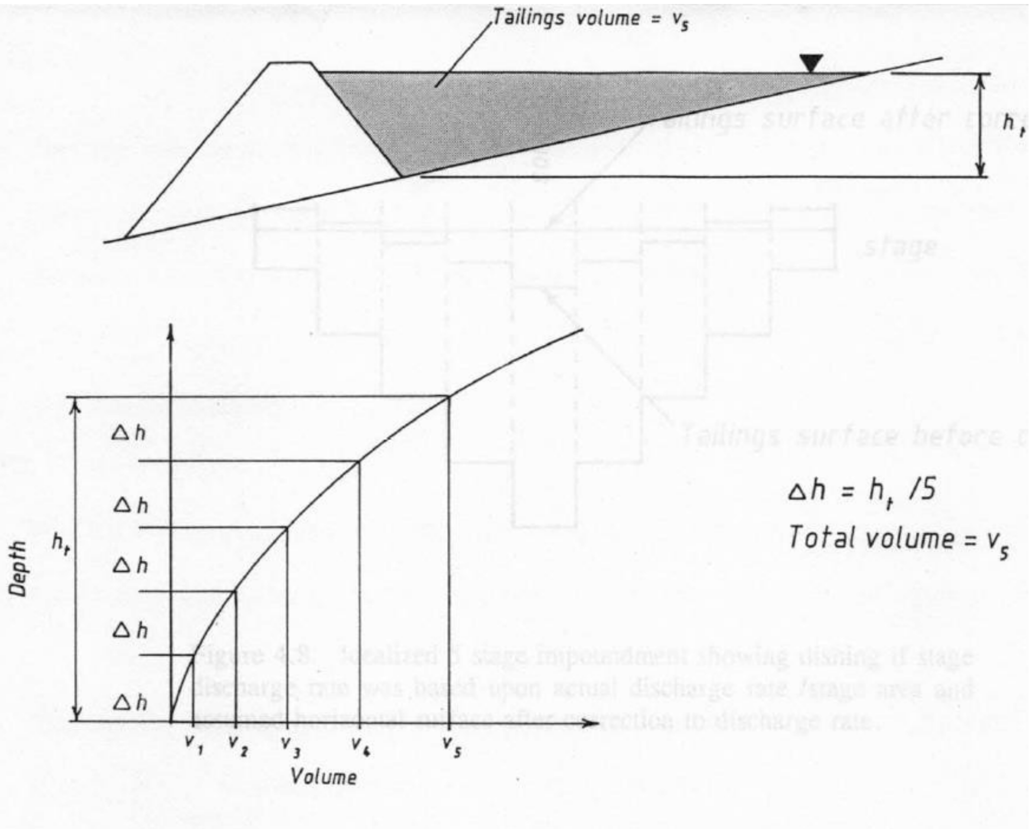
RAD10	Optimisation of radionuclide monitoring and assessment methods	RAD10A. How do we optimise methods to monitor and assess radionuclides?	SSB	Completed
Ecosystem Restoration Theme				
ESR1	Determining the requirements and characteristics of terrestrial vegetation in natural ecosystems adjacent to the mine site, including Kakadu National Park.	ESR1A. What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally inundated savanna) in natural ecosystems adjacent to the mine site, how do they vary spatially and temporally, and what are the factors that contribute to this variation?	ERA	Active
		ESR1B. What values should be prescribed to each indicator of similarity to demonstrate revegetation success?	SSB	Completed
ESR2	Determining the requirements and characteristics of a terrestrial faunal community similar to natural ecosystems adjacent to the mine site, including Kakadu National Park	ESR2A. What faunal community structure (composition, relative abundance, functional groups) is present in natural ecosystems adjacent to the mine site, and what factors influence variation in these community parameters?	Both	Active
		ESR2B. What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?	ERA	Active
		ESR2C. What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?	ERA	Active
ESR3	Understanding how to establish native terrestrial vegetation, including understory species.	ESR3A. How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?	ERA	Active
ESR4	Determine the incidence and abundance of introduced species in natural ecosystems	ESR4A. What is the incidence and abundance of introduced animals and weeds in areas adjacent to the mine site, and what are the factors that will inform effective management of introduced species on	SSB	Proposed

	adjacent to the mine site, including Kakadu National Park, and their potential to impact on the successful rehabilitation of Ranger mine	the rehabilitated mine site?		
ESR5	Develop a restoration trajectory for Ranger mine	ESR5A. What are the key sustainability indicators that should be used to measure restoration success?	Both	Active
		ESR5B. What are possible/agreed restoration trajectories (flora and fauna) across the Ranger mine site; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the mine site, including Kakadu National Park?	Both	Active
ESR6	Understanding the impact of contaminants on vegetation establishment and sustainability	ESR6A. What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants?	Both	Active
		ESR6B. Based on the structure and health of vegetation on the Land Application Areas, what species appear tolerant to the cumulative impacts of contaminants and other stressors over time?	ERA	Active
ESR7	Understanding the effect of waste rock properties on ecosystem establishment and sustainability	ESR7A. What is the potential for plant available nutrients (e.g. nitrogen and phosphorus) to be a limiting factor for sustainable nutrient cycling in waste rock?	ERA	Completed
		ESR7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?	Both	Active
		ESR7C. Will ecological processes required for vegetation sustainability (e.g. soil formation) occur on the rehabilitated landform and if not, what are the mitigation responses?	ERA	Completed

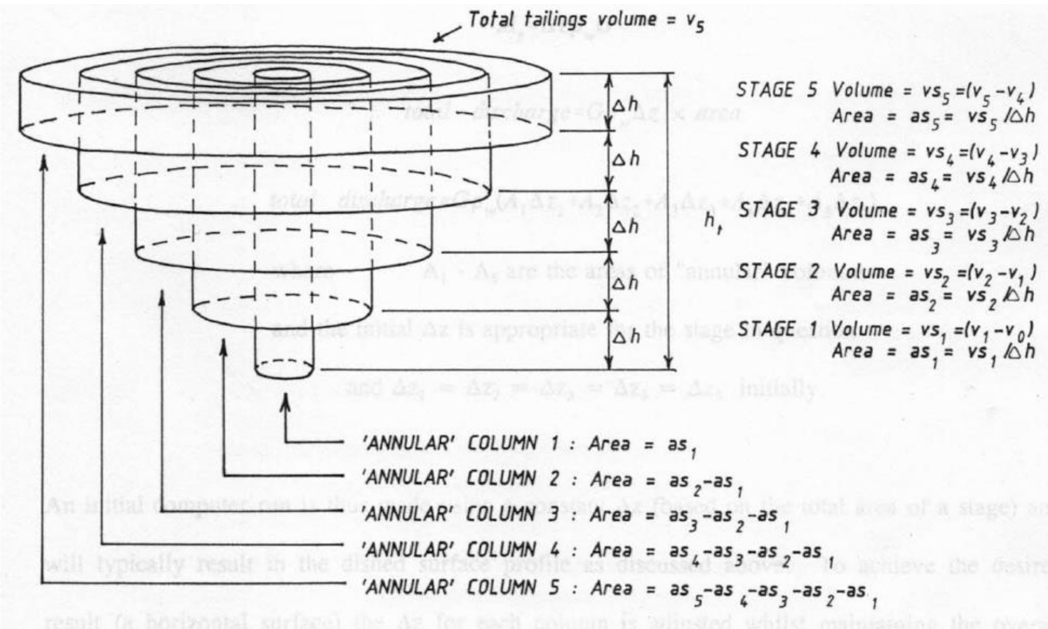
ESR8	Understanding fire resilience and management in ecosystem restoration	ESR8A. What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?	Both	Active
ESR9	Developing best-practice monitoring methods for ecosystem restoration	ESR9A. How do we optimise methods to measure revegetation and faunal community structure and sustainability on the rehabilitated site, at a range of spatial/temporal scales and relative to the areas surrounding the RPA?	SSB	Active
Cross-Theme				
CT1	Assessing the cumulative risks to the success of rehabilitation on-site and to the protection of the off-site environment.	CT1A. What are the cumulative risks to the success of rehabilitation on-site and to the off-site environment?	Both	Completed
CT2	Characterising World Heritage values of the Ranger Project Area	CT2A. What World Heritage Values are found on the Ranger Project Area, and how might these influence the incorporation of the site into Kakadu National Park and World Heritage Area?	Both	Completed

APPENDIX 5.2: CONSOLIDATION MODEL A

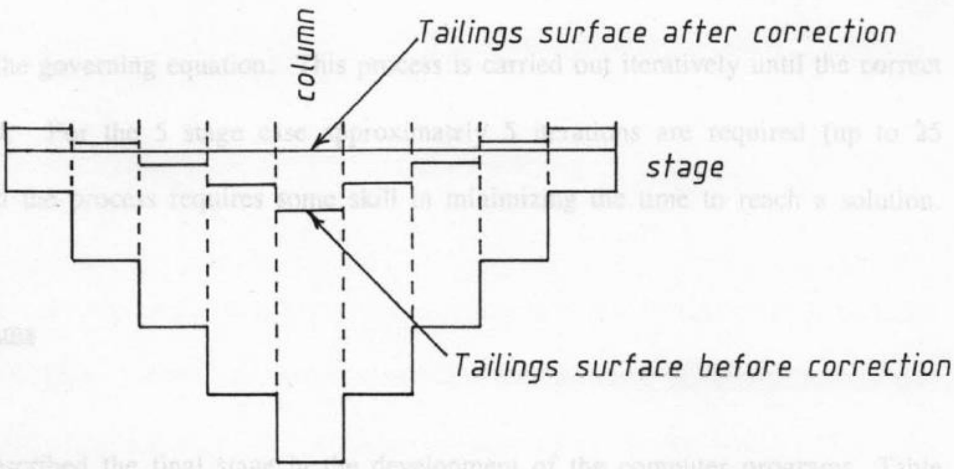
CONSOLIDATION MODEL A



ACTUAL IMPOUNDMENT



MODEL IMPOUNDMENT



Idealized 5 stage impoundment showing dishing if stage discnarge rate was based upon actual discharge rate /stage area and assumed horizontal surface after correction to discharge rate.

APPENDIX 5.3: CONSOLIDATION MODEL B

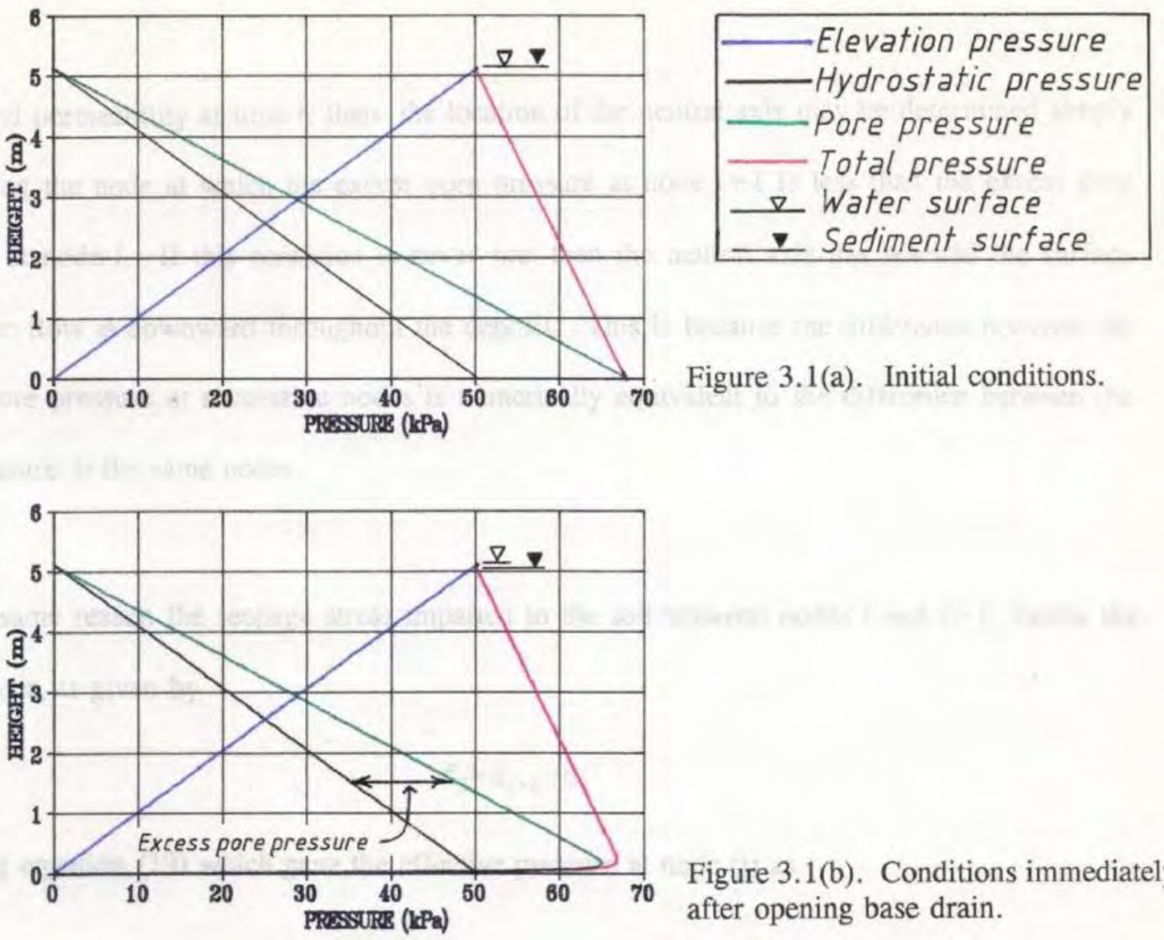


Figure 3.1(a). Initial conditions.

Figure 3.1(b). Conditions immediately after opening base drain.

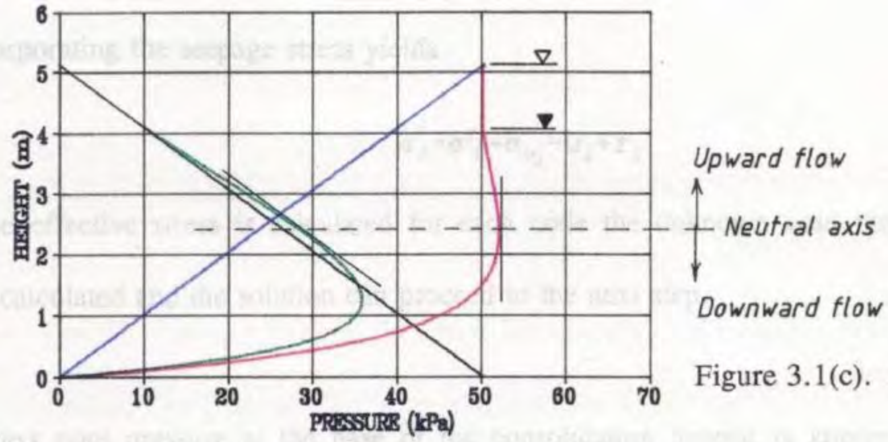


Figure 3.1(c). Intermediate case.

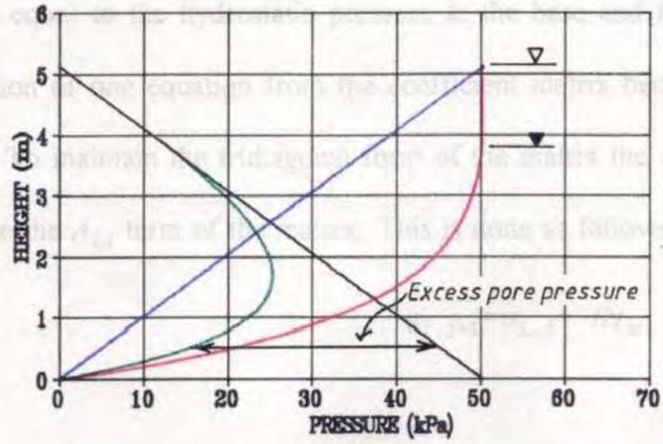


Figure 3.1(d). Approaching equilibrium conditions.

Figure 3.1. Pore pressure conditions in an underconsolidated slurry.

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APPENDIX 5.4: THE RANGER REVEGETATION STRATEGY (REDDELL & MEEK 2004

Appendix 5.4: Ranger Revegetation Strategy (Reddell & Meek 2004)

The Ranger Revegetation Strategy was developed based on decades of learnings from extensive revegetation research and trials; it was first endorsed by stakeholders and an independent scientific advisory panel (the Alligator Rivers Region Technical Committee) in 2004. Recently it has been updated, refined and published in the Ranger Mine Closure Plan. ERA are in the process of developing an Ecosystem Establishment Strategy, building on the 2004 strategy, for the Final Landform Application submission at the end of 2023.

Table A-1: The fourteen key strategy elements from Reddell and Meek (2004) and their relevance to ERA's Ecosystem Establishment Strategy

Element	Revegetation Strategy Elements from 2004	Relevance in 2022	Related MCP Section(s)
1	*Determine the likely physical and chemical characteristics of the final landform that will influence both the initial establishment and the long-term growth, development and functioning of revegetated plant communities*	Still relevant	Section 5 ESR7 & ESR3
2	*Identify and describe vegetation types that are ecologically, culturally and technically realistic target endpoints, for different facets of the final landform, based on the likely physical and chemical environments that will be created*	Still relevant	Section 5 ESR1 & ESR7
3	*Avoid disturbing, transporting and spreading the very limited topsoil available by establishing vegetation directly into in-situ materials* [waste rock]	Still relevant as waste rock is our only available growth media	Section 5 ESR1, ESR7 & ESR3
4	*Maximise surface roughness and 'patchiness' during site preparation*	Still relevant, however further development and refinement since 2004	Section 9.3.5
5	*Use seed and propagation material collected within 30 km of Ranger for all species*	Still relevant, however further development and refinement since 2004	Section 5 ESR3
6	*Focus on initially establishing a floristic composition that is dominated by a diverse range of the long-lived 'framework' species*	Still relevant, however further development and refinement since 2004	Section 5 ESR1 Appendix 5.5
7	*Introduce a range of mycorrhizal fungi from local environments to aid in the establishment of the framework species*	Still relevant	Section 5 ESR3

Element	Revegetation Strategy Elements from 2004	Relevance in 2022	Related MCP Section(s)
8	*Avoid the use of high densities of [aggressive] Acacia species*	Still relevant, however further development and refinement since 2004	Section 5 ESR3 & ESR4 Appendix 5.5
9	*Avoid actively re-introducing grasses and vigorous herbaceous species in the first year*	Currently being challenged considering the ecosystem services provided by understorey species such as stabilisation, erosion control, and habitat creation, and the difficulties experienced with establishing desirable understorey cover on TLF	Section 5 ESR3
10	*Use nursery-grown planting stock to establish the framework species*	Still relevant	Section 5 ESR3 Section 9.3.6
11	*Apply fertilisers in a strategic manner using formulations and delivery methods that maximise their effectiveness*	Still relevant	Section 9.3.6
12	*Rigorously control potential threatening weed species*	Still relevant	Section 5 ESR4 Section 9.3.6 Section 10.4
13	*Exclude fire from revegetation areas during the first three years after establishment*	Currently being challenged (ie. exclusion period extended beyond three years) considering species survivability height thresholds and potential impact on waste rock soil development and nutrient cycling	Section 5 ESR8 & ESR7 Section 10.4
14	*Design and implement a rigorous and scientifically-based strategy for on-going evaluation of the performance of the revegetation*	Still relevant	Section 5 ESR3 Section 10.4

APPENDIX 5.5: SERP SPECIES ERA ARE POTENTIALLY CONSIDERING FOR REVEGETATION

ERA Energy Resources Of Australia

APPENDIX 5.5: SERP species ERA are potentially considering for revegetation

The majority of stems (approximately 70%) used for revegetating Ranger FLF will consist of a handful of species, including dominate *Eucalyptus* and *Corymbia* trees, *Acacias*, and common fruiting shrubs. The remaining stems will be a range of tree, shrub and groundcover plants that, although in smaller densities, contribute significantly to the ecosystem's species richness, provide food and shelter for fauna, and/or are important species for Traditional Owners.

Species below include all those being considered for revegetation of the *Eucalyptus tetrodonta / miniata* savanna woodland sections of FLF. Some SERP species are not included on this list because they are not currently being considered for active revegetation due to the potential risks they pose to the establishing ecosystem, their proven ability to readily colonise waste rock, or because they typically occur in a different type of ecosystem (eg. riparian).

Species	Family	Lifeform
Overstorey Species		
Alstonia actinophylla	Apocynaceae	Tree
Corymbia bleeseri *	Myrtaceae	Tree
Corymbia chartacea	Myrtaceae	Tree
Corymbia disjuncta *	Myrtaceae	Tree
Corymbia dunlopiana	Myrtaceae	Tree
Corymbia foelscheana *	Myrtaceae	Tree
Corymbia latifolia *	Myrtaceae	Tree
Corymbia polycarpa *	Myrtaceae	Tree
Corymbia polysciada *	Myrtaceae	Tree
Corymbia porrecta	Myrtaceae	Tree
Elaeocarpus arnhemicus *	Elaeocarpaceae	Tree
Erythrophleum chlorostachys *	Fabaceae	Tree
Eucalyptus miniata *	Myrtaceae	Tree
Eucalyptus phoenicea *	Myrtaceae	Tree
Eucalyptus tectifica	Myrtaceae	Tree
Eucalyptus tetrodonta *	Myrtaceae	Tree
Eucalyptus tintinnans	Myrtaceae	Tree
Ficus racemosa *	Moraceae	Tree
Midstorey Species		
Acacia difficilis *	Fabaceae	Shrub
Acacia dimidiata *	Fabaceae	Small shrub
Acacia hemignosta	Fabaceae	Shrub
Acacia lamprocarpa *	Fabaceae	Tree
Acacia latescens	Fabaceae	Shrub
Acacia mimula	Fabaceae	Shrub
Acacia oncinocarpa	Fabaceae	Small shrub
Allosyncarpia ternata *	Myrtaceae	Tree
Brachychiton megaphyllus *	Malvaceae	Tree
Buchanania obovata *	Anacardiaceae	Tree
Calytrix exstipulata *	Myrtaceae	Small shrub
Clerodendrum floribundum *	Lamiaceae	Shrub/Small tree
Cochlospermum fraseri *	Bixaceae	Shrub/Small tree
Coelospermum reticulatum *	Rubiaceae	Shrub/Small tree
Ficus brachypoda *	Moraceae	Shrub
Gardenia fucata *	Rubiaceae	Small shrub

Species	Family	Lifeform
Gardenia megasperma	Rubiaceae	Shrub
Grevillea decurrens *	Proteaceae	Small shrub
Livistona humilis *	Arecaceae	Palm
Owenia vernicosa *	Meliaceae	Tree
Pandanus spiralis *	Pandanaceae	Palm
Persoonia falcata *	Proteaceae	Shrub/Small tree
Petalostigma pubescens *	Picrodendraceae	Shrub/Small tree
Planchonella arnhemica	Sapotaceae	Tree
Planchonia careya *	Lecythidaceae	Tree
Syzygium eucalyptoides ssp. bleeseri *	Myrtaceae	Tree
Syzygium eucalyptoides ssp. eucalyptoides *	Myrtaceae	Small tree
Syzygium suborbiculare *	Myrtaceae	Tree
Terminalia carpentariae *	Combretaceae	Tree
Terminalia ferdinandiana *	Combretaceae	Shrub/Small tree
Terminalia pterocarya	Combretaceae	Shrub/Small tree
Xanthostemon eucalyptoides *	Myrtaceae	Tree
Xanthostemon paradoxus	Myrtaceae	Tree
Understorey species		
Acacia gonocarpa	Fabaceae	Small shrub
Alloteropsis semialata	Poaceae	Grass
Ampelocissus acetosa *	Vitaceae	Vine (climber)
Aristida holathera	Poaceae	Grass
Aristida inaequiglumis	Poaceae	Grass
Aristida spp.	Poaceae	Grass
Cartonema spicatum	Commelinaceae	Herb
Cayratia trifolia *	Vitaceae	Vine (climber)
Chrysopogon fallax	Poaceae	Grass
Corynotheca lateriflora *	Hemerocallidaeae	Herb
Crotalaria spp.	Fabaceae	Herb
Cymbopogon spp.	Poaceae	Grass
Cyperus spp.	Cyperaceae	Sedge
Dioscorea transversa	Dioscoreaceae	Vine (climbing)
Eragrostis spp.	Poaceae	Grass
Eriachne armittii	Poaceae	Grass
Eriachne obtusa	Poaceae	Grass
Eriachne schultziana	Poaceae	Grass
Eriachne spp.	Poaceae	Grass
Eriachne triseta	Poaceae	Grass
Fimbristylis spp.	Cyperaceae	Herb
Flemingia parviflora	Fabaceae	Subshrub
Galactia megalophylla	Fabaceae	Shrub
Galactia tenuiflora	Fabaceae	Vine (prostrate)
Gonocarpus leptothecus	Haloragaceae	Subshrub
Grevillea dryandri ssp. dryandri *	Proteaceae	Small shrub
Grevillea goodii ssp. gooddii *	Proteaceae	Shrub (prostrate)
Grewia retusifolia	Malvaceae	Shrub
Haemodorum coccineum	Haemodoraceae	Herb
Heteropogon triticeus	Poaceae	Grass
Hibbertia spp.	Dilleniaceae	Shrub
Indigofera spp.	Fabaceae	Herb / Shrub
Larsenaikia suffruticosa	Rubiaceae	Subshrub
Marsdenia spp.	Apocynaceae	Vine
Microstachys chamaelea	Euphorbiaceae	Shrub

Species	Family	Lifeform
Petalostigma quadriloculare	Picrodendraceae	Shrub
Tephrosia oblongata	Fabaceae	Shrub
Tephrosia remotiflora	Fabaceae	Herb / Subshrub
Tephrosia spp.	Fabaceae	Herb / Shrub
Tephrosia subpectinata	Fabaceae	Shrub
Themeda triandra	Poaceae	Grass
Uraria lagopodioides	Fabaceae	Herb (Prostrate)
Vigna spp.	Fabaceae	Vine (Twining)

APPENDIX 5.6: FAUNA SPECIES LIST (SLR 2021)

APPENDIX 5.6 FAUNA SPECIES LIST (from SLR 2021)

Species list

Common name	Scientific name
Amphibians	
Bilingual Frog	*Crinia bilingua*
Copland's Rock Frog	*Litoria coplandi*
Giant Frog	*Cyclorana australis*
Giant Frog	*Litoria australis*
Green Tree-Frog	*Litoria caerulea*
Marbled Frog	*Limnodynastes convexiusculus*
Northern Dwarf Tree Frog	*Litoria bicolor*
Northern Spadefoot Toad	*Notaden melanoscaphus*
Northern Territory Frog	*Austrochaperina adelphe*
Ornate Burrowing Frog	*Platyplectrum ornatus*
Pale Frog	*Litoria pallida*
Rocket Frog	*Litoria nasuta*
Roth's Tree Frog	*Litoria rothii*
Stonemason Toadlet	*Uperoleia lithomoda*
Tornier's Frog	*Litoria tornieri*
Birds	
Apostlebird	*Struthidea cinerea*
Australasian Darter	*Anhinga novaehollandiae*
Australasian Figbird	*Sphecotheres vieilloti*
Australian Hobby	*Falco longipennis*
Australian Owlet-Nightjar	*Aegotheles cristatus*
Banded Honeyeater	*Cissomela pectoralis*
Barking Owl	*Ninox connivens*
Bar-Shouldered Dove	*Geopelia humeralis*
Black Kite	*Milvus migrans*
Black-Breasted Buzzard	*Hamirostra melanosternon*
Black-Faced Cuckoo-Shrike	*Coracina novaehollandiae*
Black-Faced Woodswallow	*Artamus cinereus*
Black-Necked Stork	*Ephippiorhynchus asiaticus*
Black-Tailed Treecreeper	*Climacteris melanura*
Blue-Faced Honeyeater	*Entomyzon cyanotis*
Blue-Winged Kookaburra	*Dacelo leachii*
Boobook Owl	*Ninox novaeseelandiae*
Broad-Billed Flycatcher	*Myiagra ruficollis*
Brown Falcon	*Falco berigora*
Brown Goshawk	*Accipiter fasciatus*
Brown Honeyeater	*Lichmera indistincta*

Common name	Scientific name
Brown Quail	*Coturnix ypsilophora*
Brush Cuckoo	*Cacomantis variolosus*
Bush Stone-Curlew	*Burhinus grallarius*
Channel-Billed Cuckoo	*Scythrops novaehollandiae*
Chestnut-Backed Button-Quail	*Turnix castanota*
Cicadabird	*Coracina tenuirostris*
Crimson Finch	*Neochmia phaeton*
Diamond Dove	*Geopelia cuneata*
Dollarbird	*Eurystomus orientalis*
Double-Barred Finch	*Taeniopygia bichenovii*
Dusky Honeyeater	*Gallinula tenebrosa*
Dusky Honey-Eater	*Myzomela obscura*
Eastern Koel	*Eudynamys orientalis*
Forest Kingfisher	*Todiramphus macleayii*
Galah	*Eolophus roseicapilla*
Galah	*Eulophus roseicapilla*
Golden-Headed Cisticola	*Cisticola exilis*
Great Bowerbird	*Phalacrocorax carbo*
Green-Backed Gerygone	*Gerygone chloronota*
Grey Shrike-Thrush	*Colluricincla harmonica*
Grey-Crowned Babbler	*Pomatostomus temporalis*
Helmeted Friarbird	*Philemon buceroides*
Large-Tailed Nightjar	*Caprimulgus macrurus*
Leaden Flycatcher	*Myiagra rubecula*
Lemon-Bellied Flycatcher	*Microeca flavigaster*
Little Bronze-Cuckoo	*Chrysococcyx minutillus*
Little Corella	*Cacatua sanguinea*
Little Friarbird	*Philemon citreogularis*
Little Woodswallow	*Artamus minor*
Long-Tailed Finch	*Poephila acuticauda*
Magpie Lark	*Grallina cyanoleuca*
Masked Finch	*Poephila personata*
Masked Owl	*Tyto novaehollandiae*
Mistletoebird	*Dicaeum hirundinaceum*
Nankeen Kestrel	*Falco cenchroides*
Northern Fantail	*Rhipidura rufiventris*
Northern Rosella	*Platycercus venustus*
Olive-Backed Oriole	*Oriolus sagittatus*
Orange-Footed Scrubfowl	*Megapodius reinwardt*
Owlet Nightjar	*Aegotheles chrisoptus*
Partridge Pigeon	*Geophaps smithii*
Peaceful Dove	*Geopelia striata*
Pheasant Coucal	*Centropus phasianinus*
Pied Butcherbird	*Cracticus nigrogularis*

Common name	Scientific name
Pied Imperial-Pigeon	*Ducula bicolor*
Rainbow Bee-Eater	*Merops ornatus*
Rainbow Lorikeet	*Trichoglossus haematodus*
Rainbow Pitta	*Pitta iris*
Red-Backed Fairywren	*Malurus melanocephalus*
Red-Tailed Black Cockatoo	*Calyptorhynchus banksii*
Red-Winged Parrot	*Aprosmictus erythropterus*
Rose-Crowned Fruit-Dove	*Ptilinopus regina*
Royal Spoonbill	*Platalea regia*
Rufous Fantail	*Rhipidura dryas*
Rufous Whistler	*Pachycephala rufiventris*
Rufous-Banded Honeyeater	*Conopophila albogularis*
Rufous-Throated Honeyeater	*Conopophila rufogularis*
Sacred Kingfisher	*Todiramphus sanctus*
Shining Flycatcher	*Myiagra alecto*
Silver-Crowned Friarbird	*Philemon argenticeps*
Southern Boobook	*Ninox boobook*
Spangled Drongo	*Dicrurus bracteatus*
Spotted Harrier	*Circus assimilis*
Spotted Nightjar	*Eurostopodus argus*
Straw-Necked Ibis	*Threskiornis spinicollis*
Striated Pardalote	*Pardalotus striatus*
Sulphur-Crested Cockatoo	*Cacatua galerita*
Tawny Frogmouth	*Podargus strigoides*
Torresian Crow	*Corvus orru*
Varied Lorikeet	*Psitteuteles versicolor*
Varied Triller	*Lalage leucomela*
Weebill	*Smicrornis brevirostris*
Whistling Kite	*Haliastur sphenurus*
White-Bellied Cuckoo-Shrike	*Coracina papuensis*
White-Bellied Sea-Eagle	*Haliaeetus leucogaster*
White-Gaped Honeyeater	*Lichenostomus unicolor*
White-Throated Gerygone	*Gerygone albogularis*
White-Throated Honeyeater	*Melithreptus albogularis*
White-Winged Triller	*Lalage sueurii*
Willie Wagtail	*Rhipidura leucophrys*
Yellow Oriole	*Oriolus flavocinctus*
Yellow-Throated Miner	*Manorina flavigula*
Zebra Finch	*Taeniopygia guttata*
Mammals	
Agile Wallaby	*Macropus agilis*
Antilopine Wallaroo	*Macropus antilopinus*
Black Flying-Fox	*Pteropus alecto*
Black-Footed Tree-Rat	*Mesembriomys gouldii*

Common name	Scientific name
Claw-Snouted Blind Snake	*Ramphotyphlops unguirostris*
Common Brushtail Possum	*Trichosurus vulpecula*
Common Wallaroo	*Macropus robustus*
Dingo	*Canis dingo*
Fawn Antechinus	*Antechinus bellus*
Grassland Melomys	*Melomys burtoni*
Northern Brown Bandicoot	*Isoodon macrourus*
Northern Quoll	*Dasyurus hallucatus*
Short-Beaked Echidna	*Tachyglossus aculeatus*
Sugar Glider	*Petaurus breviceps*
Black-Necked Snake-Lizard	*Delma tincta*
Black-Tailed Monitor	*Varanus tristis*
Reptiles	
Blind Snake	*Anilios*
Burton's Legless Lizard	*Lialis burtonis*
Bynoe's Gecko	*Heteronotia binoei*
Children's Python	*Antaresia childreni*
Frilled Lizard	*Chlamydosaurus kingii*
Gilbert`S Dragon	*Lophognathus gilberti*
Green Tree Snake	*Dendrelaphis punctulata*
Grey's Menetia	*Menetia greyii*
Karl Schmidt's Lerista	*Lerista karlschmidti*
Lively Ctenotus	*Ctenotus alacer*
Long-Nosed Water Dragon	*Lophognathus longirostris*
Marbled Velvet Gecko	*Oedura marmorata*
Metallic Snake-Eyed Skink	*Cryptoblepharus metallicus*
Northern Dtella	*Gehyra australis*
Northern Dwarf Skink	*Menetia maini*
Northern Mulch-Skink	*Glaphyromorphus darwinensis*
Northern Shovel-Nosed Snake	*Brachyurophis roperi*
Northern Small-Eyed Snake	*Cryptophis pallidiceps*
Northern Snake-Lizard	*Delma borea*
Orange-Naped Snake	*Furina ornata*
Ornate Snake-Eyed Skink	*Notoscincus ornatus*
Port Essington Ctenotus	*Ctenotus essingtonii*
Robust Ctenotus	*Ctenotus robustus*
Scant-Striped Ctenotus	*Ctenotus vertebralis*
Slender Rainbow Skink	*Carlia gracilis*
Slender Snake-Eyed Skink	*Proablepharus tenuis*
Smooth-Tailed Skink	*Glaphyromorphus isolepis*
Spotted Tree Monitor	*Varanus scalaris*
Storr's Ctenotus	*Ctenotus storri*
Storr's Snake-Eyed Skink	*Morethia storri*
Striped Rainbow Skink	*Carlia munda*

Common name	Scientific name
Swanson's Snake-Eyed Skink	*Cryptoblepharus cygnatus*
Three-Spined Rainbow Skink	*Carlia triacantha*
Two-Lined Dragon	*Diporiphora bilineata*
Two-Spined Rainbow Skink	*Carlia amax*
Water Python	*Liasis fuscus*
Zig-Zag Gecko	*Oedura rhombifer*

6 Best Practicable Technology

Issued Date: October 2022

Revision #: 1.22.0

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Cover photograph: Ping Lu, Megan Parry and Lucia Lynch monitoring Pit 1 plantings

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
As low as reasonably achievable	Abbreviated to ALARA. As low as reasonably achievable, economic and social factors being taken into account.
Best Practicable Technology	Technology from time to time relevant to the Ranger Project which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters.
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary 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.

ABBREVIATIONS AND ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
BPT	Best Practicable Technology
ER	Environmental Requirements
ERA	Energy Resources of Australia
RL	Relative Level
RPA	Ranger Project Area

6 BEST PRACTICABLE TECHNOLOGY

6.1 Introduction

A Best Practicable Technology (BPT) is a process of analysing currently available technologies against specified criteria to identify the preferred option or approach for undertaking major closure activities at the mine.

The identification and use of Best Practicable Technologies (BPTs) are a key component of the legal framework for the closure of the Ranger Mine. The process is used to support applications to the Minesite Technical Committee (MTC) and to demonstrate that impacts on the Ranger Project Area (RPA) are as low as reasonably achievable (ALARA). The Ranger Authorisation requires that "All mining operations shall be implemented in accordance with BPT" and that impacts on the RPA are ALARA. In compliance with this requirement, a BPT assessment has accompanied each proposal for consideration by the MTC. This has been the basis upon which the MTC has made its recommendations to the Minister to approve major closure activities.

The use of a BPT assessment was identified in the Ranger Authorisation (Annex A, Section 12.4) as '*that technology from time to time relevant to the Ranger Project which produces the minimum environmental pollution and degradation that can reasonably be achieved having regard to:*

- the level of effluent control achieved, and the extent to which environmental pollution and degradation are prevented, in mining and milling operations in the uranium industry anywhere in the world,
- the total cost of the application or adoption of that technology relative to the environmental protection to be achieved by its application or adoption,
- evidence of detriment, or of lack of detriment, to the environment after the commencement of the Ranger Project,
- the physical location of the Ranger Project,
- the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation, and
- social factors including possible adverse social effects of introducing new technology.'

The interpretation and subsequent development of an assessment method was undertaken by the Supervising Scientist Division and published in their 2000-2001 Annual Report (Supervising Scientist, 2001). This was built upon and further refined for tailings integration and water management by Johnston and Iles (2013) after being accepted by stakeholders in

2012[2]. The current ER definition of BPT and an explanation of how each BPT is employed in the assessment is presented in Table 6-1.

Table 6-1: Explanation of relevant matters to be included in BPT assessment

Environmental Requirement Clause	Explanation
BPT is defined as: That technology from time to time relevant to the Ranger Project Area which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters including:	BPT: That technology that ranks highest when assessed against the identified factors and is consistent with the Primary Environmental Objectives
(a) the environmental standards achieved by uranium operations elsewhere in the world with respect to (i) level of effluent control achieved; and (ii) the extent to which environmental degradation is prevented;	World's Best Practice: Options are compared with the environmental standards set by world's best practice in uranium mining and milling at the time of implementation, with respect to the level of effluent control achieved and the prevention of environmental degradation.
(b) the level of environmental protection to be achieved by the application or adoption of the technology and the resources required to apply or adopt the technology so as to achieve the maximum environmental benefit from the available resources;	Cost-effectiveness: Options are assessed with respect to both the level of environmental protection achieved and the cost of implementation.
(c) evidence of detriment, or lack of detriment, to the environment;	Proven effectiveness: Proposals for which there is practical evidence of their effectiveness are favoured over proposals for which there is only experimental or theoretical evidence.
(d) the physical location of the Ranger Project;	Location: The Ranger Mine is located in the wet-dry tropics of the Northern Territory, on Aboriginal land surrounded by Kakadu National Park, approximately 260km east of Darwin. The level of protection required for the environment and community is very high and the technology chosen is designed accordingly.
(e) the age of equipment and facilities in use on the Ranger Project and their relative effectiveness in reducing environmental pollution and degradation; and	Age of equipment: Technology in use is reviewed routinely to determine whether recent advances have been made that would result in enhanced environmental protection. Technology installed at the Ranger Mine in accordance with BPT is then reasonably allowed to fulfil its serviceable life with due consideration given to the advances in technology and the amount of serviceable life expended.

[2] MTC meeting February 2012

Environmental Requirement Clause	Explanation
(f) social factors including the views of the regional community and possible adverse effects of introducing alternative technology.	Social factors: The views of the regional community are incorporated into BPT assessment. This includes where the introduction of new technology may improve the level of environmental protection but may also have negative social consequences. Benefits in environmental effectiveness may not necessarily result in greater social acceptability.

6.2 ALARA and BPT

As noted above, the BPT process is used to demonstrate that impacts on the RPA are as low as reasonably achievable (ALARA). The ALARA concept comes from the field of radiation protection but can also be applied to non-radiation hazards. Figure 6-1 illustrates the framework that ERA uses to apply ALARA. ERA uses the BPT process to achieve the step in this framework that is labelled ‘Optioneering’.

Section 6.3 describes the criteria used and the ranking system applied to the options included in a BPT assessment. Selected options from the BPT process are then carried through the remainder of the steps in Figure 6-1 to demonstrate acceptability from the perspective of ALARA (Appendix 6.3).

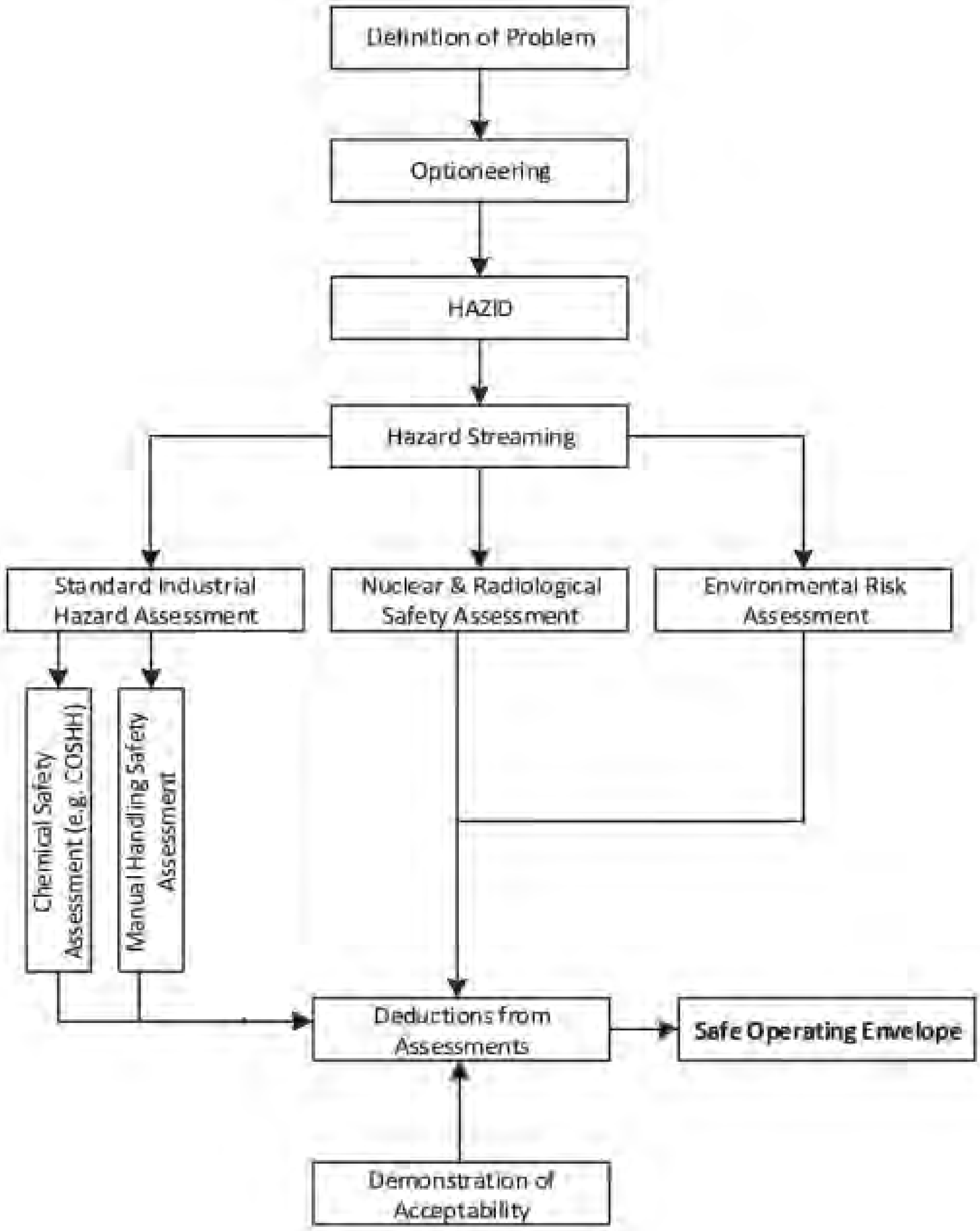

Figure 6-1 Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (source: Bryant *et al*, 2017)

6.3 Ranking and criteria of BPTs

Each BPT option is ranked against each criteria using a 5-level ranking system as follows:

- Rank 1 – Inadequate: the option does not meet current standards and it is unlikely that modifications could reverse this assessment

- Rank 2 – Poor: the option does not meet current standards but options for modifications exist that could reverse this assessment
- Rank 3 – Acceptable: the option meets current standards
- Rank 4 – Good: the option exceeds current standards
- Rank 5 – Excellent: the option exceeds current standards by a substantial margin and the option is recognised as international best practice.

If insufficient information is available to allocate a rank to a criterion in the early stages of the BPT process, the criterion shall be given an 'unable-to-evaluate' assessment. This will then prompt the development of actions to address the lack of knowledge to ensure that sufficient information will be available for evaluation prior to the application being submitted to the MTC. Where it is assessed that the criterion is not applicable (NA) to an option being considered, a 'NA' result is recorded.

Additional to the 5-level ranking system, 'show-stoppers' may also be assigned:

- A hard show-stopper is allocated to an option where it was clear from basic initial consideration that the option could not be accepted and there was no need to proceed further with assessment of the option. This might occur, for example, if an option could result in intrusion on a sacred heritage site.
- A soft show-stopper is recorded against an option if a rank equal to one or two was attributed to the option for any criterion involving occupational health and safety issues, off-site environmental protection or cultural issues. The recording of a soft show-stopper against an option would not be considered to rule out that option but it would record that the performance of the option against the particular criterion would need to be reviewed and improved before the option could be considered acceptable. The recording of a significant number of soft show-stoppers against an option would, however, be likely to rule the option out of further consideration.

A BPT score is generated for each technology option. The score is calculated using the rank against each applicable criterion, whereby:

- an option that achieves the highest possible rating for all criteria would score 100
- an option that meets standards for all criteria would score 0
- an option that achieves the lowest possible rating for all criteria would score -100.

The criteria against which each option is ranked are:

- Traditional Owner culture and heritage:
    - Would the adoption of the option have adverse impacts on the cultural practices, traditions and customs of the local Aboriginal communities?
    - Would the option threaten, in any way, the integrity of sacred sites, rock art or any other aspect of the cultural heritage of the region?

- Protection of people and the environment:
  - Would the option give rise to adverse impacts on the health and safety of Aboriginal or non-Aboriginal members of the local community?
  - Would the option have any adverse socio-economic impacts on the communities in the town of Jabiru or in the broader Kakadu region?
  - Would the option achieve protection of the natural World Heritage and Ramsar status of Kakadu NP?
  - While disturbance and environmental impact is inevitable on the project area, would adoption of the option minimise such onsite impacts?
- Fit for purpose:
  - Does the option use proven technology? Proven and demonstrated technology would be ranked higher than very new, unproven or theoretical technology.
  - How effective is the technology used in the option in meeting its desired output objective? Effective, highly robust options would rank highly.
  - How robust or sensitive is the option to variation in external factors such as weather and relevant factors (e.g. expected ground strengths, result of predecessor activities, higher or lower flows)?
  - Does the standard of environmental protection achieved by the option meet the highest standards achieved in uranium mining elsewhere in the world?
- Operational adequacy:
  - Would adoption of the practice ensure the ongoing health and safety of the workforce?
  - Would the option require extensive control and support effort to construct?
  - Is the process operationally reliable? That is, will it have high availability, or will it have features whose inherent sensitivity may impact availability?
  - Would the option be difficult to maintain?
  - Would the complexity of construction create cost risks arising from schedule uncertainty?
- Rehabilitation and closure:
  - Would adoption of the option result in closure costs that significantly detract from overall project value?
  - Would the option promote or detract from the ability to:
    - Revegetate the mine site with local native species and resulting in a low maintenance regime?
    - Establish stable radiological conditions that will ensure health risks to the public from the principal exposure pathways are ALARA?

- Establish erosion characteristics on the site that, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas?
- Meet agreed water quality criteria in creeks draining the mine site and achieve appropriate ecosystem restoration standards for water bodies on the rehabilitated landform?
- Ensure that for 10,000 years all tailings produced at the Ranger site are physically isolated from the environment and contaminants arising from the tailings do not result in any detrimental environmental impact off the RPA?
- Meet operational deadlines to achieve closure within a period that meets stakeholder expectations any legal requirements?

o Would adoption of the option extend closure beyond Traditional Owner expectations?

6.4 Completed BPTs

Table 6-2 provides a summary of the completed BPTs. Each of these BPTs were included in the 2020 MCP and the related on the ground activities have either been completed or have commenced. Appendix 6.1 details each of the completed BPTs and includes the accompanying matrices of assessment rankings.

Table 6-2 Summary of completed BPTs

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
Integrated tailings, water and closure (ITWC)	9 – PFS1 8 – PFS2 (Stage 1) 4 - PFS2 (Stage 2) 8 – Supp ITWC	Dredging 1B/1C 1B A3	Tailings reclamation via Dredging Two options carried forward for brine injection Brine injection, thickened tailings and milling until 2020 Unthickened tailings with wicks to accelerate consolidation	41.3 (Supp ITWC)	2013-2016
Salt treatment and disposal	10	1B	8 options were assessed in Stage 1, the top 2 options plus 2 additional options were assessed in Stage 2. The preferred option is brine injection to the underfill without rock screening.	19	October 2018
Brine Squeezer	27	BM2	Addition of the Osmoflo Brine Squeezer to treat Water Treatment Plant (WTP) brines to minimise additions to the pond water and process water inventory, and to optimise pond and process water treatment and disposal mechanisms.	23.7	April 2019
Closure of ranger 3 Deeps	7 - Decline 3 - Portal 9 - Ventilation Shaft	A7 B2 C9	A7 Decline: waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m). B2 Portal: Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock. C9 Ventilation Shaft: Crushed waste rock up to weathered zone, then 10 m cemented rock fill and then 10 m of crushed rock to surface; concrete collar removed.	41.7 30.8 39.5	April 2019
Progress Pit 1 to final landform	Multiple	NA	Requirement to maintain pre-mining drainage and catchment areas and to ensure that it does not degrade unduly as a result of climate change. Each version of the landform undergoes landform evolution and erosion modelling by the SSB and is peer reviewed by ARRTC. The studies, reviews and	NA	May 2019

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
			subsequent modelling done to address landform design and backfill planning are consistent with the general practice of BPT assessment.		
Tailings deposition into Pit 3 for Mill tailings and dredge tailings	3 Mill 4 Dredge	M2 D2	M1: Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing) D1: Dredge 1 and 2 subaerial	35.4 16.7	July 2019
Remnant tailings transfer – TSF to Pit 3	10	3	Scrape clean TSF floor and walls, transfer by truck, and deposit into Pit 3 south west end via a constructed tip head.	17	Included within tailings transfer approvals
High density sludge (HDS) plant recommissioning	12	11	No change to the method approved by DITT in February 2020. That is, indirect treatment by releasing HDS product into the pond water inventory (i.e. RP2), for subsequent treatment through any of the pond water treatment plants (WTPs).	44.4	February 2020
TSF North Notch Stage 3	6	A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) and construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0	June 2020
TSF subfloor material management	14	1a	Leave material *in situ.* TSF subfloor material left undisturbed in situ. All visible tailings removed. TSF is then used for process water storage.	38.2	August 2020
Blackjack (gear oil) waste disposal	5	A1	Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise	50	NA

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Approved
			contaminants prior to disposal in a bed of low permeability clay.		

6.5 Active BPTs

It is noted that the remnant tailings transfer BPT was not complete at the time of writing the 2020 MCP. However, it is now complete and therefore has been included in the completed BPTs summarised in Table 6-2 and described more fully in Appendix 6.1.

This section focuses on the active BPT, being the Pit 3 capping. Table 6-3 provides a summary and a more detailed description follows.

Table 6-3 Summary of Pit 3 Capping Best Practicable Technology

BPT Description	Number of Options/Sub-options Assessed	Preferred Option No.	Description of Preferred Option	Rating of Preferred Option	Application Status
Pit 3 Capping	7	D	Hybrid + East platform - Wicking completed sub-aqueously in Zone 1, 2, & 3 only. Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method in Zone 4 and perimeter. Sub-Aerial (passive dry out) Capping Method to cap Zone 1,2,3 after wicking.	23	Application submitted April 2022, feedback received, Application update in progress

As part of mine closure, Pit 3 capping is an integral activity as it is the permanent storage location of tailings, brine, demolition waste and a large quantity of waste rock. The originally planned method of capping relied on a series of assumptions relating to the form of the tailings at the completion of deposition into Pit 3. A key assumption was that the tailings would be largely homogeneous in nature, with a relatively consistent profile and low gradient across the pit floor. However, following the deposition of tailings into Pit 3, the actual form of the tailings did not fully align with the assumptions, in that:

- a coarse and solid beach was present at the eastern end, with a ‘hollow’ at the western end, and a gradient between the two extremities that exceeds the design basis of the capping methodology
- a layer of fine tailings was present across the pit, which behaves like a fluid. This surface body of fine tailings is of very low strength, which introduces additional complexity in terms of tailings encapsulation, capping execution and water management.

The actual tailings conditions added significant complexity to the capping methodology. As such, a BPT study was undertaken to define and assess a series of alternative capping methods that may reduce capping cost and schedule, reduce execution complexity and associated execution safety, and still achieve the relevant ERs.

The BPT assessment was conducted via a full day workshop on 22 October 2021, follow up sessions on 27 October 2021 and 26 November 2021, additional ranking assessments to resolve matters not fully addressed at the workshop/sessions, and additional solute transport modelling of high-ranking options. The BPT was documented in the report by Hatch (2021).

The options assessed, indication of risks and show-stoppers, and the final score for each option is presented in Table 6-4 (see Appendix 6.2 for details of rankings).

Table 6-4 BPT Assessment Results

Option	Option Description	Number of Class 3 & 4 Risks	Show-stoppers	Score
A	Sub-Aqueous Capping Method (Base case and current plan) Based on Golder Design and proposals from 3 x vendor execution proposals.	III: 10 IV: 2	Soft: 1 Hard: 0	7
B	East platform finished with Sub-Aqueous Capping Method (Option A) Build East platform on coarse tailings (old, beached area) to reduce capping area.	III: 11 IV: 2	Soft: 1 Hard: 0	7
C.1	Sub-Aerial (passive dry out) Capping Method Approx. 3 year dry out then capped (similar to Pit 1)	III: 5 IV: 2	Soft: 2 Hard: 0	20
C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method Use mechanical assistance to accelerate dry-out, create crust, wick conventionally through bridging layer and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	9
C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method Use mechanical assistance to accelerate dry-out, create crust, and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	18
C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method Use mechanical assistance to accelerate dry-out, create crust, wick amphibiously through crust and Sub-Aerially Cap	III: 6 IV: 2	Soft: 1 Hard: 0	16
D	Hybrid + Eastern Platform Wicking completed sub-aqueously in Zone 1, 2, & 3 only. Use C.2B method to cap (no wicks) in Zone 4 and perimeter. Use a C.1 method to cap Zone 1,2,3 after wicking.	III: 5 IV: 2	Soft: 1 Hard: 0	23

All assessed options achieved a positive overall score and had no 'hard' show-stoppers. The preferred option, Option D, achieved the highest score with 23, followed closely by Option C1 with 20 points. Option D is a hybrid method which entails (Figure 6-2 to Figure 6-5):

- pump water from Pit 3 into the RWD until a wicking level is achieved (RL -17m water level, which equates to about 2m water depth);
- sub-aqueously install wick drains into specified wicking zones (Zones 1, 2, & 3 only) to accelerate consolidation and reduce the dry out period from ~3 years to ~2 years;
- pump remaining water from Pit 3 to RWD;
- build a platform on the Eastern tailings beach of the pit floor;
- mechanically assist drying of the pit floor in the non-wicked areas of the pit using amphirol (a screw propelled vehicle able to traverse soft sites) and swamp dozers to produce a crust-like material with a nominal thickness of 1-1.5m;
- install a geotextile separation layer;
- install bridging material sub-aerially using small equipment (1-2m thick layer of waste rock);
- install secondary capping layers (~2m thick layer with Moxie and D6, then heavy mine equipment (HME));
- bulk backfill of pit (using mine HME).

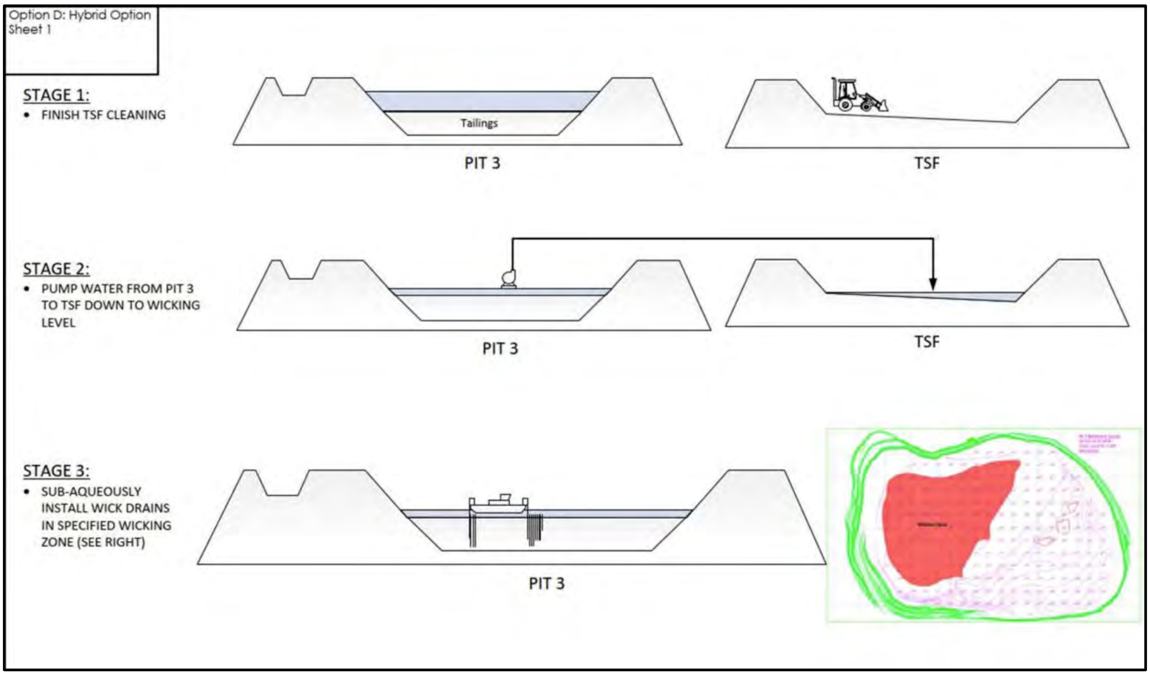

Figure 6-2 Illustration of stages 1-3 of Pit 3 capping Option D (Hatch, 2021)

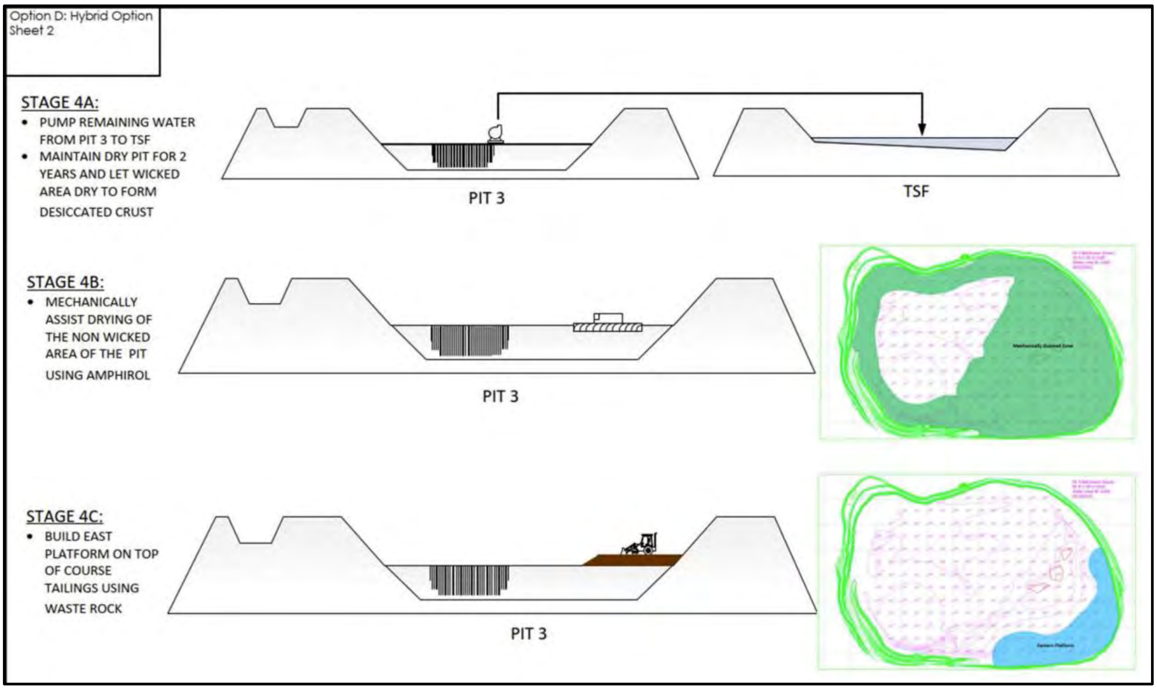

Figure 6-3 Illustration of stage 4 of Pit 3 capping Option D (Hatch, 2021)

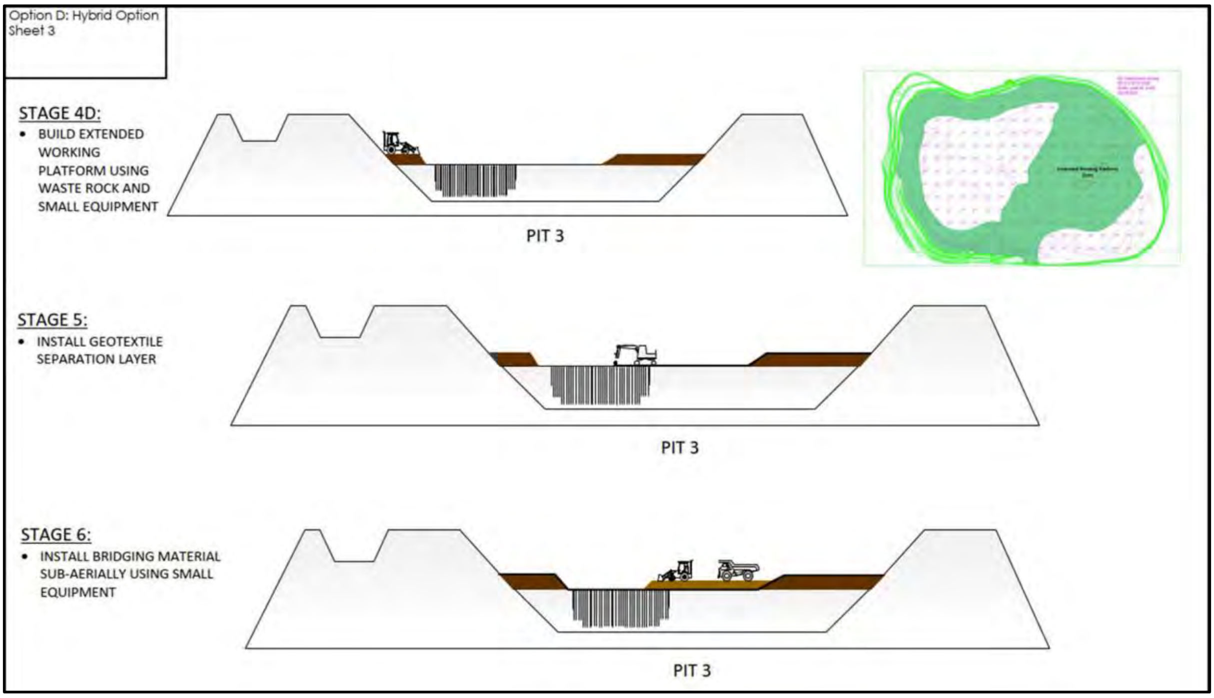

Figure 6-4 Illustration of stages 4 - 6 of Pit 3 capping Option D (Hatch, 2021)

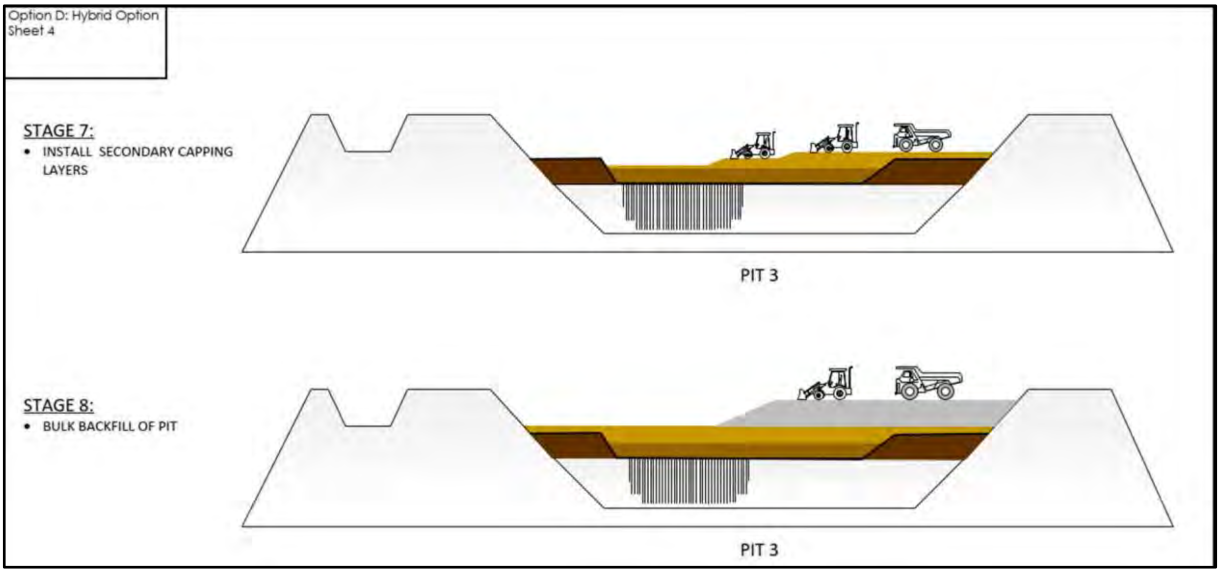

Figure 6-5 Illustration of stages 7 - 8 of Pit 3 capping Option D (Hatch, 2021)

The primary benefits of Option D are:

- that it enables the timing of demolition to be brought forward with the creation of the Eastern Platform, thereby providing a holding location for demolished material;
- the sub-aerial capping option was successfully executed in the closure of Pit 1 and uses more traditional and proven methods with lower risk; and
- the mechanically assisted development of a crust allows earlier access for capping and bulk material movement.

Based on the outcomes of the BPT assessment, the Pit 3 application was submitted to stakeholders for review in April 2022. The application is currently being revised following an adequacy assessment and feedback from stakeholders prior to resubmission.

6.6 Future BPT assessments

BPT assessments will be undertaken as required for future applications, and where any other further decisions on technology arise. Examples include the TSF/RWD deconstruction, Final Landform, and treatment/remediation of contaminated sites.

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APPENDIX 6.1: COMPLETED BEST PRACTICABLE TECHNOLOGY ASSESSMENTS

APPENDIX 6.1 Completed BPT Assessments

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6.1 Salt treatment and disposal

The need to dispose of saline water is a common process in several industries and, as a result, 25 methods were identified as potential salt management options and were considered for the BPT assessment. Many of the options considered had fatal flaws for the Ranger mine and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table A6.1-1).

Table A6.1-1 Salt treatment and disposal options

Category	Brine injection	Crystallisation	Thermal distillation
Method	• pit 3 underfill • underground silos • pit 3 underfill with rock screening	• pit 3 placement • underground silos placement	• pit 3 underfill injection • underground silos injection

The overall outcome of the BPT assessment was that brine injection to the underfill without rock screening was the highest ranked alternative. Brine injection to underground silos scored well but concerns were identified on Occupational Health and Safety issues during both the construction and the operational phases of this option. Major problems were identified for the crystallisation and distillation options, and it is considered unlikely that either option assessed would be viable. 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.

It was concluded that this issue required 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 testing to confirm the brine injection option.

6.2 Brine Squeezer

Report: *Application to operate a Brine Squeezer, 2019*

Water management is an environmentally and operationally relevant aspect of the Ranger Mine. Concentration and isolation of contaminants through water management is a significant component of the Ranger Mine closure program. In January 2019, ERA presented the results of studies into additional processing options, to the Director of Mining Operations, to support the installation of the selected option, the Brine Squeezer (ERA 2019b).

Treatment of pond water through the water treatment plants generates brines that are added to the process water inventory. This results in 200 to 1,000 ML/year of additional process water to be treated by the Brine Concentrator (BC). However, the Water Treatment Plant (WTP) brines are less concentrated than process water (less than 25 percent brine of process water concentration), and treatment options that are more cost effective than treating WTP brines as process water are available. Additional processing of WTP brines will reduce the volume added to process water, reducing the total inventory to be treated by the BC, and reducing overall risks to the closure schedule and costs associated with water treatment.

ERA investigated options to concentrate WTP brines over many years. Given the high scaling and membrane fouling potential of WTP brines, it was necessary to consider alternatives to standard reverse osmosis (RO). The implementation of the Osmoflo Brine Squeezer was established to be a cost-effective way to treat WTP brines as it minimised unnecessary additions to the pond water and process water inventory and optimised pond and process water treatment and disposal mechanisms.

To meet regulatory requirements of the Ranger Authorisation and facilitate the incorporation of novel technology at Ranger Mine, a thorough BPT assessment process was undertaken. This began in 2013 with a preliminary desktop screening assessment that investigated 27 options. From this assessment 15 options were hard show-stopped, whilst four options were soft show-stopped and four options scored poorly relative to the remaining four options, which were considered appropriate to progress for further assessment. A second, BPT assessment was then conducted in 2018 on:

- vibratory shear enhanced processing (VSEP);
- Brine Squeezer;
- electro dialysis reversal (EDR); and
- additional reverse osmosis (RO).

Using a 5-level technology ranking system where a ranking of three meets industry standards, the second BPT assessment showed the Brine Squeezer (Figure A6.1-1) to be the highest ranking option.

Pilot studies and test work were completed on two options: VSEP and Brine Squeezer. The results of these studies were used to inform the BPT assessment and revise the relevant criteria of the 2013 BPT assessment. The seven-month Brine Squeezer pilot study, completed in 2016,

conclusively demonstrated that this technology has the capability to treat the Ranger Mine pond water treatment brine, thus minimising the volume of brine and maximising the volume of release quality water on site.

This outcome had a significant influence on the 2018 BPT assessment scores for the Brine Squeezer, particularly against criteria such as *'Proven technology', 'Technical performance'* and *'Inherent Availability and Reliability'* compared to the other three technologies. The result is that during the 2018 BPT, the technology with the highest BPT score was the Brine Squeezer, followed by the EDR, VSEP and additional RO (Table A6.1-2 and following ranking matrices).

It has been demonstrated during field trials that WTP brine can be treated at up to 94 percent recovery of permeate of quality equal to, or better than, current WTP permeate. The plant, installed adjacent to the sand blast yard, comprises three trains, providing for 99 percent availability of two trains (1 standby/cleaning). Commissioning of the Brine Squeezer commenced in June 2019, with the plant now fully operational.

Table A6.1-2 Comparison of final BPT scores 2013 versus 2018

Option ID	Description	2013 BPT results	2018 BPT results
BM1	VSEP - Vibratory shear enhanced processing (FilTek)	18.8	13.2
BM2	Brine squeezer (Osmoflo)	21.9	23.7
BM3	EDR - electro dialysis reversal	30.0	19.4
BM6	Additional reverse osmosis	31.3	11.1

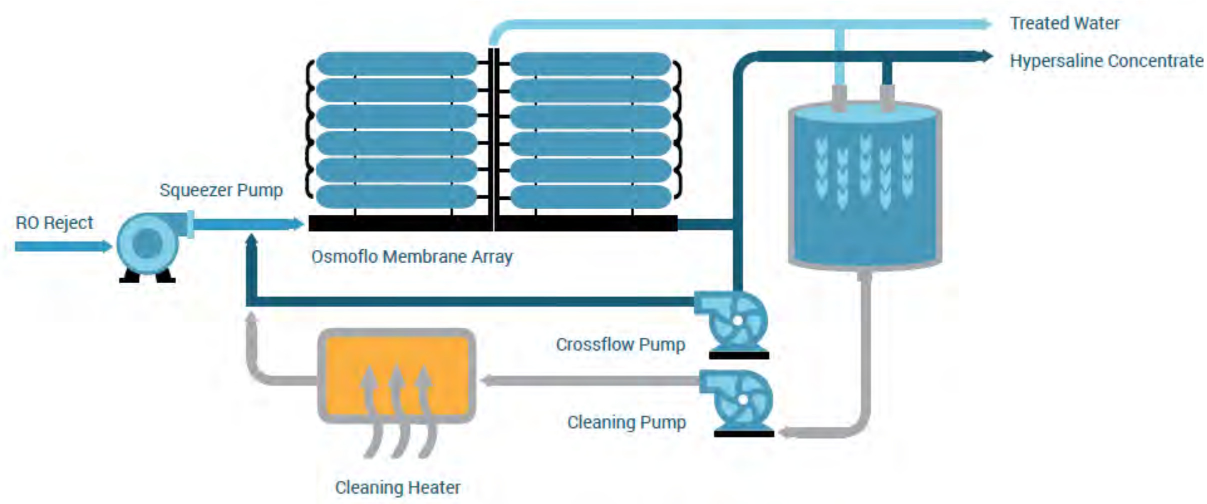

Figure A6.1-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

BM	Brine Minimisation	Rehabilitation and Closure							Constructability		
		Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
		1	1	1	1	1	1	1	1	1	1
Option ID	Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Cost	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
BM1	VSEP (FilTek)	NA	NA	NA	NA	NA	3	4	4	4	3
BM2	Brine Squeezer (Osmoflo)	NA	NA	NA	NA	NA	3	4	4	4	3
BM3	EDR - Electro dialysis reversal	NA	NA	NA	NA	NA	3	4	4	4	3
BM6	Additional RO (includes pre-treatment step)	NA	NA	NA	NA	NA	3	3	4	4	3

	Inadequate	Poor	Acceptab le	Good	Excellent	Unable to evaluate	Not applicable to this option
Rank	1	2	3	4	5	UTE	NA

BM	Brine Minimisation				TO Culture & Heritage		Protection of People and the Environment				
		Show stopper column setting			Yes	Yes	Yes	No	Yes	No	Yes
				Rank weighting	1	1	1	1	1	1	1
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic impact local community	Ecosystems of Kakadu	Ecosystems of Project Area	Long-term Protection of Environment
BM1	VSEP (FilTek)	0	0	13.2	NA	NA	4	3	4	4	NA
BM2	Brine Squeezer (Osmoflo)	0	0	23.7	NA	NA	4	3	4	4	NA
BM3	EDR - Electro dialysis reversal	0	0	19.4	NA	NA	4	3	4	4	NA
BM6	Additional RO (includes pre-treatment step)	0	0	11.1	NA	NA	4	3	4	3	NA

6.3 Ranger 3 Deeps

Report: *Application Ranger 3 Deeps Exploration Decline Decommissioning, 2018*

In May 2012, phase 1 construction works of the Ranger 3 Deeps (R3D) decline began after being approved in September 2011. This allowed for underground exploration that could provide further information regarding the viability of the proposed R3D underground mine. An additional application was submitted for phase II construction works and was approved for the extension to the exploration decline, installation of a ventilation shaft, and acquisition of bulk samples on 4 June 2013.

Exploration in the decline (Figure A6.1-2) continued until December 2014, whilst submissions were made for the construction of the R3D underground mine at the same time. In October 2014, a draft environmental impact assessment (EIS) was submitted but, following an ERA board decision in June 2015, the statutory assessment process for the proposed R3D mine was halted and the decline was placed in long-term care and maintenance.

The primary objective of the BPT assessment was to determine which combination of options was best practice for the closure of the exploration decline. For the assessment, the decline was divided into three closure areas:

- main decline (2,710 m) – seven BPT closure options assessed;
- portal (185 m) – three BPT closure options assessed; and
- ventilation shaft (located at -260 mRL; vertical length 280 m) – nine BPT closure options assessed.

The BPT assessment rankings reflect known hydrogeological conditions obtained during decline construction and core sampling of resource holes, and subsequent hydrological modelling completed by INTERA (2018). The assessment also took into consideration ground conditions and potential heavy mobile equipment limitations (e.g. gradient, manoeuvrability). The assessed option and BPT outcomes are presented in Table A6.1-3 and the ranking matrices at the end of this sub-section.

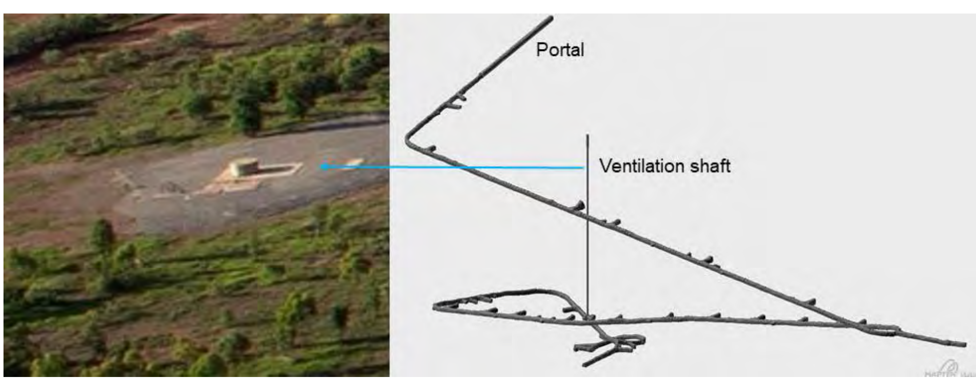

Figure A6.1-2: Aerial view of the ventilation shaft and underground infrastructure

Table A6.1-3: Decline options and best practicable technology assessment summary

Option	Option Description	Overall Rank
Decline closure (2,710 m)		
A1	Waste rock (full decline) and grouting of open holes	16.7
A2	A1 + bulkheads	12.5
A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m)	29.2
A4	A3 with cemented rock fill (CRF) instead of waste rock	25.0
A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	20.8
A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	-4.2
A7	A3 (without grouting of open holes and bulkheads)	41.7
Portal (185 m)		
B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	-11.5
B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	30.8
B3	Leave entire portal *in situ* and cover with waste rock	-10
Ventilation shaft		
C1	Waste rock; concrete collar removed	-100
C2	Waste rock, concrete *in situ*	-100
C3	Crushed waste rock; concrete collar removed	31.6
C4	Crushed waste rock; concrete collar *in situ*	-100
C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	21.1
C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar *in situ*	-100
C7	Steel plate; concrete collar removed and allow to flood	13.2
C8	Steel plate and allow to flood; concrete collar *in situ*	-100
C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	39.5

Main Decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped based on occupational health and safety (OHS) concerns, cost and operability. Three options, scoring similarly, with one of these, A5, eliminated due to cost and reliability concerns. Option A6 was eliminated due to OHS and fitness for purpose. Option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7 and selected as the preferred option.

Portal closure

For the portal closure, B1 was ranked inadequate due to difficulty and complexity. Option B3 was rejected when it became apparent that the waste rock proposed to cover the portal would not blend with the final landform and therefore at odds with the cultural criteria. Option B2 (partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock) with a score of 30.8 and no show-stoppers, was ranked the highest and selected as the preferred option.

Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped based on fitness for purpose or cultural criteria (specifically visual amenity). Two options recorded soft show-stoppers for cultural criteria (also visual amenity) and two options, C3 and C9 scored closely on the BPT assessment. For its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, option C9 (crushed waste rock up to weathered zone, then ten metres cemented rock fill and then ten metres of crushed rock to surface; concrete collar removed) was identified as the highest ranking option with a score of 39.5 and selected as the preferred option.

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	Decline closure (2,710 m)				0.0						
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	4	3	5	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	4	3	5	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	4	3	5	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	4	3	5	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	4	3	5	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	1	3	5	1
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	4	3	5	3
	Portal (185 m)				0.0						
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	NA	NA	4	3	5	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	NA	NA	4	3	5	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0	1	NA	4	3	5	1
	Vent shaft				0.0						
1	C1	Waste rock; concrete collar removed	1	0	-100.0						
1	C2	Waste rock, concrete in situ	1	0	-100.0						
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	4	4	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0	1	1				

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	2	2	4	3	4	3
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0	1	1				
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	2	4	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0	1	1				
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	5	4	3	4	3

Initial show stopper	Option ID	Option Description (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
						Fit for Purpose				**Operational Adequacy**			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
	Decline closure (2,710 m)				0.0								
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	5	4	4	2	2	2	3	NA
	A2	A1 + bulkheads	0	1	12.5	4	4	5	1	2	2	3	NA
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	4	4	4	3	4	3	3	NA
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	4	4	4	2	4	3	3	NA
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	4	4	4	2	4	3	2	NA
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	1	1	1	5	4	5	5	NA
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	4	4	4	4	4	4	4	NA
	Portal (185 m)				0.0								
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	1	4	4	1	1	1	2	NA
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	4	4	3	3	3	4	NA
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0								
	Vent shaft				0.0								
1	C1	Waste rock; concrete collar removed	1	0	-100.0	1							
1	C2	Waste rock, concrete in situ	1	0	-100.0	1							
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	3	3	4	3	3	3	5
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0								

						Fit for Purpose				Operational Adequacy			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	5	3	4	2	3	3	3	5
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0								
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	1	3	3	5	3	4	5	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0								
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	3	4	3	3	3	3	5

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	Option ID	Option Description (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
	Decline closure (2,710 m)				0.0					
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	NA	NA	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	NA	NA	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	NA	NA	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	NA	NA	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	NA	NA	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	NA	NA	3
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	NA	NA	3
	Portal (185 m)				0.0					
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	4	NA	NA	NA	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	NA	NA	NA	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0					
	Vent shaft				0.0					
1	C1	Waste rock; concrete collar removed	1	0	-100.0					
1	C2	Waste rock, concrete in situ	1	0	-100.0					
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	5	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0					
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	4	5	3	4	3

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0					
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	5	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0					
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	4	5	3	4	3

6.4 Progress of Pit 1 to final landform

Report: *Application of Progress Pit 1 Final Landform, 2019*

To support progress of the Pit 1 final landform, additional work was undertaken to address Supervising Scientific Branch (SSB) comments (Department of the Environment and Energy 2018) on an earlier change application (ERA 2018a). Works included:

- a risk assessment undertaken to update the 2016 risk assessment;
- solute mass balance and water balance;
- soil-vegetation-atmosphere modelling to estimate plant available water under various conditions;
- revision of the final landform cover on Pit 1 to maximise plant available water;
- review of research relevant to rehabilitation of the Ranger Mine;
- preliminary flood modelling and hydraulic design work were updated and refined from work in 2017 to create a Digital Elevation Model (DEM); and
- erosion and sediment control features were refined based on conceptual designs developed in 2017.

The digital elevation model (DEM) was also provided to the MTC for assessment and SSB feedback was included in the change application report (ERA 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework was developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works supported ERAs continued backfilling of Pit 1 ahead of the initial tree planting of the Pit 1 landform surface.

An application was submitted to the Director of Mining Operations, DITT in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the *Mining Management Act* (NT) and was approved in May 2019.

During the life of Pit 1, ERA has undertaken many studies and BPT assessments, including:

- assessment of the selected tailings deposition options for Pit 1, to ensure the long-term stability of tailings as part of the final rehabilitated landform in 1994;
- assessment of seepage limiting options in 2005; and
- closure studies undertaken as part of a 2008 PFS, 2009 feasibility study and further review and validation of the preferred Pit 1 closure option as part of the ITWC prefeasibility study in 2012.

Landform design has involved several iterations of the post-closure landscape models over the life of the mine with significant options analysis and refinement of the landscape reconstruction over several years. Through supporting investigations and thorough refinement processes, the backfilling option being implemented is optimal. In particular, bulk backfilling of Pit 1 has been completed using the selected bulk backfill methodology.

6.5 Tailings management

6.5.1 Integrated tailings, water and closure – PFS 1

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study (ITWC PFS): Analysis of Best Practicable Technology, 2013*

The focus of the ITWC PFS program was to evaluate the technology for reclamation, treatment and transfer of tailings from the TSF to the mined-out Pit 3, and salt management technology to ensure physical containment of brine (from the BC treatment of process water) within Pit 3 with no detrimental impact to the environment for a period of 10,000 years as required by the ERs.

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described in the sub-sections below.

Tailings reclamation

Three categories were considered for reclamation of tailings from the TSF: excavation, hydraulic mining and dredging. Each category had a subset of transfer options, giving a total of nine options taken into the BPT assessment (Table A6.1-4 and the ranking matrices at the end of Section 6.5).

Table A6.1.4: Tailings reclamation options

Category	Excavation	Hydraulic Mining	Dredging
Transfer options	• dewater and truck • dewater and conveyor • slurry and pump	• pump • thickener and pump	• pump • thickener and pump • thickener, filtration and truck • thickener, filtration and conveyor

Of the reclamation and transfer options, excavation rated poorly compared with hydraulic mining and dredging. The principal deficiencies identified were the sensitivity of excavation techniques to extreme rainfall events, environmental protection and OHS issues arising from dust from the disturbed tailings, the considerable operational effort that would be required, and the drainage requirements required for successful implementation of the process. Hence, excavation was rejected as a method for reclamation of tailings from the TSF.

Hydraulic mining and dredging emerged from the workshop with approximately equal BPT assessment scores. An overall assessment of the relative significance of the various advantages and disadvantages of the two options led to the conclusion that the disadvantages of the dredging option (operability, maintainability, radiation protection) are much more amenable to management than those associated with hydraulic mining (sensitivity to extreme rainfall, environmental protection, high capital costs). This is particularly the case for the issue of sensitivity to extreme rainfall events where management options are extremely limited, and the occurrence of such events could have a major impact on the rehabilitation schedule. For this reason, dredging was selected as the preferred option.

Tailings treatment

The principal technical advantage of filtration is the reduced time required for tailings consolidation. It was thought to have some advantages for long-term dispersal of contaminants in groundwater, but this was yet to be demonstrated and the advantage was considered to be small. Disadvantages of this option included high costs to construct, install and operate, and the high maintenance requirements. The assessment outcome of filtration at the tailings workshop was that the option should be retained for whole-of-project BPT assessment, but it appeared to be a very expensive option with limited advantages.

Cementation was considered an option to potentially reduce dispersion of solutes in groundwater if required[1], however, it did not emerge as a viable treatment option. Further trials would be required, capital costs would be high because of the need to include filtration as a preliminary step, and operational costs would be extremely high as a result of the high cement consumption implicit in the process.

Tailings deposition

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.

The assessment outcome for deposition of thickened tailings was that either option would be acceptable, however subaqueous deposition was preferred principally because it rated higher on the operability and operating costs criteria and was assessed that Traditional Owners would have a distinct visual preference for tailings covered by water rather than an exposed tailings surface. Subsequently, initial BPT workshop consolidation modelling demonstrated that subaerial deposition would provide an advantage over sub aqueous deposition. Since both options were determined to be BPT, the method was changed without the need for an additional assessment.

With filtration of tailings being retained as an option, the deposition of tailings needed to be considered. Two options were considered: dry stacking, and co-disposal with waste rock. Co-disposal of filter cake and waste rock led to higher maximum elevation of tailings in Pit 3, giving preference to dry stacking. There were, however, concerns expressed about the degree to which either technique had a proven track record, and it was noted that both would be sensitive to rainfall (a dry pit would be required).

The conclusions arising from the BPT workshop on tailings management were:

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1 The initial BPT workshop was conducted prior to the groundwater solute transport modelling from Pit 3; this option was assessed in case treatment of tailings was required in order to achieve the 10,000 year requirement for no detrimental environmental impact. Subsequent to this BPT assessment modelling has shown that additional tailings treatment is not required to mitigate solute transport.

- dredging is the preferred tailings reclamation method;
- cementation is not currently considered viable as a treatment method; and
- tailings filtration should be retained as a potential treatment method to be considered in the overall strategic workshops but is a very expensive option that produces little benefit.

6.5.2 Integrated tailings, water and closure – PFS 2

The combination of the feasible tailings management options and the feasible salt management options resulting from PFS1 and the BPT assessment are provided below:

- dredged tailings, thickened and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill)
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill)
- dredged tailings, thickened then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3

These options progressed through ITWC PFS2 and were assembled into closure strategies where the preferred technical options from PFS1 were combined with two possible processing cessation dates:

- milling will cease in 2016 - these options were given a ‘C’ designation; or
- milling will cease at the end of 2020 consistent with the terms of the Ranger Authorisation - these options were given a ‘B’ designation.

This provided a total of eight closure strategies that were assessed in two stages; these are shown in Table A6.1-5 (and the ranking matrices at the end of Section 6.5).

Table A6.1.5: Initial closure strategies to be assessed

Strategy	Brine strategy	Tailings strategy	Milling end
1C	Injection	Thickened	2016
2C	Injection	Thickened and filtered	2016
3C	Crystallisation	Thickened	2016
4C	Crystallisation	Thickened and filtered	2016
1B	Injection	Thickened	2020
2B	Injection	Thickened and filtered	2020
3B	Crystallisation	Thickened	2020
4B	Crystallisation	Thickened and filtered	2020

Stage 1 assessment

The BPT assessment of the eight identified strategies was divided into two stages. Stage 1, or the preliminary strategic assessment, was conducted soon after completion of the individual component assessments. The intention was to eliminate strategic options that clearly did not constitute BPT, and to more clearly identify information gaps in the remaining options needing to be addressed prior to the final BPT assessment of the strategic options.

The key options that were eliminated in the stage 1 assessment were tailings filtration and brine crystallisation. The results of the stage 1 assessment are shown in Figure A6.1-3.

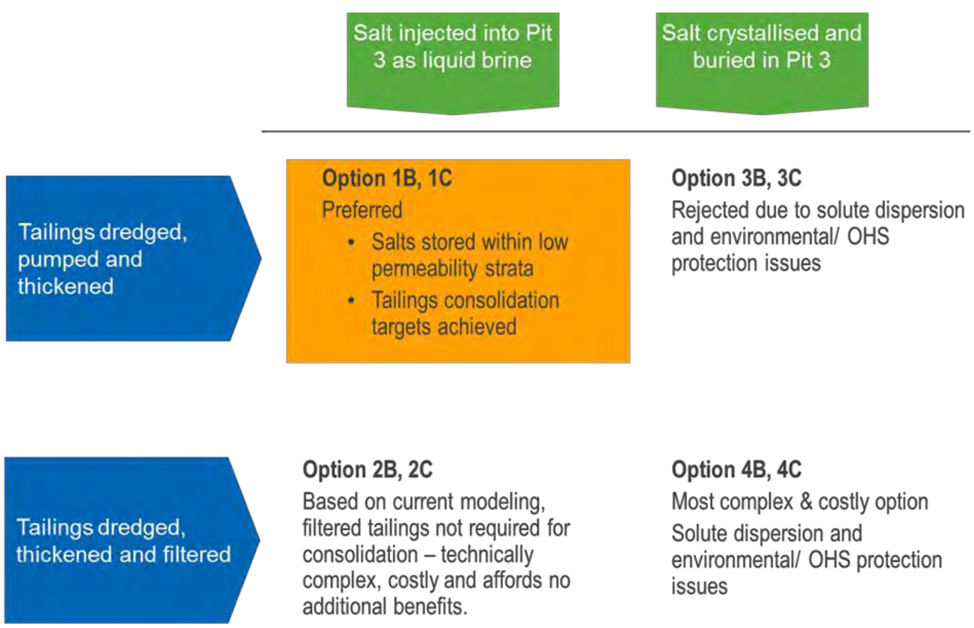

Figure A6.1.3: Outcomes of the stage 1 assessment

The tailings management workshop confirmed filtration was a very expensive option with limited advantages and therefore it was decided that filtration of tailings (2C, 2B) should not be considered further in the development of the best practice strategy for rehabilitation and closure of the Ranger Mine.

Further analysis and test work completed following the initial technical options BPT workshops confirmed brine injection was the best option for management of salt. Further to this, the Stage 1 BPT confirmed brine crystallisation was not a viable option, performing poorly under several criteria. As a result, the strategies that included crystallisation (3B, 3C, 4B, 4C) of the brine stream from the water treatment plant were rejected.

Stage 2 assessment

Based on the Stage 1 BPT assessment, all filtration and crystallisation options were eliminated (this was further validated by programs conducted between the stage 1 BPT and the stage 2 BPT). As such, the closure strategies considered in the Stage 2 BPT workshop 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 exceed the BC treatment capacity, allowing for longer term treatment of process water.

Table A6.1. Table A6.1-6 lists the options assessed in Stage 2 (detailed ranking matrices at the end of Section 6.5).

Table A6.1.6: Final closure strategies assessed

Strategy	Brief description
1C	Brine injection, thickened tailings, milling until 2016
1B	Brine injection, thickened tailings, milling until 2020
5C	Strategy 1C with extended water treatment
5B	Strategy 1B with extended water treatment

The highest BPT score of 19 was recorded for Strategy 1B; the three other options scored 15. To put this result in perspective, changing the assessed score for any individual criterion by one unit would change the overall score for that option by about two units. Hence, these results imply that option 1B is the favoured option based on the BPT assessment process, but the result is marginal.

The criteria where differences were recorded were:

- socio-economic impact on Jabiru and the region: the two extended options provide additional time for community partnerships to run and continued retention of services, the 5B case also provides additional royalty income;
- technical performance: both 2020 options scored higher because the extended milling period enables the processing of lower grade ores, previously assessed as not commercially viable;
- capital expenditure: the two extended options scored higher primarily because only one BC is required for these options;
- maintainability: the 2020 milling option with extended water treatment results in the use of the BC for nine years beyond its planned lifetime;
- operating costs: the operating costs of the extended 2020 option would be higher because replacement of major BC parts would almost certainly be required; and
- schedule: both extended options scored lower than the primary options under the schedule criterion.

6.5.3 Supplementary integrated tailings, water and closure prefeasibility study

A review of the ITWC BPT assessment was conducted in August 2016. This determined, with the exception of tailings treatment, all technical options selected as BPT remained valid.

Eight options were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment. The results are presented in Table A6.1-7 and the ranking matrices provided at the end of Section 6.5. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table A6.1.7: Supplementary tailings treatment assessment

Strategy	Technology	Show-stopper		Overall rank
		Hard	Soft	
A1	Thickened tailings (ITWC base case)			32.6
A2	Unthickened tailings	✓		-100
A3	Unthickened tailings, with prefabricated vertical drains (wicks)			41.3
A4	Unthickened tailings, with extended water treatment		✓	-6.5
A5	Unthickened tailings, with inline agglomeration and wicks			10.9
A6	Unthickened tailings with neutralisation and wicks		✓	17.5
A7	Thickened and filtered tailings (ITWC assessed)		✓	13.0
A8	Thickened, filtered and cemented tailings (ITWC assessed)		✓	6.8

For most of the detailed options assessed, a NA (not applicable) result was obtained for criteria in the ‘Culture and Heritage’, and ‘Ecosystems and Natural World Heritage Values of Kakadu NP’ categories. All activities associated with all options occur within the cultural heritage exemption zone. In addition, these methods do not have any impact on the surrounding ecosystems and World Heritage values of Kakadu during the operational phase. Hence, the BPT assessment of the tailings treatment options was dominated by the criteria under the ‘Fit for Purpose’, ‘Operational Adequacy’ and ‘Constructability’ categories.

The base case for this assessment assumed tailings would be unthickened, with three options being considered a) with wicks, b) with extended water treatment, and c) with inline agglomeration and wicks. These were assessed against the previous ITWC thickened tailings options.

The results of the BPT indicate that unthickened tailings with wicks (A3) have advantages over unthickened tailings and extended water treatment (A4) and unthickened tailings with inline agglomeration (A6). It was assessed that the use of wicks would be viewed more favourably by Traditional Owners under the ‘Living Culture’ criterion compared to unthickened (A2). The unthickened tailings option (A2) was hard show-stopped due to factors including: not all process water being removed during consolidation, subsidence and erosion of the landform, impacts on rehabilitation performance, impacts to water quality and the formation of visible salts in the landform surface, all of which could lead to an unwillingness for Traditional Owners to resume cultural practices on the site post-closure.

Unthickened tailings with wicks (A3) have been demonstrated as proven technology through its application in Pit 1. Prefabricated vertical drains, or wicks, present a sound technical method of achieving increased consolidation and ensuring the schedule requirements on rehabilitation on the RPA are met.

Inline agglomeration and wicks (A5) option faired less favourably across ‘Fit for Purpose’ and ‘Operational Adequacy’ categories than options A1 and A3, predominantly based on less certainty around achieving consolidation targets and potential reliability issues related to inconsistent input densities. There was also a high uncertainty around the complexity of integration with existing dredging operations, high operational expenditure and complexities associated with construction of the plant on the pit access ramp.

Unthickened with extended water treatment (A4) was soft show-stopped under category ‘Construction, Environmental and Cultural risks’ because of the increased number of vehicles through Kakadu NP necessary to transport new infrastructure and the substantial increase in workforce required to construct a new water treatment plant. It emerged as the least favoured option, scoring ‘inadequate to ‘poor’ against most categories under ‘Fit for Purpose’, ‘Operational Adequacy’ and ‘Constructability’. The low ranking against these criteria was strongly influenced by high sustaining capital and operating costs associated with the existing BC, long procurement lead times required to purchase a new plant or additional infrastructure to expand the existing plant, and the complex operational nature of the plant potentially leading to a high number of interruptions and downtime.

Strategies A6 through A8 all recorded soft show-stoppers under ‘Construction’, ‘Environmental’ and ‘Cultural’ risks criterion, attributed to the effects of increased traffic volumes through Kakadu NP associated with new infrastructure and increased construction workforce in Jabiru. These options also recorded soft show-stoppers under OHS, attributed to increased risks of vehicle incidents during tailings transfer to Pit 3. In addition to the above, concerns identified during the ITWC PFS around strategy A8 (thickened, filtered and cemented) remain. These include the extremely high operational costs as a result of high cement consumption and uncertainty around the long-term stability of cement, which is susceptible to sulfate attack. Significantly more development work would be required before this would be considered a viable option when compared to strategies that were assessed.

Conclusions

The BPT assessment has considered viable thickened tailings options from the previous ITWC PFS and new, unthickened tailings treatments. Of the eight options assessed, one option was hard show-stopped (unthickened A2) and four were soft show-stopped.

Three options were considered viable; however inline agglomeration with wicks (A5) scored the lowest of the three with the assessment identifying some inherent issues around achieving consolidation targets, high operational costs and construction complexities, compared to the other two options (e.g. thickened and unthickened with wicks).

There was no material difference in the assessment scores for the thickened (A1) and unthickened with wicks (A3) options. However, ERA has extensive knowledge around strategy A3, based on the performance of the Pit 1 backfill strategy and subsequent tailings consolidation being achieved via this method.

6.6 Tailings deposition into Pit 3 for mill tailings and dredge tailings

Report: *Application Pit 3 Tailings Deposition, 2019*

In preparation for cessation of mining and processing activities at Ranger Mine, a further assessment of the methods for tailings deposition was undertaken. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 to change the deposition method of tailings in Pit 3 from subaerial (to a tailings beach) to subaqueous (into water) (ERA, Alan Irving & Associates 2019). The application was approved in July 2019. The change was proposed to improve deposition, specifically to:

- prevent segregation;
- prevent accumulation of fine tailings in inundated areas of the pit; and
- accelerate backfilling with consolidated tailings.

Following detailed assessment of various subaqueous deposition configurations and multi-spigot subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 to assess the range of potentially viable deposition options (GHD 2019). To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria. This resulted in an overall ranking calculated for each option (Table A6.1-8 and the ranking matrices at the end of this sub-section).

Table A6.1-8 Tailings deposition options and best practicable technology assessment summary

Option	Option Description	Overall Rank
Mill Tailings		
M1	Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing)	41.7
M2	Subaerial deposition from multiple spigots on the east wall (one at a time, frequently changing)	35.4
M3	Subaqueous deposition	16.7

Dredge Tailings		
D1	Dredge 1 and 2 subaerial	20.8
D2	Dredge 1 and 2 subaqueous	16.7
D3	Dredge 1 subaqueous & Dredge 2 subaerial	12.5
D4	Dredge 1 subaerial & Dredge 2 subaqueous	10.4

The BPT assessment found that for mill tailings, the two subaerial options (M1 and M2) were similarly effective, and slightly better, than subaqueous discharge (M3) due to the higher cost and greater complexity of subaqueous deposition. Option M2 has the advantage of maintaining a lower, more level tailings surface. Both M1 and M2 promote overall drainage from east to west and are more cost effective than subaqueous deposition. However, M1 scored lower on schedule and both M1 and M2 will result in a slightly higher tailings level in the east of the pit.

The assessment found that for dredge tailings, the subaerial options scored more favourably on costs, constructability, operability and maintainability criteria. This is primarily due to the lower complexity of the subaerial method and because most of the subaerial facilities are already in place. However, the subaerial options scored poorly on schedule and technical performance, as the tailings surface will be more steeply sloping with a higher maximum elevation in the pit requiring additional work to even out the tailings prior to commencement of pit capping.

Conversely, the subaqueous option scored more favourably on schedule, technical performance and environmental protection, since this method promotes less tailings segregation and more rapid consolidation, and the tailings surface will be flatter with a lower maximum elevation in the pit.

Whilst relative advantages and disadvantages were identified, and all options were considered acceptable against each of the assessment criteria, a combination of options M2 (subaerial deposition from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected.

BPT FINAL ASSESSMENT										
			Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option
		Rank	1	2	3	4	5	UTE	NA
ITWC Project				TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting		Yes	Yes	Yes	No	Yes	No
			Rank weighting	1	1	1	1	1	1
Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Town/Region	Ecosystems of Kakadu	Ecosystems of Project Area
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	0	1	15	3	3	4	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	0	1	15	3	3	4	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	0	1	19	3	3	4	4	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	0	1	15	3	3	4	4	4	3

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option			
	1	2	3	4	5	UTE	NA			
ITWC Project	Fit for Purpose					Operational Adequacy				
	No	No		Yes	No	Yes	No	No	No	No
	1	1	1	1	1	1	1	1	1	1
Option Description	Proven technology	Technical performance	Robustness	Environmental Protection	CAPEX	Safety Occupational Health	Operability	Inherent availability and reliability	Maintainability	OPEX
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	4	3	4	3	3	4	4	3	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	4	3	4	4	3	4	4	3	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	5	3	4	3	3	4	4	3	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	5	3	4	4	3	4	4	2	2

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option		
	1	2	3	4	5	UTE	NA		
ITWC Project	Rehabilitation and Closure						Constructability		
	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
	1	1	1	1	1	1	1	1	1
Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	3	3	UTE	2	2	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	3	3	UTE	2	1	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	3	3	UTE	2	2	3	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	3	3	UTE	2	1	3	4	3

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area
A1	Thickened (ITWC base case)	0	0	32.6	4	NA	4	3	NA	3
A2	Unthickened	4	0	-100.0	1					
A3	Unthickened - wicks	0	0	41.3	3	NA	4	3	NA	4
A4	Unthickened - extended water treatment	0	1	-6.5	3	NA	4	3	NA	3
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	NA	4	3	NA	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	UTE	NA	4	4	NA	3
A7	Thickened & filtered tailings	0	3	13.0	4	NA	4	3	NA	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	NA	4	3	NA	2

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No	No	Yes	No	Yes	No	No	No	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
A1	Thickened (ITWC base case)	0	0	32.6	5	4	3	4	2	4	4	4	4	3
A2	Unthickened	4	0	-100.0		1								
A3	Unthickened - wicks	0	0	41.3	5	3	2	4	3	4	5	5	5	5
A4	Unthickened - extended water treatment	0	1	-6.5	5	2	2	4	1	4	1	2	2	1
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	3	2	4	3	4	3	3	3	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	5	UTE	2	4	2	2	4	4	4	1
A7	Thickened & filtered tailings	0	3	13.0	5	4	3	4	1	2	3	3	3	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	UTE	3	5	1	2	3	3	2	1

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					Rehabilitation and Closure						Constructability		
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
A1	Thickened (ITWC base case)	0	0	32.6	4	4	3	4	4	3	4	3	4
A2	Unthickened	4	0	-100.0	1		1	1					
A3	Unthickened - wicks	0	0	41.3	4	4	3	4	4	3	3	4	4
A4	Unthickened - extended water treatment	0	1	-6.5	4	4	3	4	4	2	4	2	2
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	4	4	3	4	4	3	3	3	2
A6	Unthickened - neutralisation and wicks	0	2	17.5	4	4	3	4	4	3	4	2	UTE
A7	Thickened & filtered tailings	0	3	13.0	4	4	3	4	4	4	4	2	3
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	4	3	4	4	4	4	2	3

						Traditional Owner Culture & Heritage		Protection of People and the Environment			
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Ecosystems & the natural world heritage values of Kakadu	Ecosystems of the project area	Community Health and Safety	Socio-economic Impact on Local Communities	Ecosystems & natural world heritage values of Kakadu	Ecosystems of the Project Area
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time – infrequent switching between two locations (current scenario)	0	0	41.7	4	3	3	3	4	3
No	M2	Sub-aerial, discharge from a single point at a time – frequent switching between multiple locations (spigots)	0	0	35.4	4	3	3	3	4	3
No	M3	Sub-aqueous	0	0	16.7	4	3	3	3	4	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	3	3	3	4	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	4	3	3	3	4	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	4	3

Best Practicable Technology Matrix continued...						Fit for Purpose					Operational Adequacy
			Showstopper column setting			No	No	No	Yes	No	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Proven technology	Technical performance	Robustness (closure only)	Environmental protection	CAPEX	Occupational health & safety
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time – infrequent switching between two locations (current scenario)	0	0	41.7	5	4	3	3	5	4
No	M2	Sub-aerial, discharge from a single point at a time – frequent switching between multiple locations (spigots)	0	0	35.4	5	4	3	3	4	4
No	M3	Sub-aqueous	0	0	16.7	5	3	4	4	2	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	2	3	3	4	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	5	4	5	4	2	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	5	3	4	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	5	3	4	3	3	3

Best Practicable Technology Matrix continued...						Operational Adequacy				Rehabilitation and Closure	
			Showstopper column setting			No	No	No	No	Yes	Yes
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Operability	Inherent availability & reliability	Maintainability	OPEX	Revegetation (closure only)	Radiation (closure only)
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	5	5	5	3	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	5	4	4	3	3
No	M3	Sub-aqueous	0	0	16.7	3	4	3	2	3	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	3	4	4	3	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	2	3	3	2	3	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	3	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	3	3

Best Practicable Technology Matrix continued...						Rehabilitation and Closure				Constructability		
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes	No
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Erosion (closure only)	Water (closure only)	Tailings (closure only)	Schedule	Construction occupational health & safety	Construction environmental and cultural risks	Construction complexity
Mill Deposition												
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	3	NA	4	2	4	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	3	NA	4	3	4	5	4
No	M3	Sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
Dredge Deposition												
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	NA	3	1	4	5	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	NA	3	2	3	5	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	NA	3	2	3	5	3

6.7 Remnant tailings transfer

The bulk of the tailings within the Tailings Storage Facility (TSF) was dredged and transferred into Pit 3 in 2020/2021. Remnant tailings, the material that remained on the TSF floor and walls after the bulk tailings transfer, also needed to be encapsulated in Pit 3 as per the ERs. This BPT investigated 10 options to determine the best method to undertake this activity.

A BPT workshop was conducted in February 2021 to assess the range of potentially viable transfer options. Each option was assessed against the relevant criteria and the resulting scores are shown in Table 6.1-9.

Table 6.1-9: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
1	Pre-Cap Pump (base case)	2
2	Post-Cap Truck (Pit 3 west end)	6
2a	Post-Cap Truck (Pit 3 east end)	0
2b	Post-Cap Truck (temp store in Pit 3 THWS rather than TSF SE temp cell)	-6
3	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall, tailings slurried to push lower into pit)	17
3a	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	6
3a (i)	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	4
3b	Pre-Cap Truck, sucker truck ramp to north wall (below cap)	2
3c	Pre-Cap Truck, Pit 3 west ramp, barge or floating conveyor transfer to west central end of pit	0
4	Bury tailings in TSF	Hard show-stopped

Option 3 was selected as the preferred method for the transfer of remnant tailings, having the highest score of 17. Each individual criteria ranked for Option 3 received as ‘3’ or greater, indicating that the selected approach meets or exceeds current standards across all assessed fields.

The remnant tailings transfer commenced in Q2 2021, following construction of the Pit 3 tip head and upgrades to the required haul roads. Some of the remnant tailings have ‘hung up’ on the internal wall of Pit 3 and the most effective method to move these tailings deeper into the pit is the subject of current assessment.

6.8 High Density Sludge plant recommissioning

Report: *Application to release water from the High Density Sludge (HDS) Plant, 2020*

The HDS plant was recommissioned on a trial basis in 2019 with the HDS product water recycled into the process water inventory. The recommissioning of the HDS plant was a planned strategy to increase the capacity of process water treatment during closure. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in January 2020 to approve the release of HDS treated process water generated from the recommissioned plant by either of the following options:

- Direct treatment through Water Treatment Plant 1 (WTP1) and subsequent release to the Corridor Creek Wetland Filter;
- Indirect treatment by releasing HDS product into the pond water inventory, for subsequent treatment through any of the pond water treatment plants (WTPs).

Approval was granted in February 2020 with specification for discharge of water to RP2 when releasing HDS product water via indirect treatment as per the application. This approval was contingent on ERA implementing operational controls described in the revised application.

To support this application a BPT assessment was conducted to build upon the previous BPT analysis that was completed to support the original construction of the HDS plant in 2004. The recent BPT assessment evaluated twelve (12) options to address additional process water treatment capacity. The majority of options scored high (31 – 44.4) and differed marginally in the weighting of individual criteria namely ‘Robustness’, ‘Cost’, ‘Schedule’ and ‘Construction complexity’ (Table A6.1-10 and the ranking matrices at the end of this section).

Table A6.1.10: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
5.1	Recommission the existing HDS plant, full treatment and transfer of product water direct to WTP1 (dry season only).	31.0
5.2	Recommission the existing HDS plant, full treatment and transfer product water direct to pond water inventory (year round).	33.3
5.3	Recommission the existing HDS plant, adaptive operation (full treatment) with product transfer to either WTP1 (dry season) or pond water storage (year round).	33.3
5.4	Recommission the existing HDS plant, partial treatment and transfer product water direct to WTP1 (year round).	31.0
6.1	Repurpose of mill infrastructure for large scale HDS treatment.	16.7
6.2	New build of larger HDS plant for large scale HDS treatment.	16.7
7.1	BC single train equivalent construction.	35.7
7.2	BC duplication construction.	33.3
8.1	Direct feed process water (untreated) to existing UF/RO infrastructure.	40.5
8.2	Direct feed process water (untreated) to new UF/RO infrastructure similar to current.	33.3
8.3	Discharge process water (untreated) direct to pond water inventory (untreated).	38.1
11	Do nothing.	44.4

All options exceeded current standards for environmental protection and proven technology. The options that ranked highest overall (38.1 – 44.4) were assessed as not feasible for current implementation on the basis that they did not align with the overarching objectives, required significantly high capital expenditure ($10M+), or would likely cause impacts to the closure schedule (i.e. construction delays or conflicts with other closure commitments).

The option identified as most suitable for implementation involved the use of the existing HDS plant under adaptive operational conditions to optimise treatment capability (option 5.3). This option received the mean overall ranking (33.3) and represents a rational approach to addressing project limitations whilst maintaining effective environmental outcomes.

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting				Yes	Yes	No	Yes	Yes
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local	Ecosystems & Natural world heritage	Ecosystems of the Project Area
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	3	4	4	3	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	3	4	4	3	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	3	4	4	3	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	3	4	4	3	4	4
6.1	Re-purpose mill infrastructure			16.7	3	4	3	3	4	4
6.2	New build HDS plant			16.7	3	4	3	3	4	4
7.1	BC single train equivalent			35.7	3	4	4	3	5	5
7.2	BC duplication			33.3	3	4	4	3	5	5
8.1	Direct feed to existing UF/RO infrastructure			40.5	3	4	4	3	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	3	4	4	3	4	4
8.3	Discharge direct to pond inventory			38.1	3	4	4	3	4	4
11	Do nothing			44.4	3	4	4	3	5	5

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No		Yes	No	Yes	No	No	No	No
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	4	4	3	4	4	4	3	3	3	3
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.4	Recommission the existing HDS plant, partial treatment			31.0	4	4	3	4	4	4	3	3	3	3
6.1	Re-purpose mill infrastructure			16.7	4	4	4	4	3	4	3	4	3	3
6.2	New build HDS plant			16.7	4	4	5	4	2	4	3	4	3	3
7.1	BC single train equivalent			35.7	4	5	4	5	2	4	4	4	4	3
7.2	BC duplication			33.3	4	5	5	5	1	4	4	4	4	3
8.1	Direct feed to existing UF/RO infrastructure			40.5	4	3	3	4	5	4	4	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	4	3	4	4	2	4	4	4	4	4
8.3	Discharge direct to pond inventory			38.1	4	3	2	4	5	4	4	4	4	4
11	Do nothing			44.4	5	4	1	4	5	4	NA	NA	NA	3

					Rehabilitation and Closure						Constructability		
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
6.1	Re-purpose mill infrastructure			16.7	NA	NA	NA	3	NA	2	3	3	2
6.2	New build HDS plant			16.7	NA	NA	NA	3	NA	2	3	3	2
7.1	BC single train equivalent			35.7	NA	NA	NA	4	NA	3	3	3	2
7.2	BC duplication			33.3	NA	NA	NA	4	NA	2	3	3	2
8.1	Direct feed to existing UF/RO infrastructure			40.5	NA	NA	NA	4	NA	3	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	NA	NA	NA	4	NA	3	4	4	3
8.3	Discharge direct to pond inventory			38.1	NA	NA	NA	4	NA	3	4	4	4
11	Do nothing			44.4	NA	NA	NA	4	NA	1	5	5	5

6.9 TSF North Notch Stage 3

Report: *Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility North Notch Stage 3, 2020*

The water level of the TSF continued to be lowered to maximise the efficiency of the dredges during the transfer of tailings to Pit 3. As a result of the lowering water level, there was a need to create notches within the TSF walls to increase the pumping efficiency and to maintain safe access to the floating infrastructure. An application was submitted to the Director of Mining Operations, Department of Primary Industry and Resources (DPIR) (now Department of Industry, Tourism and Trade [DITT]) in April 2020 to approve reduction of the clay core crest height to Relative Level (RL) 37.8 m and to manage future raises in crest height with the construction of clay bunds across the notch if required. The DPIR (now DITT) approved the application in June 2020 and agreed to the provision of water balance modelling updates of the inventory at the beginning of each dry season to ensure sufficient capacity for the upcoming wet season.

Notching the TSF wall proved to be fit for purpose and environmentally sound for the construction of the previous three notches. The construction of a further notch within the footprint of the North wall notch did not require a BPT assessment. However, the reduction in crest height to a level that enabled the completion of dredging presented a risk of inadequate water storage volume when considering the future needs of the TSF for process water storage facility. The purpose of this BPT assessment was to identify the most environmentally sound approach for ongoing safe access to the TSF during dredging whilst ensuring adequate crest height to meet the freeboard requirements of the Ranger Authorisation until 2024.

A total of six options were assessed as part of the BPT assessment (Table A6.1-11 and the ranking matrices at the end of the section).

Table A6.1-11 BPT options assessment for TSF notch

Option	Option Description	Overall Rank
A1	Construct North Notch 3 to RL 36. (clay core RL 35.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0
A4	No additional notch. 1.1 Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services and gantry into a local cutting. Crane used from Notch 2 for large lifts.	-2.8
-A5	Continue use of North Notch 2 using large crane and modified gantry.	Hard show-stopper

A6	North-East Ramp. Remove current ramp in North-East corner of TSF. Cut in new ramp, beginning from further back, in stockpile area, and notching down into TSF wall to RL36.3m. Creates notch in North-East corner. Access as per A1.	-19.4

Most of the options received scores close to zero, indicating that they meet industry standard. No option was considered to substantially exceed industry standard. This is expected given the unfamiliar activity of removing tailings from a tailings storage facility. The continued use of North Notch 2, requiring a modified gantry and an estimated 600 – 700 tonne crane for ongoing access to the lift workboats, was hard show-stopped at the beginning of the assessment. Gantry modification to the extent required to meet safety requirements was considered to be prohibitively expensive.

Option A2, the construction of a third notch in the North wall to a height of RL 37.3 m, was determined to be the most suitable approach. This option includes the contingency to construct a clay bund within the notch if it is required to ensure adequate freeboard during the wet seasons. It is assumed that Pit 3 remains available to receive process water from the TSF during extreme weather events to minimise the risk of overflow into the notch.

Although options A1 and A3 received the same final overall ranking, option A2, with the higher notch level, has a lower capital expenditure and construction time than A1 and A2. Capital expenditure and construction time includes clay bund and notch infill. There is a risk of overtopping the notch resulting in seepage into the dam walls in option A2. This risk is removed with the infill of the notch as proposed in option A3. Proposed risk mitigation measures, such as the construction of a clay bund and the cessation of tailings pore water transfer from Pit 3 reduce this risk to an acceptable level and justified the selection of option A2 over option A3.

						Protection of People and the Environment			Fit for Purpose				
			Show stopper column setting			Yes	No	Yes	No	No		Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Community health & safety	Socio-economic impact on local communities	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1			3	3	3	2	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1			3	3	2	2	4	4
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1			3	3	3	3	4	1
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6			3	2	2	3	3	3
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0								
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8			3	2	3	2	1	1

						Operational Adequacy					Rehabilitation and Closure		Constructability		
			Show stopper column setting			Yes	No	No	No	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Occupational Health & Safety	Operability	Inherant availability & reliability	Maintainability	OPEX	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1	3	2	3	3	3	3	3	3	3	3
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6	3	2	1	3	4	3	3	3	3	2
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0										
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8	3	3	3	3	3	3	3	3	3	3

6.10 Tailings Storage Facility subfloor material management

Report: *MTC Application Ranger Mine Tailings Storage Facility ‑ Subfloor Material Management, 2020*

ERA undertook an assessment into the viable options for managing the TSF subfloor contaminated material as part of closure planning for the TSF and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material *in situ* rather than disposal into Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 was required to consider this subfloor material. The deconstruction of the TSF does not occur until later, and as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works.

Based on the outcomes of the BPT assessment, an application was submitted to the Director of Mining Operations, DITT for approval in March 2020. The application was updated in June 2020 following stakeholder feedback and the DITT approved the application in August 2020.

The BPT assessment involved comparing the option of leaving the contaminated subfloor material *in situ* against a number of methodologies for disposing the material within Pit 3 (Table A6.1-12 and the ranking matrices at the end of this section).

Option 1 was developed as a worst-case scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, to allow for completion of the relevant supporting studies. It is intended that Option 2 will be reviewed on the basis that Option 1 demonstrates a greater ‘net environmental benefit’ than Option 3 as part of this initial assessment. A total of 12 options were reviewed for disposal of the material within Pit 3.

Table A6.1-12 BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	Option description	Score
1a	Leave material *in situ*. TSF subfloor material left undisturbed *in situ*. All visible tailings removed. TSF is then used for process water storage.	38.2
2	Leave material *in situ*. TSF subfloor material left undisturbed *in situ* with some form of remediation which may use TSF wall material for capping or another methodology.	Initial show-stopper
3a.1	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 for use as secondary cap. TSF used for process water storage.	-17.6
3a.2	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, intermediate stockpile, with transfer to Pit 3 for use as primary cap.	Initial show-stopper

Option	Option description	Score
3a.3	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, no stockpile, placed within south-west of Pit 3 as primary cap wedge deposit. TSF used for process water storage.	-35.3
3a.4	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via dredging, not stockpiled, with transfer to Pit 3 for use as primary cap. TSF used for process water storage.	Initial show-stopper
3a.5	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, crush, screen and pump to Pit 3 (above tailings). TSF used for process water storage.	-41.2
3a.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 and intermixed with mineralised waste rock (co-disposal). TSF used for process water storage.	-23.5
3a.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically, stockpiled, with transfer to south-west of Pit 3 as secondary cap wedge deposit. TSF used for process water storage.	-23.5
3b.1	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and use as secondary cap. TSF used for process water storage.	Initial show-stopper
3b.2	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, partially transferred to Pit 3 and use as secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	Initial show-stopper
3c.7	Dispose of material within Pit 3. 4 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and placed in south-west as secondary cap deposit. TSF used for process water storage.	-29.4
3d.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Schedule optimised.	-29.4
3d.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Solute optimised.	-29.4

To compare Options 1 and 3, an understanding of the risk of contaminants mobilising into the surrounding environment was necessary to determine how effectively the TSF subfloor could be isolated at each management location. Isolation effectiveness is assessed with regard to the likelihood of contaminants entering groundwater and surface waters, which create solute transport pathways and potentially increase exposure of contaminants to sensitive receptors. The management option that poses the lowest environmental risk and/or avoids having ‘a net adverse effect’ would be considered the most viable for implementation.

Option 1a (leave *in situ*) ranked highest overall and is the only option with a positive ranking of 38.2. This option scored highest overall for aspects such as ‘Environmental Protection’, ‘Living Culture’, ‘Cultural Heritage’, ‘Ecosystems & Natural World Heritage’, and ‘Tailings’, indicating that these aspects meet current standards and are more likely to achieve greater level of environmental and cultural protection than the other management options. This option scored lowest overall for ‘Revegetation’ (3) and ‘Erosion’ (2), indicating that this option presents greater risk to final landform management than the Pit 3 transfer options. Overall, this option had the least number of soft show-stopper aspects (‘Community Health’, ‘Radiation’ and ‘Erosion’) in comparison to the other options and was identified as the most viable option for contaminated material management.

						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Robustness (closure only)	Environmental Protection	CAPEX
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	5	2	3	5	5	4	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0								
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	2	3	2	2	4	4	3	2
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	2	2	2	2	2	4	3	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	2	3	2	1	2	4	3	1
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2

Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	TO Culture & Heritage: Environmental Protection	TO Culture & Heritage: CAPEX	Protection of People and the Environment: Occupational Health & Safety	Protection of People and the Environment: Inherent availability and reliability	Fit for Purpose: Revegetation (Closure only)	Fit for Purpose: Erosion (Closure only)	Fit for Purpose: Water (Closure only)	Fit for Purpose: Tailings (Closure only)
		Show stopper column setting				Yes	Yes	Yes	Yes	No	No	Yes	No
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0								
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0								
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	2	3	2	2	4	4	2	1
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" schedule optimised "" Note: ""It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	2	2	2	2	4	4	3	1
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" solute optimised "" Note: ""It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	2	2	2	2	4	4	3	1

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	2	2	2	3	5	5	5	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0									
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	4	2	3	1	2	2	3	3	3
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	4	2	3	1	2	2	2	2	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	4	2	3	1	1	1	2	3	2
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	4	2	3	1	2	2	3	2	3
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	4	2	3	2	2	2	3	2	2

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	0	0	0	0	0	0	0	0	0
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0									
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0									
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	4	2	3	1	2	2	3	2	2
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" schedule optimised "" Note: ""It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	4	2	3	1	2	1	3	2	3
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal "" solute optimised "" Note: ""It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	4	2	3	2	2	1	3	2	2

6.11 Blackjack waste disposal

Report: *Best Practicable Technology (BPT) Assessment Blackjack Waste Disposal, Coffey 2018*

In July 2018, Coffey Services Pty Ltd (Coffey) facilitated a BPT workshop to assess options for the disposal of hydrocarbon waste generated by the Ranger Mine. As part of uranium ore processing, a hydrocarbon lubricant known as blackjack (gear oil), is injected onto the spindle of the ball mill. The inventory forecasted at closure is approximately 72 kL, which equates to approximately 10 (205 L) waste blackjack drums produced annually. There are potential risks associated with blackjack disposal.

Analysis of drummed waste blackjack concluded that the waste at Ranger is contaminated above exemption levels as set out in the National Directory for Radiation Protection (Welman, 2013). Therefore, the waste blackjack cannot be disposed of off-site at a non-radioactive waste facility. The disposal of blackjack is required to be in line with Rio Tinto and ERA policies and standards, and the Ranger ERs. Another risk includes the possibility of light-non-aqueous phase liquids to separate as free product from the blackjack and potentially leak into groundwater. As part of the BPT assessment, each option submitted for review identified and discussed the potential risks associated with the method proposed.

The BPT assessment considered five options for waste disposal including:

- Tellus ‐ National Geological Repository (A1)
    - Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise contaminants prior to disposal in a bed of low permeability clay.
- Scholer ‐ Diesel fired waste incinerator (A2)
    - Design, manufacture and supply a two-stage waste oil incinerator for consecutive burning of black jack at the Ranger Mine. Overall, the two-stage incineration system ensures complete combustion, eliminating discharge of any toxic incompletely combusted compounds, including potential and actual carcinogenic combustion by-products.
- CDM Smith – Immobilisation & In-cell disposal of contained blackjack in Pit 3 (A3)
    - A proposal was submitted by CDM Smith based on a concept design to include an underground repository during the backfilling of Pit 3. The blackjack waste in this case would be pre-treated and immobilised, retained in a containment structure and buried in a multi-layered barrier system. With regards to pre-treatment, the blackjack waste will be treated physically (solidification process) and chemically (stabilisation process) then be encapsulated within a purpose-built cell in Pit 3 to provide additional layers of containment.

- In-cell disposal of contained blackjack in Pit 3 (A4)
    - Blackjack waste that is currently stored in metal drums will be placed in a containment structure and backfilled in-between waste rock and tailings in Pit 3. This excludes the pre-treatment process and immobilisation as per the CDM Smith A3 option above.
- National radioactive waste management facility (A5)
    - A national radioactive waste management facility was included as part of the original submissions of options however was removed from further consideration before the scheduled BPT assessment, as the proponents were unable to meet the closing date for submissions.

The BPT Assessment determined rankings for each of the five options (Table A6.1-13 and the ranking matrices at the end of this section).

Table A6.1-13 Black jack disposal options and best practicable technology assessment summary

Option	Option description	Score
A1	Tellus – National Geolgoical Repositories	50.0
A2	Scholer – Waste Oil Incinerator	23.8
A3	CDM Smith – Immobilisation and in-cell disposal into Pit 3	-7.1
A4	In-cell disposal into Pit 3	-2.5
A5	National radioactive waste management facility	0.0

Tellus' National Geological Repository (Option A1) received the highest overall score, with 50 points. The second highest was Scholer's Waste Oil Incinerator, scoring 23.8 points. Tellus' National Geological Repository (Sandy Ridge) has received final approval and licencing to accept low-level radioactive waste and is the adopted option.

						TO Culture & Heritage		Protection of People and the Environment				
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes	Yes
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area	Long term protection of the environment (Operations only)
	A1	Tellus - National Geological Repositories	No	No	50.0	3	3	4	NA	3	5	5
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	2	3	NA	3	3	5
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	4	4	NA	4	4	3
	A4	In-cell disposal into pit 3	No	Yes	-2.5	3	4	4	NA	4	4	1
	A5	**National Radioactive Waste Management Facility	Yes		0.0							

						Fit for Purpose			Operational Adequacy	Rehabilitation and Closure			Constructability		
			Show stopper column setting			No	No	Yes	No	Yes	No	No	Yes	Yes	No
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Environmental Protection	OPEX	Environmental Acceptability (Operations only)	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Tellus - National Geological Repositories	No	No	50.0	4	3	4	5	5	5	5	NA	4	NA
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	4	4	3	3	3	5	3	4	3
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	2	2	3	1	3	2	2	4	2
	A4	In-cell disposal into pit 3	No	Yes	-2.5	4	2	1	4	1	3	2	2	4	3
	A5	**National Radioactive Waste Management Facility	Yes		0.0										

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APPENDIX 6.2: BPT ASSESSMENT MATRICES FOR PIT 3 CAPPING

BPT ASSESSMENT RANKING DATABASE

Pit 3 Capping Options

			Show stopper column setting			TO Culture & Heritage		Protection of People and the Environment			
						Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living Culture (Closure)	Cultural Heritage	Community Health & Safety	Socio-Economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu NP	Ecosystems of the Project Area
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	4	4	4	3	4	4
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	4	4	4	3	4	4
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	3	4	2	4	4	2
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	4	3	4	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	3	4	3	4	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	3	4	3	4	4	3
	D	Hybrid + Eastern Platform	0	1	23	3	4	2	4	4	3

BPT ASSESSMENT RANKING DATABASE

Pit 3 Capping Options

			Show stopper column setting			Fit for Purpose				
						No	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven Technology	Technical Performance	Sensitivity to external Factors	Environmental Protection	CAPEX
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	2	3	4	4	2
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	2	3	4	4	2
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	4	5	3	4	4
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	3	3	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	3	5	3	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	3	5	3	4	4
	D	Hybrid + Eastern Platform	0	1	23	4	5	3	4	3

BPT ASSESSMENT RANKING DATABASE
Pit 3 Capping Options

			Show stopper column setting			Operational / Execution Adequacy		
						No	No	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Operability/ constructability	Inherent availability, maintainability and reliability	OPEX
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	1	2	4
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	1	2	4
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	4	4	2
	C.2A	Sub-Aerial (accelerated dry out by mechanical assistance) with conventional wicking through bridging layer Capping Method	0	1	9	3	4	3
	C.2C	Sub-Aerial (accelerated dry out by mechanical assistance) with Amphibious wicking through mechanically assisted crust Capping Method	0	1	18	4	4	3
	C.2B	Sub-Aerial (accelerated dry out by mechanical assistance) with no wicking and sub-aerial Capping Method	1	1	16	4	4	1
	D	Hybrid + Eastern Platform	0	1	23	4	4	4

BPT ASSESSMENT RANKING DATABASE
Pit 3 Capping Options

						Rehabilitation and Closure						Constructability	
			Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	No
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation	Radiation	Erosion	Water (Closure Only)	Tailings	Schedule	Construction Occupational Health and Safety	Construction Complexity
	A	Sub-Aqueous Capping Method (Base case)	0	1	7	3	4	3	3	4	3	2	2
	B	East platform finished with Sub-Aqueous Capping Method	0	1	7	3	4	3	3	4	3	2	2
	C.1	Sub-Aerial (passive dry out) Capping Method	0	2	20	3	4	3	3	4	2	4	3
	C.2A	Sub-Aerial (accelerated mechanical assistance) conventional wicking through bridging layer	0	1	9	3	4	3	3	4	2	2	2
	C.2C	Sub-Aerial (mechanical assistance) Amphibious wicking through mechanically assisted crust	0	1	18	3	4	3	3	4	2	2	3
	C.2B	Sub-Aerial (mechanical assistance) no wicking	1	1	16	3	4	3	3	4	2	2	3
	D	Hybrid + Eastern Platform	0	1	23	3	4	3	3	4	2	3	3

APPENDIX 6.3: ALARA

Multiple frameworks informing closure criteria at Ranger mine

M Iles *BMT (Associate), Australia*

Abstract

The Ranger Project Area (RPA), site of Energy Resources of Australia Ltd.'s Ranger mine, is surrounded by (but separate from) Kakadu National Park (KNP) World Heritage Place and Ramsar wetland. Closure requirements differ for on and off the RPA.

The Mirarr Indigenous landowners source food and drinking water up and downstream of the mine and wish to resume these activities on the site after closure. The regulatory Environmental Requirements (ERs) specify that waters and tailings from the mine must not impact the KNP values which includes the local Indigenous culture, health of the local people and the biodiversity and ecological processes of the region. The ERs also state that impacts on the RPA must be as low as reasonably achievable (ALARA). Closure criteria for water and sediment on and off the RPA need to support these diverse values and goals.

The ANZG (2018) WQMF was used to identify indicators to represent KNP values, human health and biodiversity and derive water and sediment quality criteria to support management of these values. Risk and vulnerability assessments were used, at relevant stages in the WQMF, to assess the results of sediment and water quality monitoring and predicted post-closure water quality.

ALARA is widely understood and applied to radiation hazards but not chemical hazards. A fourth framework is required to provide information that will be used to assess if impacts on the RPA are ALARA. This paper demonstrates the role of these frameworks in water and sediment closure criteria development at Ranger mine.

Keywords: *water quality objectives, risk assessment, ecological vulnerability, as low as reasonably achievable (ALARA), closure criteria*

1 Introduction

Energy Resources of Australia Ltd. (ERA) is undertaking closure activities at its Ranger mine, which is surrounded by (but separate to) Kakadu National Park (KNP) World Heritage Place and KNP Ramsar site in the Northern Territory of Australia (Figure 1).

Water at and leaving the mine site following closure has the potential to impact community values on and off the Ranger Project Area (RPA) after closure if not properly managed. High level Environmental Requirements (ERs) for the protection of people and the environment during and after mining at Ranger have been set by the Australian Government (Commonwealth of Australia 2000). Those relevant to water quality specify that:

- Waters leaving the RPA do not compromise the achievement of the primary environmental objectives related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds
- Impacts on the RPA are as low as reasonably achievable (ALARA)
- The strategy for closure of the mine is assessed using a best practicable technology (BPT).

The Mirarr Indigenous landowners source food and drinking water up and downstream of the mine and wish to resume these, and other cultural activities, on the site after closure. In recognition of the importance of waterways on the RPA they requested that in riparian zones and water bodies, the standard of rehabilitation be as high as is technically possible and the level of contamination be as low as technically possible.

Closure criteria for water and sediment on and off the RPA and decision-making processes need to support achieving these diverse values and water management goals. Iles (2019) discussed plans for (i) applying the ANZG (2018) water quality management framework (WQMF) for setting closure criteria at Ranger, and (ii) the role of BPT and understanding ecosystem vulnerability when determining if impacts are ALARA. Stakeholders agreed with the planned approach in principle provided they were involved in decisions on what is reasonable (the R in ALARA), the goal of 'technically possible' was properly considered and it was clear how these different frameworks inform the different management goals on and off the RPA.

This paper describes:

- The holistic framework that is being adopted by ERA to identify closure options that are BPT and most likely to result in impacts on the RPA that are ALARA
- How risk and vulnerability assessments are being applied to understand the impacts associated with water quality
- How the process can inform decisions on 'technically possible' and 'reasonable', and
- How these fit within the WQMF to establish closure criteria and assess compliance with the ERs and community values.

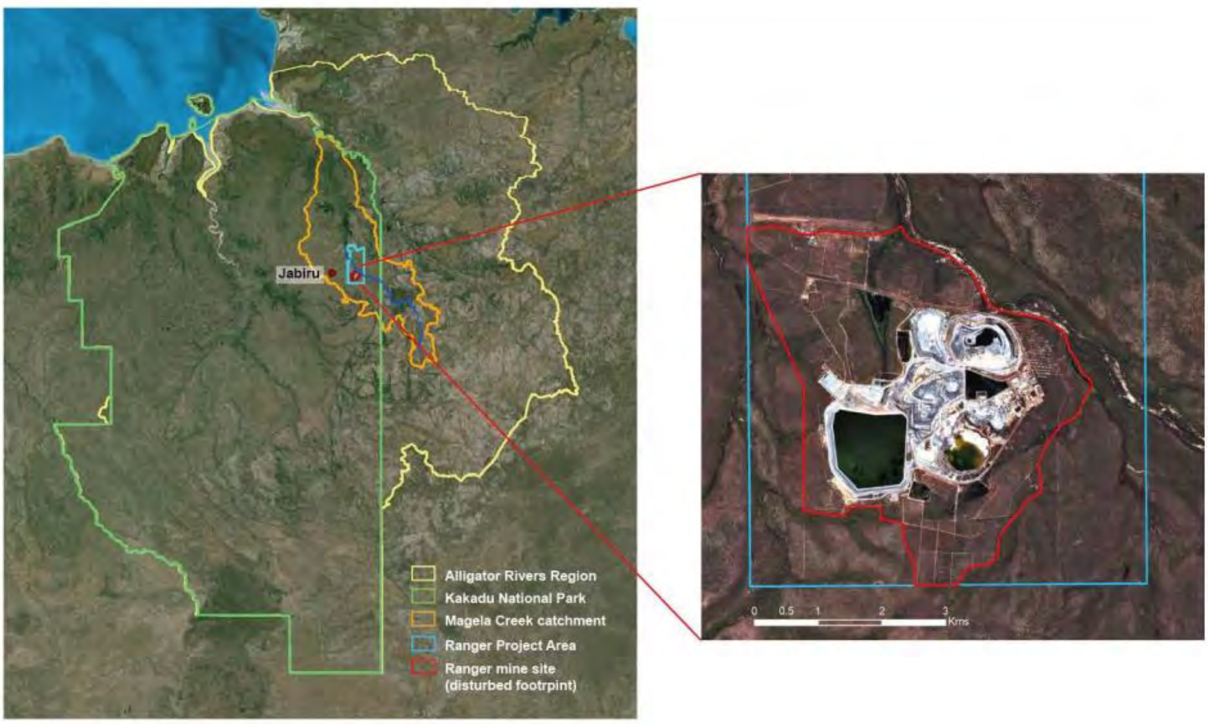

Figure 1 Ranger project area and mine site location

2 Assessment frameworks to support water closure criteria

Multiple assessment approaches are being used to develop closure criteria for the water related management goals for Ranger mine and assess compliance with these. These include the:

- ANZG (2018) WQMF
- Environmental risk assessment framework

- Ecological vulnerability assessment framework (VAF)
- BPT multi-criteria decision analysis framework
- ALARA framework.

These different frameworks have many aspects in common (**Error! Reference source not found.**) and do not stand alone with steps in common creating a web of frameworks (Figure 2)

Error! Reference source not found. Approach for assessing compliance with water quality related Environmental Requirements

Environmental Requirement	Assessment approach	Applicable Framework
Protect the people and biodiversity	Quantitative source-pathway-receptor risk assessment comparing current or predicted water and sediment concentrations to guideline values for species protection, drinking water, recreational water	ANZG 2018 Water quality management framework (WQMF) Environmental risk assessment Ecological vulnerability assessment framework (VAF)
Protect ecological processes, World Heritage and Ramsar values	Identify key indicator species/groups and sensitivity to main contaminant	As above. Indicators for World Heritage and Ramsar values set under the VAF
Impacts to be ALARA on the RPA	Iterative risk, vulnerability and BPT assessments	As above plus ALARA framework
Closure strategy is BPT	Multi-criteria decision analysis	BPT framework (a step within the ALARA framework)

2.1 Water quality management framework

ERA is following the ANZG (2018) WQMF to provide a process for stakeholders to develop agreed water quality objectives that apply both on and off the RPA. The WQMF provides a sequential stepwise approach (central wheel in **Error! Reference source not found.**) to setting management goals through to assessing, refining and deriving water and sediment quality objectives and guideline values. Several of the steps are also common to the VAF and ALARA framework and the environmental risk assessment is embedded both within the WQMF and the ALARA framework. The relationships are illustrated in Figure *2*.

Steps 1 to 5 of the WQMF cover setting objectives for each value being protected and identifying the most stringent of these as draft guideline values. At step 6 whether the objectives/guidelines can be met was tested using a source-pathway-receptor environmental risk assessment (section 2.2.1). This is also part of the ALARA process (section 2.3.2). If exceedance of the objectives/guideline values results in unacceptable risk Steps 7 and 8 of the WQMF are triggered.

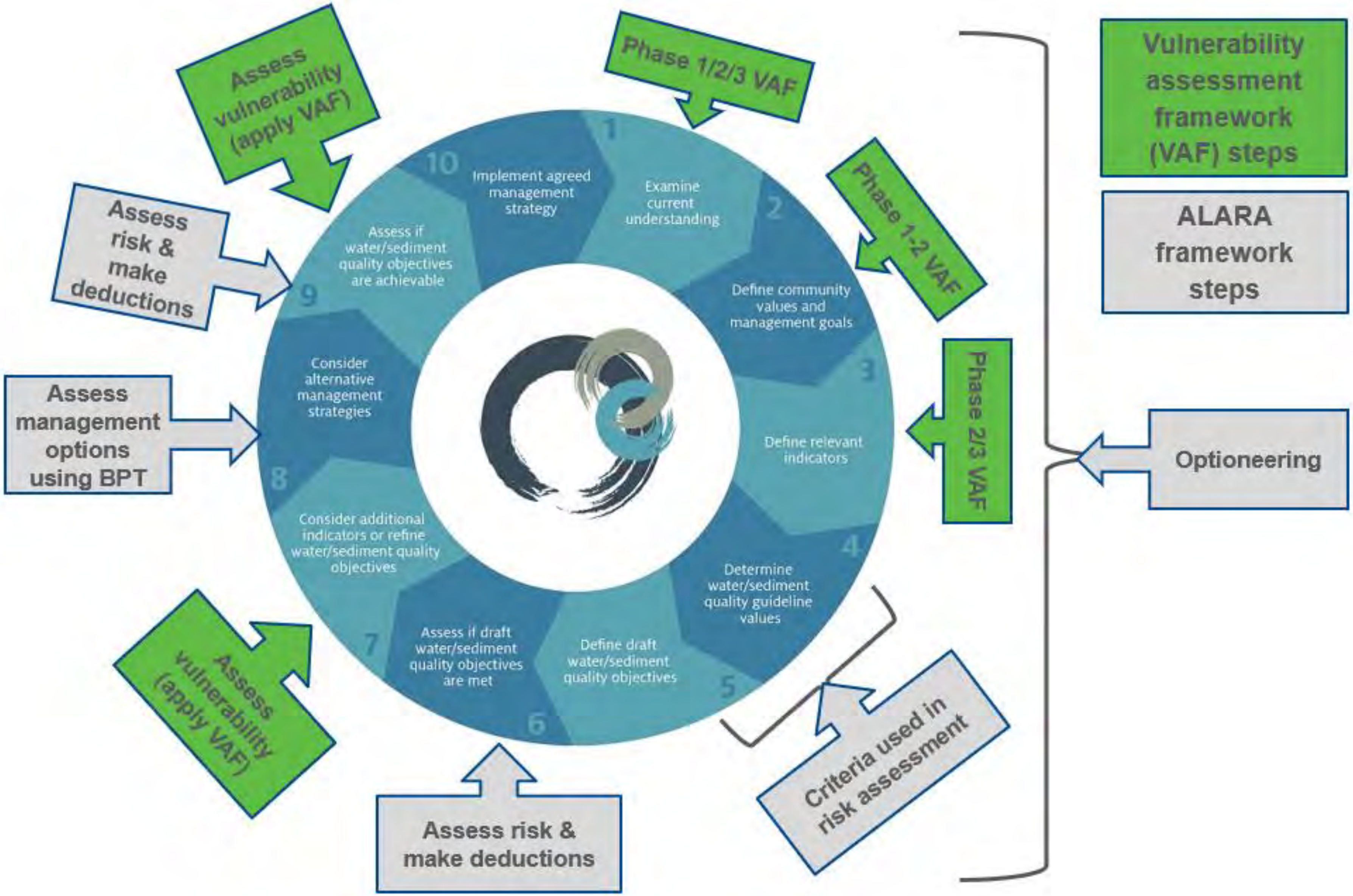

Figure 2 **Alignment of the WQMF (central wheel) with the ALARA and vulnerability assessment frameworks**

Step 7 of the WQMF involves a review of additional information and possible amendment of the criteria. The activities at this point differ for water bodies on and off the RPA. A review of conservatism in the solute transport models that provide the predicted water quality following closure is relevant to all sites being modelled and assessed. For water bodies on the RPA the VAF (section 2.2.2) is applied to provide an additional line of evidence to support discussions on whether impacts on the RPA are and ALARA.

Step 8 of the WQMF, relevant to both on and off the RPA, considers alternative management options. For this ERA uses the BPT and ALARA processes described in section 2.3. Step

It is important to note that Traditional Owners have reported concerns about trying to integrate cultural values with the ‘’scientific, legal and technical domains of a process that will take place within a framework controlled by those from the dominant non-Indigenous culture’’ (Garde 2015). The application of this framework has been, and will continue to be, discussed with stakeholders, including the representatives of the Traditional Owners through working groups, consultative forums and site visits. This is particularly important for agreeing on management goals for waterbodies on the RPA and determining if impacts are ALARA.

2.2 Risk assessment and ecological vulnerability

2.2.1 Environmental risk assessment

A key environmental risk on site is the release of dissolved substances from mineralised and contaminated materials in mine areas (Bartolo et al. 2013). An understanding of potential impacts from these contaminants on environmental and cultural values is an important element of planning for closure. Studies have been conducted for over 40 years to understand the contaminants and nature of, and risks to, the health of the ecosystem and people.

An assessment was conducted by ERA and BMT Ltd (Iles & Rissik 2021) to identify the risks posed from the different contaminants and contaminant sources on the mine site or predicted to come from the site after closure. The assessment was conducted using the ERA risk assessment tools modified to make use of the detailed evidence available for the site. Quantitative predictions of future water quality (including predictions for 10,000 years) and evidence of existing contamination was compared to water and sediment quality objective and guideline values identified in Steps 4 and 5 of the WQMF. The risk assessment fits into Step 6 of the WQMF and is also an activity under the ALARA framework (section 2.3.2). At several sites risks were identified which triggered application of the VAF (section 2.2.2) and a review of solute transport model conservatism and management options. These activities are part of the WQMF (Steps 7 and 8) and the ALARA framework.

A separate paper in these proceedings (Iles & Rissik 2022) describes the risk assessment.

2.2.2 Ecological vulnerability

Ecological vulnerability assessment fills the knowledge gap that exists between laboratory and field effects experiments on a sub-set of species or assemblages, to understanding risks to higher levels of organisation and/or to other species and species groups (De Lange et al. 2010). Ecological vulnerability assessment considers not only the direct sensitivity of organisms to a stressor, but the potential for indirect flow-on effects through trophic and habitat relationships.

ERA commissioned BMT to develop a framework (the VAF; Figure *4*) to assist in understanding the potential impacts from contamination levels of magnesium greater than the 99% species protection guideline value. The initial phases of the project identified relevant water types, environmental values and indicators for waterways at, and adjacent to, the RPA which specifically reflect community values and meet statutory requirements outlined in the ERs (BMT WBM 2017). The later phases of the project developed the VAF to assess the vulnerability of the key species and functional groups identified as important ecological components underpinning the environmental values related to the ERs (BMT 2001).

The VAF assesses (i) exposure of ecological components based on water quality modelling and distribution of identified indicator species/communities, (ii) their direct and indirect sensitivity to contaminant exposure based on laboratory and field studies, and (iii) their capacity for recovery based on a review of the traits of ecological components. A separate paper in these proceedings (Richardson et al 2022) provides detail on developing and applying the VAF to Ranger waterbodies. The findings provide information of the vulnerability of the important ecosystem components for water quality predicted to occur under modelled closure scenarios. Knowledge gaps are identified and plans to address these are underway.

The understanding of ecosystem response to predicted water quality for given closure scenarios provides important information for deciding if impacts are acceptable and ALARA or if additional/alternative management strategies are needed.

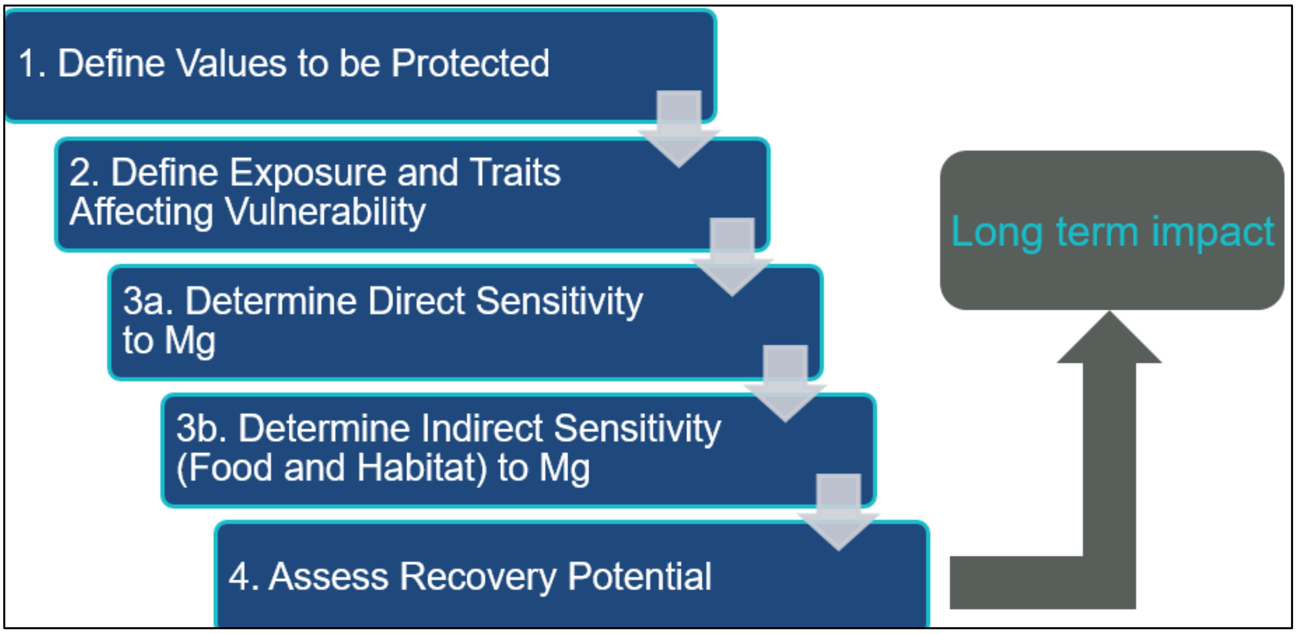

Figure 3 **The ecological vulnerability assessment framework (VAF) (source BMT 2021)**

2.3 ALARA & BPT

2.3.1 Best Practicable Technology

To comply with the ERs, the closure of Ranger must be implemented in accordance with BPT. SSB interprets BPT as the technology that is consistent with achieving the primary environmental requirements and ranks highest when considering: world best practice, cost effectiveness, proven effectiveness, Ranger's location, age of equipment and social factors (Supervising Scientist 2000). To ensure the BPT concept was effective for driving the closure strategy at Ranger, ERA expanded these categories to include cultural and heritage aspects and protection of the environment in the closure criteria themes of tailings, water, sediment, erosion and ecosystem establishment (Johnston & Iles 2013). The new criteria remained consistent with the original broad matters in the formal definition of BPT (ERA 2020). ERA reviews and updates the BPT criteria to keep them relevant to the phase of operations. This is done as part of the continuous improvement cycle and in consultation with stakeholders.

The BPT assessment process compares different management options and ranks them against each other based on scores for each of the BPT criteria. All scores are combined to a single value and the different options ranked (ERA 2020). The option with the best score is deemed to be BPT and taken through further assessments including further detailed risk assessment and BPT assessment of operational and design options for the chosen option.

Criteria can be weighted, and this has been suggested as a means of ensuring the highest level of protection for waterbodies and riparian zones and for allowing options to be compared on their technical ability to reduce impacts as well as comparison based on their cumulative score for all criteria. The risks associated with an option identified by such a weighted process would need to be assessed.

2.3.2 As Low as Reasonably Achievable

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. ALARA is well established for radiation protection but is not directly transferable to assessments of non-radiadiological hazards such as chemical pollutants. A fundamental issue is the difference in approach between optimising radiation protection and control of chemical pollution. The former is recognised as using a top-down approach, while the latter is based on a bottom-up approach (Domotor et al. 1999, Tran et al. 2000).

According to Tran et al (2000) in radiation safety a top-down approach sets an upper limit and practices are put in place, using the ALARA procedure to consider cost and other factors, to reduce the risk further. The bottom-up approach works the opposite way. Numeric targets are based on an acceptable risk range. A target is set to limit exposure to the lower end of the acceptable risk range. If after considering the technical feasibility, costs, and other factors it is demonstrated the target is not achievable a decision may be made to accept a higher risk and set a target allowing exposure at the upper end of the acceptable risk range.

The ANZG (2018) WQMF for setting water quality criteria follows a bottom-up approach as described by Tran et al. (2000). The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. If the targets cannot be achieved steps in the WQMF can be followed and alternative targets proposed. There is a need though to do this in the context of demonstrating relaxed targets are aligned with impacts that are ALARA.

Tran et al. (2000) recommends a flexible risk management framework and assessing multiple or cumulative risks as an approach to dealing with the differences between the top-down radiation safety ALARA approach, and the bottom-up numeric targets approach. Bryant et al. (2017), modified the radiation safety ALARA procedure to sit within a holistic hazard assessment framework for multiple hazards (Figure 4). ERA is adopting this framework of combined options-risk assessments in an iterative approach to identify a rehabilitation strategy with environmental impacts on the RPA from exposure to chemical pollutants that are ALARA.

The optioneering stage of the ALARA framework is where goals and criteria are established, and multi-criteria decision analysis of potential options is undertaken. ERA uses the WQMF to set goals and criteria and the BPT framework for decision analysis. This is where options that would achieve contamination that is as low as technically possible can be considered.

The risk assessment stage is where the environmental risk assessment and VAF occur along with other assessments in the ERA risk management process (e.g. assessments of health, safety and compliance with other closure requirements). Options and risk assessments are also steps in applying the ANZG (2018) WQMF.

If the impacts are not acceptable then steps in the ALARA framework (and the WQMF) can be revisited with discussions on cost, technical feasibility, and social expectations occurring to identify alternative management options.

Domotor et al. (1999) says ALARA is not a given value or numeric limit but is a process to assess a situation and ensure appropriate factors are considered. ERA propose that the water quality associated with the ALARA option (identified through applying the ALARA framework) be considered as numeric closure criteria (ERA 2020). Stakeholders agreed with this approach coupled with discussions on whether the proposed management option and resulting impacts are reasonable.

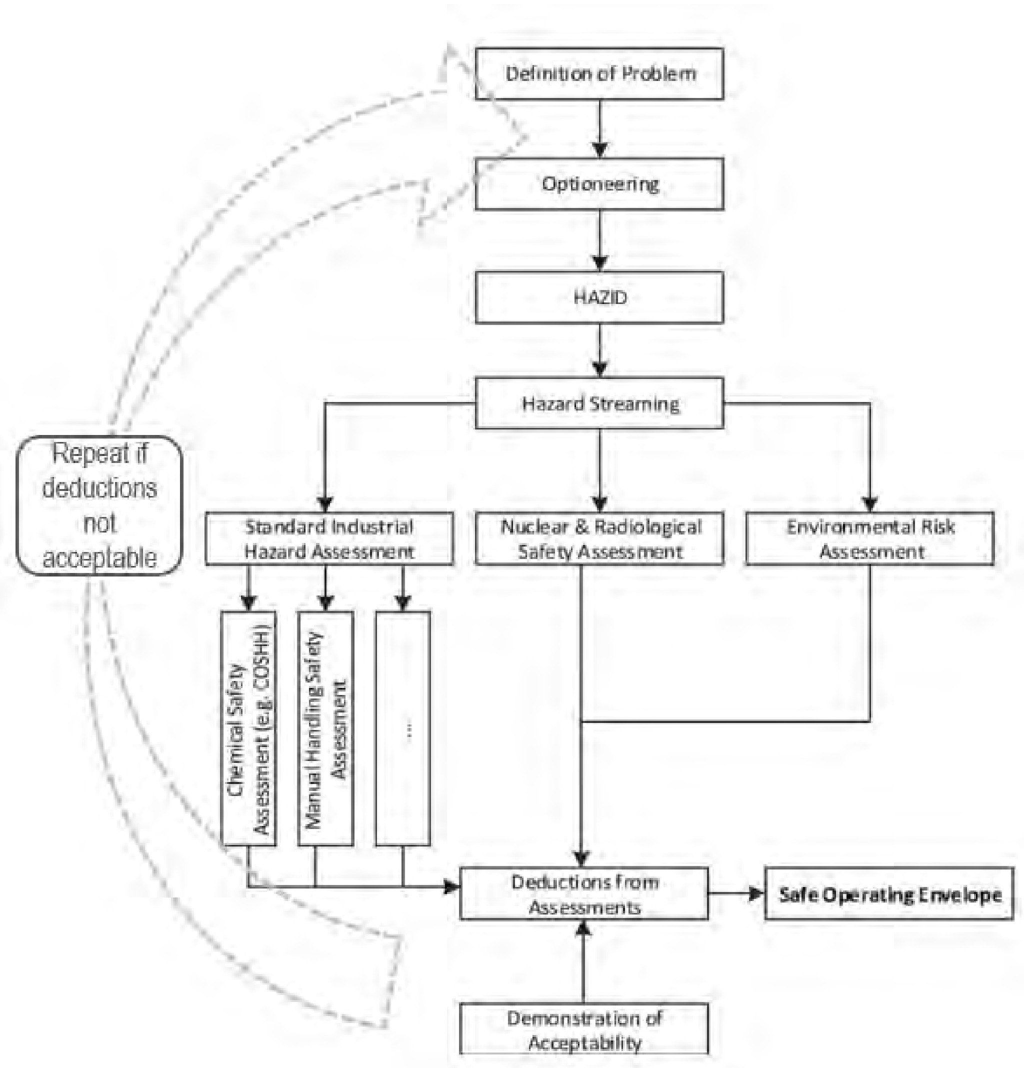

Figure 4 Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (modified from Bryant et al 2017)

3 Conclusion

ERA has applied multiple frameworks to inform derivation of water quality closure criteria for the Ranger mine to protect people, the ecosystem, and the World Heritage and Ramsar values of KNP and impacts that are ALARA on the RPA. The ANZG (2018) WQMF is central to this and is related to the other frameworks that are being used.

Deriving goals, indicators and guideline values that support the legislative ERs and Traditional Owner expectations occurs both within WQMF and the optioneering step in the ALARA framework. Assessing compliance with these is done by conducting assessments of source-pathways-receptor risks and ecological vulnerability. These are done under their own frameworks but sit within the WQMF and ALARA frameworks.

Using the approach demonstrated by Bryant et al (2017), ERA's BPT and risk management processes can be used, iteratively if required, to identify closure options that provide an ALARA outcome according to the process.

ERA has proposed that (i) by applying the ALARA framework in an iterative manner, management options that have been assessed as BPT and have acceptable levels of risk and impact (compared to management goals) can be identified, and (ii) the water quality associated with this option be used as closure criteria for water bodies on the RPA.

Stakeholders agreed with this approach coupled with discussions to determine if the proposed option is reasonable considering what is technically possible. Flexibility within the BPT decision making process can be used to assess options that provide as low as technically possible pollution control. Demonstrating the application of the ALARA framework and WQMF and sharing results from the BPT, risk assessment and VAF activities undertaken within these frameworks is vital to inform these discussions.

Acknowledgement

I acknowledge the Mirarr, the Traditional Owners of the lands that form the Ranger Project Area and ERA my previous employer for whom this work was completed.

Understanding the different assessment approaches and how to apply the various frameworks was greatly assisted by collaboration over the years between ERA staff, members of various Ranger stakeholder committees and key consultants. I would like to acknowledge the help of Ms Sharon Paulka (ERA), Dr Chris Humphrey and Dr Andrew Harford (SSB), Dr Darren Richardson and Dr Dave Rissik (BMT) Dr Chris Brady (NLC), and Dr Arthur Johnston (formerly from the Supervising Scientist Division).

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7 Risk assessment and management

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APPENDICES

Appendix 7.1: RANGER CLOSURE RISK ASSESSMENT 7-12

Cover photograph: Collecting Quinine Bush (*Petalogstigma quadriloculare*) seeds

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
As Low As Reasonably Achievable	Abbreviated to ALARA. As low as reasonably achievable, economic and social factors being taken into account.
Risk	The chance of something happening that will have an impact on objectives. NOTE 1: A risk is often specified in terms of an event or circumstance and the consequences that may flow from it. NOTE 2: Risk is measured in terms of a combination of the consequences of an event and their likelihood. NOTE 3: Risk can be a threat or an opportunity, but only threats or potential risk events are addressed in the MCP.
Risk Analysis	Systematic process to understand the nature of and to deduce the level of risk. NOTE 1: Provides the basis for risk evaluation and decisions about risk treatment.
Risk Assessment	The overall process of Risk Identification, Risk Analysis and Risk Evaluation and shall be retained in accordance with procedure.
Risk Control	The process of elimination or minimisation of risks.
Risk Evaluation	The process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria.
Risk Management Process	The systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, assessing, controlling and monitoring risk.
Risk Priority Class	One of four categories where a hazard can be located on the ERA Ranger Risk Matrix – from CRITICAL to HIGH to MODERATE to LOW.
Risk Ranking	The level of risk allocated to a non-conformance if a corrective or preventative action is not carried out. The 5 x 5 Consequence/Probability model.
Risk Register	A register of risk information and controls kept at ERA, categorized into functional areas.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
BPT	Best Practicable Technology
ER(s)	Environmental Requirements
ERA	Energy Resources of Australia Ltd
FS	Feasibility Study
HSE	Health Safety and Environment
HSEC	Health, Safety, Environment and Communities
IPCC	Intergovernmental Panel on Climate Change
ITWC	Interim Tailings water and closure
KKN	Key Knowledge Needs
MCP	Mine Closure Plan
mRL	Meters Relative Level
MOL	Maximum Operating Level
PFS	Prefeasibility Study
RBS	Risk Breakdown Structure
RP2	Retention Pond 2 – also denotes other retention ponds used on site – e.g. RP1, RP3, RP6
RPA	Ranger Project Area
RWD	Ranger Water Dam
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

7 RISK ASSESSMENT AND MANAGEMENT

Risk assessment and management is a central element of the Energy Resources of Australia Ltd (ERA) business framework and is undertaken in accordance with the internal Hazard Identification and Risk Management Standard (ERS003) and ERA Closure Risk Management Plan (ERA, 2020). The Ranger Mine Closure Risk Management Plan applies a holistic suite of risk management techniques across all risk areas including strategic, technical, commercial, safety and environmental and establishes a framework for:

- Risk identification;
- Risk evaluation; and
- Risk treatment (actions).

The objectives of risk management are to improve execution and reduce risk exposure. To achieve these objectives, ERA has implemented a transparent, proactive, structured, and consistent process that provides a clear indication of the most significant risks and mitigating actions.

ERA also engages in a consultative process with key stakeholders to ensure there is transparency and that due consideration is given to the identification of closure threats, existing controls, and planned actions to address risks. Successful management of risks requires the implementation of a clear risk management strategy supported by adequate resources and a strong risk-aware culture. The Ranger Mine closure risk management strategy emphasises the development of purpose-specific, risk-based plans at various stages within the major project delivery functions, all within the context of a risk-based project plan that is integrated with and supported by the Health and Safety Quality and Environmental systems. This involves maintaining an up-to-date risk register that is regularly consulted and reviewed.

To support risk management during closure execution, specific risk management accountabilities and responsibilities are assigned to relevant project and support personnel. Additionally, the closure management team is responsible for ensuring that the management plans are implemented, and resources are made available when required.

Since 2008, ERA has held regular risk assessment workshops to identify key risks relating to the closure of the Ranger Mine. A workshop was held in August 2016 to identify specific closure environmental risks in relation to Best Practicable Technology assessments. This was followed by several assessments undertaken as part of the Ranger closure feasibility study during 2018, with the outcomes presented in the 2018 Mine Closure Plan (MCP). In 2019, following the completion of another closure risk review and release of the 2018 MCP, the risk register was updated to incorporate the comments received from stakeholders. The closure risk register continues to be regularly reviewed and updated. Another detailed review of the closure environmental risks is planned for 2023.

The current closure environmental risk register is provided in Appendix 7.1. For each identified risk event, Appendix 7.1 lists the causes, consequences, existing controls, effectiveness of controls, rationale for this effectiveness rating, how the risk is trending, the risk class/classification, planned actions and the date the particular risk event was last reviewed and updated.

7.1 Standards and requirements

ERA developed the Hazard Identification and Risk Management Standard (ERS003) to ensure that all hazards and opportunities for a particular project are identified, assessed and strategies are developed to manage risks (ERA, 2018). The standard is integrated within element three of the ERA Health, Safety and Environmental Management System, which has been certified to meet the requirements of the AS/NZ ISO14001:2015 and AS4801 national standards (AS4801 has been superseded by AS45001 and ERA will be moving to AS45001 in late 2022). The basic AS/NZS ISO 31000 process as illustrated in Figure 7-1 forms the procedural framework for the management of risks at the Ranger Mine.

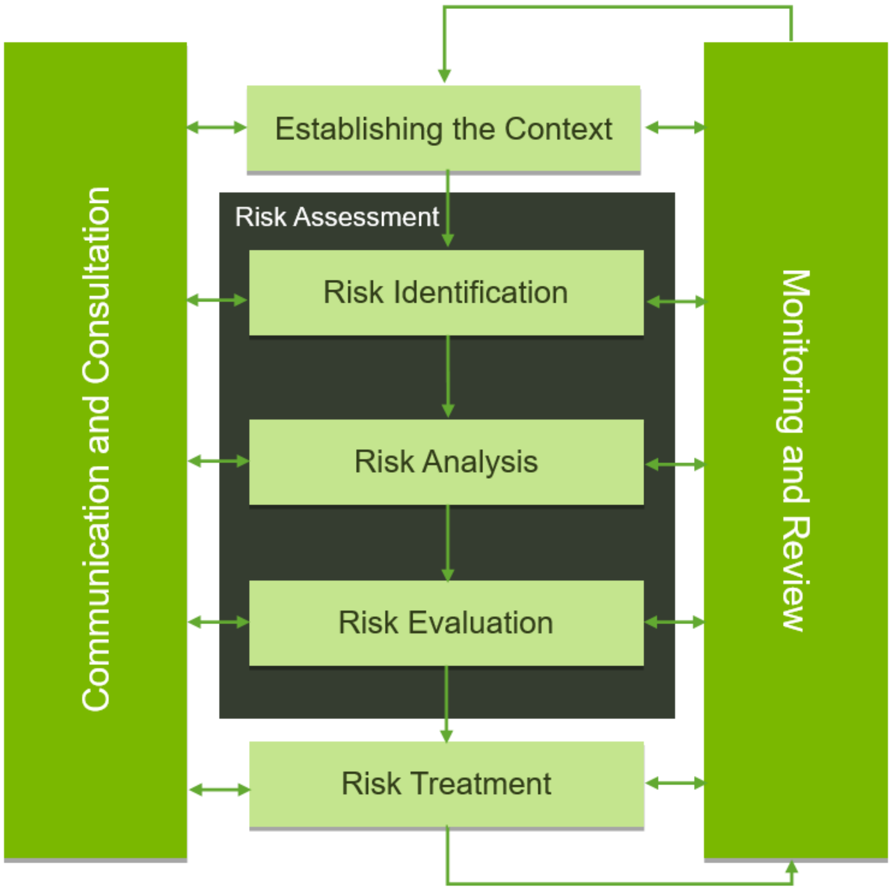

Figure 7-1: ISO 31000 Risk Management Process

The management process applied to risk assessments at the Ranger Mine is consistent with the following national and corporate management standards:

- AS/NZS ISO 14001 Environmental management systems – specification with guidance for use;

- AS48012 Occupational health and safety (OHS) management systems – specification with guidance for use;
- AS ISO 31000:2018 Risk Management– Principles and guidelines;
- Environmental risk management – Principles and processes (HB 203:2012);
- Rio Tinto Risk Policy and Risk Management Standard (Rio Tinto, 2019) Rio Tinto Health, Safety and Environment (HSE) management system – Element 3 hazard identification and risk assessment; and
- Rio Tinto HSE performance standards.

In addition, ERA is required to comply with the Commonwealth Environmental Requirements (ERs), set out in the Ranger Authorisation 0108-18 (the Authorisation), to minimise risk through the implementation of effective controls that enable:

- 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; and
- maintenance of the nature and biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.

7.2 Previous closure risk assessments

ERA has used the risk assessment process to identify potential environmental closure risks through several risk assessments completed to date.

The outcome of past and recent risk assessments and modelling studies inform the assessment, along with sources, pathways and receptors as discussed previously with stakeholders (Bartolo *et al*. 2013). This fundamental approach that was used in 2013, of identifying and assessing risks based on sources, pathways and receptors, will be undertaken again in 2023.

A review of the respective risk assessments was completed in 2019 with an objective of incorporating relevant risks from these earlier registers into an updated register to reflect the current status of the Ranger Mine closure strategy. Since this time, the resulting register continues to be reviewed and update to ensure currency. Section 7.3.7 discusses the timings and triggers for these regular reviews. The following provides a summary of the more specific risk assessments and reviews that have been undertaken:

- Pit 1 Interim Tailings, Water and Closure (ITWC) Prefeasibility study (PFS) risk register, 2008: The purpose of this risk analysis was to identify and evaluate threats and opportunities associated with the options considered for Pit 1 closure to PFS level. The output of this risk analysis helped determine the appropriate closure method to be advanced to feasibility level.

- ITWC PFS risk register, 2011: The purpose of this risk analysis was to identify and evaluate threats and opportunities associated with all aspects of closure across a 14-year schedule (2012 to 2026) and 10,000-year tailings containment period.
- Tailings transfer risk register, 2012: The purpose of this risk analysis was to identify and evaluate threats and opportunities associated with elements of the tailings transfer process from the Ranger Water Dam (RWD) to Pit 3, including dredging, Pit 3 pumping system, power requirements and procurement.
- PFS brine injection prefeasibility operational risk register, 2012: The purpose of this risk analysis was to identify and evaluate the risks associated with the brine injection aspect of the Ranger Mine closure project.
- Feasibility study (FS) tailings and brine management closure risk register, 2013: The purpose of this risk analysis was to identify and evaluate the risks associated with the tailings and brine management aspect of the Ranger Mine closure project. Elements assessed during this risk assessment included brine injection, tailings transfer and implications for both Pit 3 and the tailings dam during the activity, dredging, Pit 3 pumping system and operational readiness.
- Ranger Mine Pit 1 closure risk environmental register, 2016: The purpose of this risk analysis was to identify and evaluate the consequences and significance of the opportunities and threats on the surrounding environment, associated with the closure of Pit 1, and the final average tailings deposition in the pit to a level of 7 mRL.
- Ranger MCP risk assessment, 2016: this risk assessment was presented in the 2018 MCP and at the time incorporated all other risk assessments undertaken over the life of the Ranger Mine. As part of the scoping, the Best Practicable Technology (BPT) options were considered in the risk assessment.
- Ranger Closure Feasibility Study, 2018: This risk assessment rolled all previous closure risk assessments up into a single register that is now hosted on the Rio Tinto risk platform ‘Archer’. This risk register is actively reviewed and managed as part of the Ranger Closure Project.
- Ranger Closure Risk Review, 2019: This risk review was completed to address the comments received on the risk identified and included within the 2018 MCP.
- Social Risk Review, 2020: This risk review was completed to address the threats or opportunities that may result from how the business/project impacts upon and interacts with communities and stakeholders.
- Annual Ranger Closure Risk Review, 2020; this risk review was completed to challenge the risk profile and provide confidence that the most material risks to achieving the strategic objectives and targets are understood. The risk threshold is reviewed against the business’s objectives and targets, the risk profile is challenged due to external or internal influences/decisions, the control effectiveness is reviewed based on assurance outcomes and implemented actions, new risks are captured and existing risks are closed or tolerated.

- Ranger Closure Quarterly Risk Reviews: The purpose of these risk reviews is to ensure that the information remains current, including risk trend update, control effectiveness, overall control effectiveness, action status and overall action status.
- Multiple ad hoc reviews: Determined by business need, risk owner or other with the aim to ensure that information is current and material risks are being actively managed, meaning new risks can be identified or existing risks reviewed.
- Annual Ranger Closure Risk Review, 2021; the annual process mentioned above for 2020 was repeated in 2021.
- Operations and closure risk review, 2021. This risk review was completed to address the changes to the operational health, safety, environment and communities (HSEC) risk profile due to the cessation of operations.
- Pit 3 Capping and Backfill, 2022. The aim of which was to identify risks (including design and implementation) which have the potential to impact the achievement of the Pit 3 Capping and Backfill objectives. These were then reviewed against the project portfolio to ensure material risks to project are being monitored at the right level in the business and risks have been incorporated into the risk register provided in Appendix 7.1 of this MCP.

7.3 ERA closure risk assessment methodology

All closure risk assessments have been facilitated by competent personnel, involved a range of technical and subject matter experts, and followed the standard processes described above. The key elements of this methodology are:

- setting the context and scope for the assessment;
- identifying key objectives and assumptions;
- setting risk acceptances and thresholds;
- identifying key stakeholders and participants;
- generating a list of applicable risk scenarios (threats) and consequences based on potential risk exposure pathways between identified hazards (causes/triggers) and receptors (i.e. person or environment);
- identifying the existing control measures available to mitigate each threat and the control effectiveness (rating);
- evaluating the risk likelihood and maximum reasonable consequence for each threat using the descriptors included within the Rio Tinto HSEC 5 x 5 risk determination matrix to establish an overall risk class, which can range from Class I (Low) to Critical IV (Critical);
- identifying additional control measures for significant threats rated as either Class III (High) or Class IV (Critical) to ensure the residual risk rating is as low as reasonably achievable (ALARA);

- recording outcomes within the ERA closure risk register to ensure active management is maintained during implementation and execution;
- developing action plans as required to support the implementation of effective control measure and assign accountabilities;
- communicating risk information; and
- reviewing and updating risk events, controls and action status.

Further detail relating to each of these elements is provided within the following sub-sections. The closure risk assessment will continue to be reviewed and updated following further internal or external workshops and as material changes to the planned closure activities are required. Therefore, the closure risk portfolio is an evolving tool that is integrated into daily planning and operations. The outcomes of the ERA closure risk assessment will continue to be used for evaluating priorities and management strategies throughout the closure process.

7.3.1 Purpose and scope

The purpose of the ERA closure risk assessment is to identify threats and consequences associated with mine closure activities and evaluate the significance of the potential threats to the environment on and surrounding the Ranger Project Area (RPA). The risk assessment considered the threats that may occur during the closure (decommissioning, rehabilitation, early monitoring) and monitoring and maintenance phases.

Closure commenced at the scheduled completion of processing in January 2021. Closure includes decommissioning, the general works associated with rehabilitating the site to an agreed standard of environmental protection and the re-contouring and revegetation of the final landform.

The monitoring and maintenance phase is the period post-decommissioning where active works have generally ceased and the progression towards the development of a long-term viable ecosystem and meeting closure criteria has commenced. This phase may require initial management as landform settling, subsidence and erosion occur, and vegetation establishes. Passive water management techniques may be implemented where required.

7.3.2 Assumptions

The following assumptions were made in undertaking the closure risk assessment:

- technical advice, generated from both internal and external sources (e.g. contractors, consultants, associates, government agencies and research partners), was assumed to be appropriate;
- existing ERA controls will continue to be applied where applicable; and
- all standard ERA risk controls will be applied.

7.3.3 Risk Management Tool

Mine Closure risks are managed using the RSA Archer Integrated Risk Platform. This tool provides the project and the business with a consolidated and clear view of risks, including version and history tracking and unique identification of risks and their components for future tracking purposes.

7.3.4 Risk Identification

The aim of risk identification is to generate a comprehensive list of credible risk events related to mine closure based on planned closure activities. Beyond the routine risk reviews and updates discussed in **Section 7.3.7**, material changes to planned activities (e.g. directional drilling from the wall of Pit 3 for brine disposal) trigger a review and update of relevant risks.

7.3.5 Risk Relationships

All risks have a Risk Breakdown Structure (RBS) element assigned within the risk database at the time of evaluation. The RBS element aligns the risks with the high-level project work breakdown structure, which assists in categorising the risks for the various project reporting needs. A standard risk numbering convention is also assigned that allows for tracking and identification of similarly themed risks.

7.3.6 Risk Evaluation

ERA has established an extensive suite of environmental management controls, processes and standards that have been implemented during operations and remain applicable during closure. Existing controls are taken into account when determining the risk ranking, thus the 'residual' rather than the 'inherent' (baseline or un-mitigated) risk is used in the risk ranking (as per ISO 31000). Control effectiveness is also assessed as an indicator of successful risk mitigation and provides a prompt for additional controls to be considered.

A 5 x 5 risk matrix (Table 7-1) is used to determine the overarching risk classification for each identified risk event. The risk classification is a function of the consequence and likelihood ratings determined in accordance with AS ISO 31000:2018 and ERA Standard: HSEC Hazard Identification and Risk Management. The overarching risk classification is determined to be either; Class I (Low), Class II (Moderate), Class III (High) or Class IV (Critical).

The risk classification identifies the level of management action that must be taken to mitigate the risk (Table 7-2). A risk that results in Class III or Class IV is a material risk that requires active management and consideration of additional control measures.

Table 7-1: Risk Class Determination

Likelihood	Consequence Severity				
	Very low	Low	Moderate	High	Very high
Almost certain	Class II	Class III	Class IV	Class IV	Class IV
Likely	Class II	Class III	Class III	Class IV	Class IV
Possible	Class I	Class II	Class III	Class IV	Class IV
Unlikely	Class I	Class I	Class II	Class III	Class IV
Rare	Class I	Class I	Class II	Class III	Class III

Table 7-2: Risk management response

Risk Class	Response
Class I	Risks that are below the risk acceptance threshold and do not require active management.
Class II	Risks that lie on the risk acceptance threshold and require active monitoring.
Class III	Risks that exceed the risk acceptance threshold and require proactive management.
Class IV	Risks that significantly exceed the risk acceptance threshold and need urgent and immediate attention.

The criteria for assessing the likelihood rating (Table 7-3) are used to assign a qualitative probability of occurrence that ranges from ‘rare’ to ‘almost certain’.

The consequence rating criteria (Table 7-4) provides a range of qualitative severity ratings that range from ‘very low’ to ‘very high’. The consequence definitions are based on the ERA risk scheme and were customised to align with the particular environmental and cultural aspects of the Ranger Mine.

It is noted that some risks have the 10,000 year timeframe. The lowest likelihood band available under standard business risk processes is <1:100 years which is titled ‘Rare’. It is considered not credible to obtain a higher degree of accuracy for even more remote risks. As such for these risks that refer to impacts in 10,000 year the likelihood (frequency) rankings and not used, rather the likelihood (probability) rankings are used. It should also be noted that the environmental impacts from these risks are assessed using modelling techniques that incorporate uncertainty analysis, to provide a higher degree of confidence.

Table 7-3: Likelihood qualitative criteria

	Likelihood				
	Rare	**Unlikely**	**Possible**	**Likely**	**Almost certain**
Frequency interval (multiple events)	Less than once per 100 years	Once in ten to once in 100 years	Once per year to once in ten years	Twice per year to once per year	More than twice per year
Probability (single events)	<5 %	5–20 %	20–50 %	50–75 %	>75 %

A control effectiveness rating is determined for each risk event to evaluate whether they will sufficiently mitigate the risk (Table 7-5). If the controls for any given threat/risk event are rated as either C3 (Marginal) or C4 (Weak) then further assessment is required to determine feasible controls.

Table 7-4: Consequence qualitative criteria

	Consequence				
Consequence Type	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Licence to Operate / Stakeholders	2 - Informal disapproval from local stakeholders.	3 - Stakeholder actions resulting in days of operational impacts.	4 - Stakeholder actions resulting in weeks of operational impacts. Local reputation damage.	5 - Stakeholder actions resulting in months of operational impacts. National reputation damage.	6 - Stakeholder actions resulting in years of operational impacts. International reputation damage.
Health & Safety	2 - Low level short term inconvenience or symptoms. Typically a first aid case.	3 - Injury or illness requiring medical treatment, that does not lead to restricted duties or lost time.	4 - Injury / illness with moderate damage or impairment to one or more persons.	5 - Single fatality or severe permanent impairment	6 - Multiple fatalities or severe permanent impairment to multiple people.
Environment	2 - Harm to the environment that is localized, and is quickly and easily rectified.	3 - Harm that is localized, and is rectified or reversed within a few days to weeks.	4 - Harm that is largely localized but starts to be unconfined, rectified within weeks to months.	5 - Harm that is unconfined, and is rectified or reversed within months to years..	6 - Widespread environmental harm that is rectified or reversed within several years to decades.
Radiation (employees, contractors or public)	2 - Measurable increase in radiation dose with outcomes remaining below dose constraints.	3 - Increase in radiation dose above the dose constraints but still below international limits.	4 - Increase in radiation dose to above international limits.	5 - Radiation doses above 100 mSv to an individual and likely to significantly increase the risk of cancer to that individual.	6 - Radiation doses to multiple individuals above 100 mSv or acute radiation syndrome to an individual.

	Consequence				
Consequence Type	**Very Low**	**Low**	**Moderate**	**High**	**Very High**
Communities & Social Performance	2 - Short term loss of trust with communities. Damage to cultural heritage of low significance.	3 - Loss of trust with communities taking weeks to resolve. Non-disruptive organised opposition.	4 - Loss of trust with communities that cannot be resolved through routine procedures.	5 - Widespread, sustained opposition from communities.	6 - Systemic opposition from communities that impacts community trust at other Rio Tinto assets.
Legal & Regulatory Compliance	2 - Non-compliance with agreements or laws that can be resolved via informal discussion or direct engagement.	3 - Breaches of agreements or laws resulting in formal notices or written warnings.	4 - Breaches of agreements or laws resulting in low-level fines or payments.	5 - Breaches of agreements or laws or legal action resulting in fines, settlements or payments that are material at the Site level, or short term suspension of operations.	6 - Breaches of agreements or laws or legal action resulting in fines, settlements or payments that are material at the Business Unit level, long term suspension of operations or sanctions against responsible managers.
Closure and Legacy Management	2 - Changes to closure scope which have limited impact.	3 - Changes to scope with a noticeable increase in complexity and/or degree of difficulty of closure.	4 - Change to scope with a moderate increase in complexity and/or degree of difficulty of closure.	5 - Changes to scope with a significant increase in complexity and/or degree of difficulty of closure.	6 - Material changes to scope with a major increase in complexity and/or degree of difficulty of closure.
Schedule (Time)	3–6 weeks	6 weeks–3 months	3–6 months	6–12 months	1–2 years

Table 7-5: Control and Overall Control Effectiveness

Control Rank	Description	Guidance
C1	Good	Substantially effective/adequate design Controls are considered adequately designed **and** are operating effectively on almost all occasions.
C2	Satisfactory	Mostly effective/adequate design. Controls are considered adequately designed **and** are operating effectively on most occasions.
C3	Marginal	Inadequate design/partially effective. Controls are considered inadequately designed **or** are only operating to partial effectiveness on most occasions.
C4	Weak	No controls/ineffective. There are no controls designed **or** the existing controls are operating ineffectively on all occasions.

Further to this, the Ranger Mine Closure portfolio captures 'Overall Control' effectiveness and 'Overall Action Status' as an indicator of the overall health of the mine closure risk portfolio.

7.3.7 Communication and Consultation

All closure project personnel are actively encouraged to identify and discuss potential risks as a normal part of daily work, regardless of their role. The full closure risk portfolio is available to all project personnel through the internal ERA intranet, promoting project team members to actively incorporate risk management into their daily discussions and promotes continual review of risks as a part of normal project activities.

Communication is also supported by a formal project risk reporting process, as outlined in Figure 7-2. Beyond the routine risk reviews and updates shown in Figure 7-2, material changes to planned activities (e.g. directional drilling from the wall of Pit 3 for brine disposal) trigger a review and update of relevant risks.

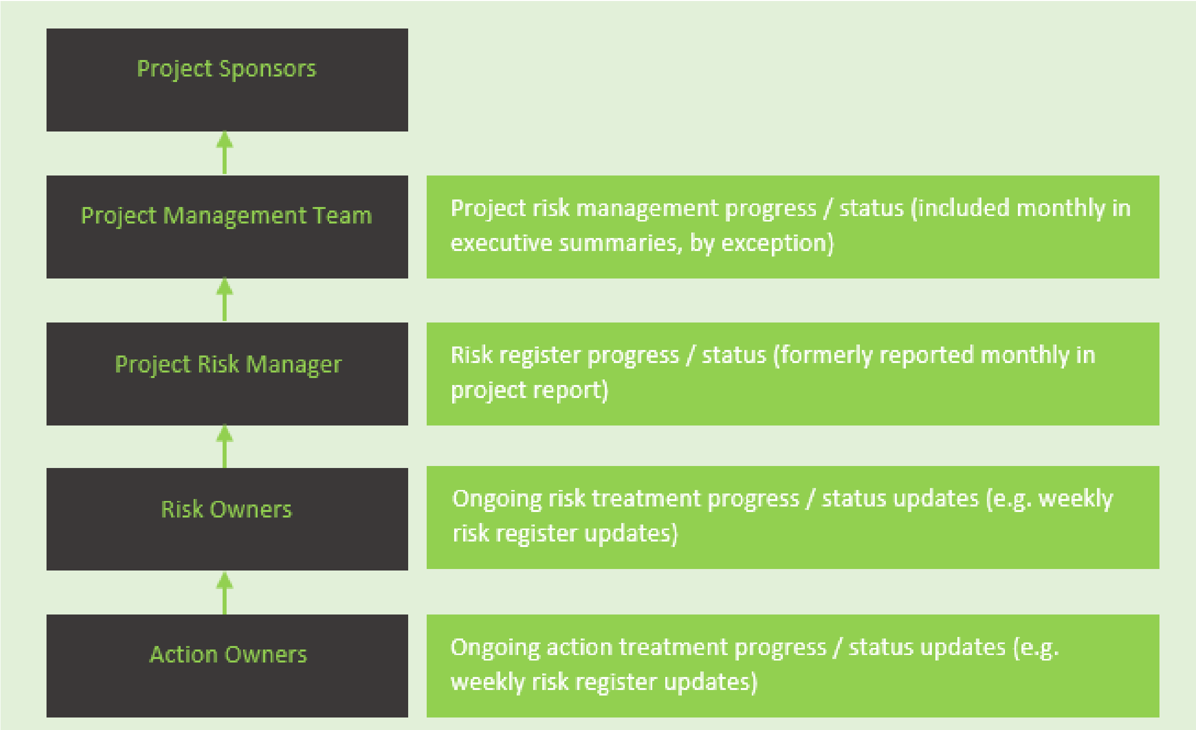

Figure 7-2: Risk Reporting Structure

Consultation on risk related matters occurs regularly through the following channels:

- Monthly notifications are sent to action owners on overdue actions, regular reminders are sent to risk and action owners to ensure data is complete and current.
- Fortnightly risk meetings are conducted to review and report on risk movement, review overdue actions, discuss trending, capture emerging risk and highlight concerns.
- Quarterly reviews are conducted with the aim to ensure that the information remains current, including risk trend update, control effectiveness, overall control effectiveness, action status and overall action status.
- Annual reviews are conducted with the aim to challenge the risk profile and provide confidence the most material risks to achieving the strategic objectives and targets are understood. The risk threshold is reviewed against the business' objectives and targets, the risk profile is challenged due to external or internal influences/decisions, the control effectiveness is reviewed based on assurance outcomes and implemented actions, new risks are captured and existing risks are closed or tolerated.
- Ad hoc workshops are determined by business need, risk owner or other with the aim to ensure that information is current and material risks are being actively managed, meaning new risks can be identified or existing risks are reviewed. These ad hoc workshops may be triggered by material changes to planned closure activities.
- A monthly summary of material risk is provided in the Closure Steering Committee for further monitoring and action, as necessary.

- A monthly reporting on the overall status and health of the risk register.
- Bi-annual risk portfolio health checks are undertaken (i.e. missing fields, querying data and providing overall summary).

7.4 Current risk profile

There are 45 environmental and technical risks related to mine closure at the time of writing this 2022 MCP.

The risks within each class are listed below, with additional information provided for the Class IV (Critical) risks: including causes, consequences, existing controls, control effectiveness, how the risk has been trending over time, and when the risk was last updated. This information is provided for all risk events within Appendix 7.1.

The number of risk events per class are:

- 5 Class IV (Critical) risks;
- 21 Class III (High) risks;
- 14 Class II (Moderate) risks; and
- 5 Class I (Low) risks.

7.4.1 Class IV (Critical) risks

There are five (5) Class IV (Critical) risks in the current risk register (see Appendix 7.1 for details). These are:

- Extraction of process water from Pit 3 takes longer than planned (ID No. 797894):
    - there are numerous potential causes for this risk event including: longer than modelled tailings consolidation, poor installation/performance of wick drains and/or under drain pump, delay in backfilling Pit 3, and inability to validate the modelling to stakeholder acceptance;
    - the consequences relate largely to additional cost and time for process water treatment;
    - the existing controls relate to specialist consultants being engaged to undertake the modelling and for this modelling to be independently reviewed;
    - the control effectiveness is rated ‘Satisfactory’ and the risk trend is ‘Stable’;
    - the risk was last updated on 7 July 2022.
- Failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu National Park (ID No. 597589):
    - potential causes for this risk event revolve largely around insufficient controls being implemented for vehicle hygiene (e.g. wash downs) and insufficient monitoring;

  - the consequences relate to the environmental and biodiversity impacts in the surrounding Kakadu National Park, and reputational and cost impacts to ERA;
  - the existing controls relate to clear vehicle hygiene procedures in place and successfully implemented, and dedicated resources managing the monitoring and treatment of the weed;
  - the control effectiveness is rated ‘Marginal’ and the risk trend is ‘Decreasing’;
  - the risk was last updated on 8 March 2022.
- Inadequate pond water storage availability (ID No. 597532):
  - potential causes for this risk event relate to extreme rainfall events, premature closure or management of water storage ponds;
  - the consequences relate to the unauthorised release of water to the environment, delay in closure activities due to flooding, reputational and cost impacts to ERA;
  - the existing controls relate to sound planning for water storages and the contingency plan to construct retention pond 7;
  - the control effectiveness is rated ‘Marginal’ and the risk trend is ‘Stable’;
  - the risk was last updated on 8 March 2022.
- Unable to inject brine into the Pit 3 underfill (ID No. 504876):
  - there are numerous potential causes for this risk event but they materially relate to blocked injection wells, and brine not filling the void spaces as expected;
  - the consequences relate to the need for additional injection wells, temporary storage of brine in RWD prior to injection increasing the total dissolved solids load in process water resulting in increased cost of treatment, increased cost and schedule;
  - the existing controls relate to the use of proven technologies by experienced practitioners in the form of directional drilling, the ability to access and clean-out injection wells drilled from the Pit 3 wall, and modelling of the underfill voids;
  - the control effectiveness is rated ‘Marginal’ and the risk trend is ‘Stable’;
  - the risk was last updated on 8 March 2022.
- Rainfall is greater than planned in the Water Model (P50) increasing the process water inventory to manage/treat, leading to later completion of process water treatment than planned (ID No. 504166):
  - potential causes for this risk event are extreme one-off rainfall events, particularly towards the later stages of closure;
  - the consequences relate to the need for additional storage and treatment of process water, increased cost and schedule;

  - the existing controls relate to sensitivity analysis included in the modelling and planning, sound planning for water storages and the contingency plan to construct retention pond 7;
  - the control effectiveness is rated ‘Satisfactory’ and the risk trend is ‘Stable’;
  - the risk was last updated on 8 March 2022.

7.4.2 Class III (High) risks

There are twenty-one (21) Class III (High) risks in the current risk register (see Appendix 7.1 for details). These are:

- Damage occurs to cultural heritage site during rehabilitation works;
- Perception amongst local community of downstream contamination from Ranger closure impacting ability to engage in traditional activities;
- Over time, climate change causes a significant shift to the expected environmental baseline of the RPA restricting ERA in meeting its environmental requirements;
- Large scale fire or natural disaster (e.g. cyclone) destroys immature vegetation;
- Planned active process water treatment tactics (i.e. plant capacity) do not meet the assumed productivities modelled for site inventory reduction;
- Solutes and sediments from surface runoff from final rehabilitated site enters off-site water bodies at greater than closure criteria;
- Groundwater solute transport outcomes are not as expected;
- Inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), leads to inadequate water treatment tactics;
- Process water exceeds MOL in Pit 3;
- Tailings consolidation is slower than expected;
- Slope failure in Pit 3 or stockpiles;
- Tailings Storage Facility wall breached during deconstruction works or while still in use;
- Elevated levels of contaminants (metals) in bush tucker;
- Unplanned contaminated materials found on RPA;
- Requirement for more extensive remediation / removal of contaminated plumes than planned;
- Insufficient volume or quality of trees from nursery for revegetation;
- Insufficient volume or quality of viable seed stock available for whole of site revegetation;
- Excessive erosion impacts landform stability and revegetation success;
- Uncertain terms of access to RPA from 9th January 2026, including Traditional Owner Access to significant areas;

- Closure of Ranger Mine impacts on local economics causing reputational damage; and
- Site condition does not meet Stakeholder expectations resulting in rework.

7.4.3 Class II (Moderate) risks

There are sixteen (16) Class II (Moderate) risks in the current risk register (see Appendix 7.1 for details). These are:

- Direct and indirect impact to cultural heritage sites during post closure – especially if signage/demarcation is decommissioned;
- Unable to extract expressed tailings pore water;
- Larger scale failure of the capping surface;
- Localised failure of the geotextile or capping surface;
- Erosion and gully formation across landform surface exposes contained tailings;
- Insufficient infrastructure and capability to manage offsite discharge of release water;
- Dust from rehabilitation works enters environment;
- Total above baseline radiation dose to plants and animals exceed UNSCEAR values;
- Radiation doses from the final landform exceeds dose constraint and annual dosage limit to the public, post closure;
- Sediment from surface water from rehabilitated landform impacts billabongs resulting in the need for subsequent remediation;
- Major native fauna does not return to landform;
- Feral (introduced) animals occur at higher densities than in surrounding Kakadu National Park;
- Low plant survival rates in the field during establishment and vegetation decline after/at establishment;
- Failure to consider closure impacts on downstream customers, hauliers or other communities.

7.4.4 Class I (Low) risks

There are five (5) Class I (Low) risks in the current risk register (see Appendix 7.1 for details). These are:

- Remnant mineralized material discovered in stockpiles after Pit 3 bulk backfill completed;
- Spillage of hazardous material during rehabilitation works in Pit 3;
- Loss of process water containment during Pit 3 activities;
- Disposal location for contaminated material not available following backfill of Pit 3;
- Increased aquatic weed establishment in RPA billabongs impacts Kakadu National Park.

7.5 Risk management

Considerable attention and work have been placed on the identification and management of closure risks for the Ranger Mine since 2008. ERA acknowledges that this work is not complete. It is continuing and subject to ongoing reviews and updates as more information becomes available from the KKN studies and from monitoring activities. ERA also plan to undertake another significant review of the environmental risks (including controls, planned activities and contingency measures) in 2023.

With specific regard to risk management, the current risk register provided in Appendix 7.1 shows that for the 45 risks:

- 351 existing controls are in place;
- the effectiveness of the control currently in place is identified for one (1) risk as 'weak', twelve (12) risks as 'marginal', nineteen (19) risks as 'satisfactory', ten (10) risks as 'good', and three (3) risks are currently unrated;
- two (2) risks have an 'increasing' risk trend (i.e. have worsened), thirty-nine (39) risks have a 'stable' trend (i.e. have not worsened or improved), and four (4) risks has a 'decreasing' trend (i.e. have improved);
- with regards to those risk events that are in a class that requires further management action (i.e. Class IV and Class III risks):
  - for the five (5) Class IV risks, 9 actions are currently being implemented;
  - for the twenty-one (21) Class III risks, 65 actions are currently being implemented.

REFERENCES

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Energy Resources of Australia Ltd (ERA) 2018*. HSEC Hazard Identification and Risk Management. ERA Standard ERS003*. Energy Resources of Australia Ltd, 12 July 2018.

Energy Resources of Australia (ERA), 2020. *Ranger Closure: Risk Management Plan.* Energy Resources of Australia Ltd, Darwin, Doc ID CDM.03-0000-MR-PLN-00001, 11 September 2020.

Rio Tinto 2019. Risk Management Standard. RIS-B-001

APPENDIX 7.1: RANGER CLOSURE RISK ASSESSMENT

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
797894	Extraction of process water from pit 3 takes longer than planned	Tailings consolidation takes longer than modelled. Poor installation of wick drains. Poor performance of under drain pump. Delay in back-filling Pit 3. Unable to measure consolidation at the tailings surface over time to reach the closure goal of 95% consolidation. Stakeholders do not agree that consolidation criteria has been achieved. Stakeholders do not accept the consolidation criteria is sufficient for the pumps to be turned off. Stakeholders do not accept groundwater modelling. Inability to validate consolidation model to required confidence.	Increased cost from additional process water treatment through the BC. Requirement for another process water treatment process to treat water post-BC. Infrastructure and access required to RPA. Schedule impact - demolition plan may not allow for plant.	Assurance of consolidation model being completed by stakeholders (2 independent reviews). [504190] Continued stakeholder engagement via ongoing presentations to stakeholders through MTC and RCCF. [1083233] CPT Testing to inform consolidation model and wick design. [504194] Ongoing monitoring and modelling of tailings during deposition phase. [602110] Pit 1 actual consolidation rates known and model adjusted to suit; ongoing monitoring. [504193] Pit 3 design is based on the learning of Pit 1. [602105] Placement of bulk backfill will be undertaken to lead to timely completion of consolidation. [602107] Prefabricated vertical drains (wicks) installed to maximise consolidation. [602106]	Satisfactory	Majority of controls are good but risk still critical, more actions and controls may be required. Actions will be revisited when Pit 3 capping works commence.	Stable	Class IV	Monitoring the success of existing decant towers, pumping systems, and the number and distribution of the settlement towers, which may also be equipped with pumps. Beyond the use of the settlement towers, risk contingency is installation of additional extraction and/or monitoring bores, following completion of capping and backfill works.	7/07/2022
597589	Failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu National Park	Weed has spread without ERA detection. Insufficient monitoring of area surrounding operational area. Insufficient controls in place around vehicle hygiene. Insufficient staff knowledge of weed / transmittance of weed.	Potential to impact close out certificate. Weed may be listed as a declared weed species, creating an increased obligation to manage. Impacts ERA's ability to demonstrate ability to manage rehabilitation. Loss of containment of the Spigelia weed to the operational area. Environmental and biodiversity impacts in surrounding areas. Eradication/ remediation of Spigelia detracts from other BAU tasks (i.e. other weeds).	Clear procedures around vehicle hygiene (e.g. washdowns) Dedicated resources to manage treatment [616678] External Stakeholder monitoring, managing and regular consultation [616681] Mini ipads for weed monitoring [936385] Monthly reporting to weeds Branch of Gov [597593] Polaris ATV used for weed management [607791] Regular monitoring and surveys of Spigela weed [597592] Weed Management Plan [597591] Weed specific training (exclusive to Spigela) [597594]	Marginal	Marginal until we know more from season change and what impact that may have on additional controls.	Decreasing	Class IV	Investigate the opportunity for partial coverage of Spigelia through final landform development.	8/03/2022
597532	Inadequate pond water storage availability.	Rehabilitation of catchment areas without direct release approval. Removing retention ponds. Delays in civil works. Significant rainfall event. RP6 conversion to process water Q1/2 2024. Closure sequence removes RP6 as a pond water store in 2024. Pit 3 backfill reduces capacity to deal with RP2 spillage. High volume/storage in RP2 and RP6. Limited capacity to treat pond water for release. Significant pond water catchment increase. Potential delayed conversion of Catchments to release water. Lack of contingency post 2024.	(Prior to 2023) RP2 spill into pit 3 converting pond water to process water. (Post 2023) RP2 spill into pit 3 delaying back fill (1-2 months, volume dependent). Unauthorized discharge of pond water to environment. Site inundation/localized flooding causing bulk material movement plan delays. Potential unauthorized release of water off-site. Limited environmental damage and significant reputational damage. Delay in closure activities due to flooding of these areas.	Continuous monitoring of pond water level and volumes [700068] Developing catchment conversion plan for BMM operations [1047332] OPSIM Water Balance model and forecast. [597533] RWMP001 Ranger Water Management Plan. [700052] Water model validated throughout operations [1047331] Weekly water treatment plant operational coordination meeting [1047329]	Marginal	Controls are not fully mitigating the threat until actions are complete.	Stable	Class IV	Develop detailed plan for catchment management (inc. catchment conversion). Develop a water management plan for bulked and final landform construction, and a post closure sediment management plan. Plan and execute wet season preparation activities for 2022-2023 wet season.	8/03/2022
504876	Unable to inject brine into underfill.	Scaling in pipelines associated with wells causes sufficient back pressure to prevent well operating (caused by scale and brine TSS). All 5 wells may block. Cold process water used to flush the pipe becomes blocked from detached scale. Floating Brine injection pipeline is kinked and stops/slows flow or is otherwise damaged. Blocking underfill around wellheads. Failure of underdrain bore or inability to reinstate bore. Delay in reinstatement of underdrain bore. Insufficient injection flow rate capacity. Brine does not fill void space as expected. Lack of operating data on brine injection due to in-operation of underdrain. Brine detected in underdrain. Insufficient brine void space. Groundwater drawn into under drain during operation of pumps. Failure of underdrain bore to relieve pressure within the underfill. Underfill in the vicinity of injection bore discharge (well heads) becomes blocked. Brine storage assumptions do not meet the storage requirements for site salt inventory. Errors in modelling of underfill void space. Lack of quality assurance (injection well permeability test not undertaken). Lack of quality assurance during underfill backfill activities (increased laterite material, increased compaction).	Brine recycling leads to increased Total Dissolved Solids (TDS) in process water, causing increased cost of treatment. Requirement for additional wells to be drilled. Significant additional maintenance costs. Additional cost for replacement under-drain pumping infrastructure. Significant capital cost associated with contingent brine disposal. Extended process water treatment duration (with risk of additional process water from rainfall). Installation of additional bores required to replace failed bores. Increased cost from alternative salt storage system. Increased schedule for alternate salt storage.	Ability to directionally drill additional steel-cased bores, with accessible headworks and positive-displacement pump injection capability. [504877] Ability to directionally drill additional steel-cased bores, with accessible headworks and positive-displacement pump injection capability. [1047292] Additional pipe available on-site to allow faster installation of replacement. [504880] Assurance Plan with production metrics developed. [504878] Conductivity meter on the under-drain water flow. [602390] Contingency plan for blocked well head [936477] Data gathering plan for performance of brine injection. [504882] Delivery lines (to manifold with original system, to headworks with replacement bores) able to be pigged and flushed. [1047291] Full pump replacement held on-site as critical spare. [504881] HDS plant incorporated into water model, removes salt from circuit. [602389] Once Pit 3 capping and backfill is complete, ability to vertically drill additional bores through capping and tailings into underfill [1047293] Pigging strategy. [504883] Underfill engineered with a 20% contingency for brine storage (based on 100% of process water treated via BC) [602387] Underfill volume review of as-built undertaken (Mark Goghill Nov. 2016) and determined contingency of 20% [602388] Water model capable of forecasting TDS. [504879]	Marginal	The replacement directionally drilled bores include several features, such as the ability to access the bore headworks for downhole cleaning and descaling, and the ability to deliver fluid to the bore under high pressure, which are expected to improve their lifetime relative to the original bores. A 'marginal' effectiveness of controls is in place because the controls will not ensure that each specific injection well is successful and additional bores are likely.	Stable	Class IV	Brine storage options study. Contingency plan for brine injection system development.	8/03/2022

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
504166	Rainfall is greater than planned in the Water Model (P50) increasing the process water inventory to manage/treat leading to later completion of process water treatment than planned.	Rainfall exceeds the P50 as modelled. Extreme "one off" rainfall event (particularly later in the closure schedule).	Additional process water treatment increases schedule beyond closure date - cost + legal/regulatory & reputational impacts. Increased cost from additional process water treatment through the BC. Increased cost from requirement to implement process water contingency (large scale HDS). Delay in rehabilitating the TSF/RP6 due to need to use for process water storage for longer. High water inventory in 2020-21 prevents TSF being cleaned as process water cannot all fit in Pit 3.	Industry established tool used (water model) with model assured. [504167] OBS upgrade for process water treatmenmt [936453] Process water volume tracked against water model prediction [602101] Regular Water Model update. [504171] Scenario of extreme weather event late in the closure schedule assessed during feasibility study and included in water management plans. [504174] Water inventory sensitivity to rainfall is well understood via model based on significant data base (>100 years of data). [504168] Water Model uses significant historical data records from local monitoring location. [504169]	Satisfactory	Controls are considered appropriate at this time - as rainfall has not exceeded average in the last two wet seasons.	Stable	Class IV	Complete a concept level study to determine a suitable location and design for RP7, including in TSF options as contingency. Confirm the P50 values that are to be taken into the Feasibility Reforecast.	8/03/2022
936478	Over time, climate change causes a significant shift to the expected environmental baseline of the RPA restricting ERA in meeting its environmental requirements.	Changing climate results in conditions unfavorable for target revegetation species. Temperature and excessive dry weather affects early survival of revegetation. Impacts to understory growth rates and survival. Increase in burning season and severity of fires. Increase in weed encroachment from the mine site into KNP as invasive species have a higher competitive advantage in changing climates. Increase in pests or diseases, such as myrtle rust, affecting vegetation on the rehabilitated site. Increase in number and intensity of storms/cyclones. Nutrient cycling changes due to impacts on soil biota. Higher temperatures coupled with longer drier periods. Increased evaporation leads to an increase in contaminants washed into onsite and receiving water during the first flush. Longer hotter dry periods could dry out billabongs and expose previously unexposed acid sulfate soils (ASS). Toxicity of contaminants will increase in higher temperature water. Increased erosion during storm events. Lack of information and knowledge regarding these subjects.	Selected vegetation communities to become unviable. Increased weed presence. Damage to vegetation. Increased hot fires, leading to increased tree mortality. Increased long term management and monitoring requirements. Increased cost associated with rectification works. Delay in project schedule. Delay in Mine Close Out Certification. Delayed relinquishment of areas. Unable to meet Environmental Requirements. Lack of agreement with stakeholders on defined, measurable criteria. Faunal decline due to fires and tree mortality impacts.	Current groundwater modelling incorporates considerations for climate change [936484] Early understorey growth and survival will be monitored and remediated as required during the management period. [936483] Irrigation strategy creates cyclone resistance (encourage deep root development). [1069939] Landform Evolution Model (LEM) has climate change scenarios and a synthetic rainfall data set for 10,000 years. [1092045] Monitor climate projections and ensure that new information is accounted for when selecting plant species for revegetation. [936482] Monitor performance of revegetation actions and make adjustments as required. [936481] Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [1092052] Ongoing review of climate risk assessment following IPCC updates. [1047337] Revegetation Adaptive Management Plan [1047336] Revegetation management plan draft. [1092066] Revegetation strategy designed to meet closure criteria for resilience (e.g. species mix, irrigation, weed monitoring) [1092069] State and Transition model for revegetation [1047335] Weed management plan [1092077] YFM001 Fire Management Plan [1092080]	Weak	There are still unknowns in climate change projections. Controls rely heavily on modelling.	Stable	Class III	Develop agreed scenario for climate change, with Stakeholders, so unknowns or reduced and appropriately considered. Revegetation Adaptive Management Plan to improve Revegetation Management Plan. Review climate risk assessment for Ranger in light of the 2022 IPCC report.	8/03/2022
694650	Elevated levels of contaminants (metals) in bush tucker.	Bioaccumulation of contaminants from surface water/sediments, and/or soils. Localised areas of higher uptake coinciding with higher harvesting rates. Metals mobilized by exposure of ASS (Acid Sulfate Soils).	Non-compliance with ER 3.1. Increased uptake of metals.	Alligator Rivers Region Technical Committee (ARRTC) process and key knowledge needs developed. [500616] Bush food consumption restrictions to particular areas of the RPA may apply post closure. [694655] Bush food monitoring program [1047356] Closure criteria working group [507828] Diet confirmed through consultation [1047354] Singular RP1 additional sediments investigation. [988328] Site specific concentrations factors (BRUCE database) [1047355] Site specific research undertaken against identified knowledge gaps. [499956] Stakeholder communication strategy and management e.g. Traditional Owners (TOs), Minesite Technical Committee (MTC), Alligator Rivers Region Advisory Committee (ARRAC), Alligators Rivers Region Technical Committee (ARRTC), technical working groups, community engagement. [693662] Stakeholder engagement. [518282] Water Pathways Risk Assessment to inform additional contamination knowledge gaps [988327]	Marginal	Further work ongoing.	Stable	Class III	Review diet assumptions and concentration factors for manganese - consider peer assessment. Determine an appropriate uranium environmental investigation level (EIL). Undertake additional sediment sampling at RP1 and Coonjimba billabong. Undertake aquatic vegetation investigation as a part of the Bushtucker Investigation & Assessment study. Undertake faunal bushtucker investigation as a part of the Bushtucker Investigation & Assessment study. Undertake flora assessment of on-site fruit as a part of the Bushtucker Investigation & Assessment study.	8/03/2022

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
505863	Damage occurs to cultural heritage site during rehabilitation works.	Vehicle movement in restricted areas. Non-conformance with the land disturbance permit process. Breach to the cultural heritage management system. Not all sites identified. Indirect impact from closure activities e.g. water run-off, erosion, sedimentation, changes to landforms. Not meeting agreed mitigation measures. Increased dust from closure activities. Suspended sediments binding to vegetation. Elevated major ions in shallow groundwater.	Breach of NT Heritage Act 2011 and Sacred Sites Act 1989. Reputation impacted. Cost of remediation. Fines. Civil/criminal action. Loss of trust. Solute and sedimentation affects cultural site of significance. Delay in schedule for final landform completion. Damage (real or perceived) to cultural site.	Aboriginal Areas Protection Authority (AAPA) certificate. [505865] Access restricted to sites through signage and / or fencing. [505868] Cultural Heritage Management Plan includes corrective actions for unplanned solute or sediment load at sacred site. [1045954] Cultural Heritage Management system including general induction and heritage induction, mitigation measures, incident process and additional security of sensitive sites [505864] Database of cultural heritage sites. [505867] Land Disturbance Permit system. [505866] Maintain multiple ERA representatives with relationships to specific stakeholders i.e. GAC [696045] Solute transport modelling to understand issue and design controls. [1045956]	Satisfactory	Controls are considered appropriate at this time.	Stable	Class III	Complete all actions from 2019 CH audit. Develop sediment and water quality control plan. Ensure that Feasibility Reforecast reflects the final landform design to address stakeholder recommendations. Land disturbance process to be reviewed against CH requirements and rehabilitation process. Undertake role review for the Cultural Heritage training matrix.	8/03/2022
505718	Slope failure in Pit 3 or stockpiles.	Unknown latent geotechnical conditions. Vehicle enters area of known instability. Rapid drawdown of water. Flood event over walls. Pressurization of existing weakness from excessive surface water outside the pit.	Engulfment, bogging, or rollover causing vehicle damage and/or injury. Schedule delay during investigation and rectification. Impact to additional works/ critical path.	Bi-annual geotechnical inspection, assessment and review of the slope stability in Pit 3 and stockpiles. [592105] Prism monitoring of Pit 3. [927855] Slope dump management plan updated annually through geotechnical consultant. [505719] Vehicle standards. [505721]	Satisfactory	New plan in place, control improving.	Stable	Class III	Conduct risk assessment for upcoming wicking works. Geotechnical investigation, assessment and review of the slope stability in Pit 3 and stockpiles.	8/03/2022
505249	Insufficient volume or quality of trees from nursery for revegetation.	Higher than expected mortality in the nursery due to disease, fire, theft. Under skilled and/or inexperienced propagators. Lack of viable seed. Technical issues in the nursery - e.g. procedures, equipment failures. Poor production rates. Poor nursery implementation planning. Low plant propagation success. Current nursery unable to support proposed production requirements. Site access post 2025. Highly congested schedule and peak planting demand in 2024-2025.	Delay to revegetation. Unable to get stakeholder acceptance. Reduced in floristic diversity and density. Delay in revegetation schedule. Revegetation does not support fauna diversity. Unable to meet cultural criteria.	20% allowance for infill. [505250] Alternative off site nursery available if required. [602401] CDM.03-0000-NH-PLN-00002 Ranger Closure Revegetation Plan (Final Landform). [694601] Disease control activities in nursery. [505254] Expert propagation knowledge and implementation provided by existing contractor. [602399] Interative allowances for unviable seeds per species is factored into seed collection requirements. [505251] Learnings from Pit 1 will be taken into remaining work - lead time for additional seeds & seedlings. [505256] Management of combustables in nursery area. [505253] Nursery secured. [505252] Planting and propogation trials successfully completed. [505255] Primary nursery (expansion) [829839] Primary nursery (fit for purpose). [693556] Primary nursery constructed on site [602400] Revegetation handover checklist [1092063]	Marginal	Margin for error has been addressed, iterative processes continually updating knowledge source.	Stable	Class III	Consider accelerating revegetation packages for LAAs and final landform. Ensure planting requirements are levelled as a part of the Feasibility Reforecast (FR). Incorporate stage 13 results into revegetaton plan. Investigate opportunity to open an offsite nursery within the Kakadu National Park. Consider recommencing the use of the old nursery.	8/03/2022
505238	Large scale fire or natural disaster (e.g. cyclone) destroys immature vegetation.	Wild fires from external sources. Wild fires from ongoing operational management practices. Lightning strikes. Inadequate weed management. Inadequate response capability. Extreme weather event - flood, wind, drought. Resilience factors are dependent on vegetation type and time (e.g. 5-15 years).	Reduction in floristic diversity and density. Re-sprouting from lignotubers post fire, delays the maturation of the final landform revegetation. Increased active management of revegetation. Low representation of fauna taxa. Increased weed densities. Increased erosion due to lower revegetation success across landform. Potential water quality impact from increased erosion. Large scale damage to new vegetation.	Deep rooting of trees [607821] Delayed introduction of high biomass grasses, reduces fire risk. [602392]	Satisfactory	Controls are considered appropriate at this time and studies are continuing to be progressed.	Stable	Class III	Develop weed hygiene package to address prevention and management of weed spread on the RPA. Integration of weed management plan.	8/03/2022
504648	Planned active process water treatment tactics (i.e. plant capacity) do not meet the assumed productivities modelled for site inventory reduction.	BC does not achieve planned production profile. Higher TDS impacts BC productivity. Implementation of Brine Squeezer upgrade delayed. Brine Squeezer does not perform as planned.	Additional process water treatment increases schedule beyond closure date - cost + legal/regulatory & reputational impacts. Delay in rehabilitating the TSF/RP6 due to need to use for process water storage for longer.	BC evaporator vessel scaling issue understood and addressed. [504649] BC fan upgrade completed. [504652] BC operation reached a sustained rate of 115% with no fan upgrade. [504651] BC seed cyclones upgraded. [504650] Regular review and update of the water model [1092057] Brine squeezer being implemented - schedule in Water Model. [504653] Performance guarantees from vendor for BC upgrade. [1093480] Sensitivity analysis on current water model complete. [504658]	Marginal	Further work ongoing.	Stable	Class III	Develop a compendium of past water treatment plans and current status. Develop Brine Concentrator Recovery Execution Plan. Develop/revise Asset Management Plan. Feasibility Reforecast to review planned performance of water treatment tactics. Installation of the Brine Squeezer upgrade.	8/03/2022

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
504641	Process water exceeds Maximum Operating Limit (MOL) in Pit 3.	Very high rainfall event. Additional tailings/material transferred from TSF to Pit 3. Additional tailings from mill. Notching of TSF reduces volume that can be stored in TSF. Seepage of process water from Pit 3 into the environment	Overflow of process water from Pit 3. Seepage of process water from Pit 3into the environment. Requirement to store water in TSF stops dredging operations.	Approved MOL based on surrounding head data to ensure Pit 3 remains a sink. [504642] Monitoring of water levels in Pit 3 [1047327] Pumps in pit 3 maintained through the wet season to allow pump back. [973177] Regular bathymetric surveys to determine process water inventory. [504644] Tailings quantities well understood - production data and Fugro survey. [504643] Significant capacity in the Ranger Water Dam (converted from TSF)	Marginal	Dependent on future rainfall.	Stable	Class III	Continue to monitor (risk trending down now RWD operational)	8/03/2022
504622	Solutes and sediments from surface runoff from final rehabilitated site enters off-site water bodies at greater than closure criteria. (surface water)	Poor quality water shedding from waste rock is released offsite. Uncontrolled erosion on the final landform (e.g. gullying). Water management structures undersized and/or unable to cope with extreme events. Poor quality water from legacy contaminated sites (LAA/contaminated sediments) enters offsite waterbodies at greater than predicted quantities/qualities. Exposed ASS releases contaminants to water column.	Sediments and/or solutes entering offsite environment at greater than closure criteria. Billabong sedimentation. Ecosystem damage. Closure criteria not met; no lease relinquishment. Levels of contamination in offsite drinking water exceed health guidelines. Elevated levels of contaminants (metals) in bush tucker.	Bathymetry and I-site scanning of billabongs [936473] Characterisation of LAA and billabong sediments (partially complete). [504627] Historic and ongoing studies into erosion. [504625] Landform flood study informs sedimentation controls design. [504624] Post-closure Management Plan. [504628] Ranger Conceptual Model (RCM) and solute transport modelling completed. [504623] Source term review. [936474] Surface water pathways risk assessment [936475] TSF solute transfer study completed by Intera. [504626]	Unrated		Increasing	Class III	Conduct study to review the confidence and suitability of TSS sensors. Consider reactive transport for Manganese, Ammonia, Uranium and Radium in Solute Transport Model.	29/04/2022
504602	Groundwater solute transport outcomes are not as expected.	Higher than estimated solute load from interred tailings in Pit 1 and Pit 3. Higher than estimated solute load from Brine injection into Pit 3 underfill. Higher than estimated solute load from Pit 1 and Pit 3 backfill methodology. TSF deconstruction plan (leaving contaminated material and plume in situ). Higher than estimated solute load from final land form. Tailings consolidation modelling underestimates pore water expressed. Failure of decant structures to remove expressed pore water. Incorrect assumptions of hydraulic properties. Incorrect Hydrolithological Units (HLUs). Incorrect assumptions of source concentrations. Higher than estimated solute load from leaving Mill plume and other contaminants in situ. Mineralised material excluded from Pit 3. Seepage rates from pit tailings/waste rock are higher than predicted. Early cessation of Active water treatment. Volumes of process water and pit tailings flux are not recovered and treated, as predicted. Tailings migrates into overlying waste rock layer.	Downstream environmental impact. Additional scope and cost required to address solute transfer. Ongoing long term water treatment required. Prosecution due to lack of Compliance. Reputation impacts. Impact to cultural heritage sites. Non-compliance with ER 3.1 & 11.3 (ii) (e.g. KNP values are compromised; Ramsar status is compromised, aquatic biodiversity of ARR is compromised). Water quality closure criteria isn't met. Potential toxicity to downstream aquatic biota. Bioaccumulation in bush tucker rendering it unfit for consumption.	Closure execution and post closure groundwater monitoring to inform model validation and updates. [1105980] Detailed assessment via Water Pathway Receptors Risk Assessment and Vulnerability Assessment Framework (VAF). [1105968] Groundwater and Surface Water interaction Study. [1105972] Monitoring of bores / site groundwater during closure to to track the performance of the model. [1105967] Non conservative assessments available for certain Constituents of Potential Concern (COPCs), including reactive transport and bioavailability modelling. [1105976] Ongoing engagement/peer review with stakeholders through presentation of water studies at RCCF and ARRTC forums. [1105979] Review source term for magnesium, manganese, ammonia, uranium and radium. [1105977] Short term deviations (approx. 5 years) can be handled by decant operations. [1105966] Significant database of site hydrogeological characteristics. [1105961] Tailings consolidation model updates to improve predictive capability of the model. [1105962] Uncertainty analysis of Intera Model. [1105960] Update of Solute Source Terms Conceptual Models. [1105981] Validation of ground water model through monitored real data informing the update of Ranger Conceptual Model and Groundwater Uncertainty Analysis. [1105978] Verified the tailings consolidation model from geotechnical and geophysical investigations. [1105963]	Satisfactory	Controls are considered appropriate at this time, however further contingency will be considered.	Stable	Class III	Review and verify tailings consolidation model. Consider reactive transport for Manganese, Ammonia, Uranium and Radium in Solute Transport Model.	19/08/2022
	Insufficient volume or quality of viable seed stock available for whole of site revegetation.	Changes in seasonality - e.g. dryer wet season leads to less flowering and fruiting. Size of areas to be revegetated concurrently, exceed stock capacity. Late seasonal fires impacts seed collection. Predation (birds). Local provenance area may still be too restrictive. Availability of contractor/labor force to meet demand. Limited seed harvesting capacity. Loss of seed in storage (fire, theft, disease, vermin, fungus, failure of air-conditioned) Loss of license to collect seed. Variable seed viability after collection. Inadequate land access. Inadequate resources for seed collection. Single contractor with seed collection permit. Direct seeding (if progressed) requires more seed. Stakeholder approvals not formally agreed (requirements may change in future). Non woodland domain species not in plan or considered by FS. Revegetation plan focused on seed not vegetative propagation.	Reduction in floristic diversity and density. Delay in revegetation schedule. Revegetation does not support fauna diversity. Reputation damage. Unable to meet cultural criteria for a sustainable food and medicinal source. Unable to meet closure criteria. Unable to meet 2026 date. Contracts being renegotiated with uncompetitive terms for ERA. Inability to meet stakeholder requirements or changing expectations.	Backup airconditioning in seed storage room. [504584] Current seed collection permit with Kakadu National Park with KNPS (expires 2023). [504576] Dedicated equipment for collecting grass seed [557230] Dedicated equipment for collection of seed i.e. EWP, brush harvester. [693553] ERA conducts annual and opportunistic seed collection on the Ranger Project Area (RPA). [504585] Main planting for shrubs and trees will be planted via tube-stock rather than direct seeding (significantly less seed required) [602122] MTO and schedule of seed requirements complete (including by species). [504586]		Overall effectiveness considered marginal. Stakeholder relationships are positive.			Ongoing review and update of Species Establishment and Research Plan to inform seed requirements.	

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
504574				Nursery expansion including seed storage facility. [504583] Ongoing collection and storage of seed stock by third party. [504575] Ongoing review and update of seed collection and propagation plan regarding seed viability (including storage, handling, duration of viability). [797817] Primary fit for purpose seed storage facility including climate control, security etc. [693557] Quality assurance process applied to see management (viability testing regime). [693559] Emergency management / security plans and fire protection in place for seed storage Seed collection and management procedures Secondary fit for purpose seed storage facility. [726843] Secure Contract in place with third party seed and plant provider [936388] Seed management database, collection schedule and metric to manage performance. [504578] Stakeholder agreed tree and shrub species list. [504580]	Marginal		Stable	Class III		8/03/2022
504475	Excessive erosion impacts landform stability and revegetation success.	Final landform not matched to rainfall characteristics. Insufficient sedimentation controls. Insufficient erosion controls. Tailings not fully consolidated. Rainfall is greater than anticipated (eg. Climate Change scenarios). Revegetation insufficient or ineffective in minimizing erosion.	Revegetation requires ongoing management. Extensive cracking and subsidence occurs over the landform leading to an increased maintenance regime. Stability issues occur along the developing gullies causing excessive erosion. Tailings or Low 2 material becomes exposed.	Access tracks designed to minimise erosion and/or not cause erosion. [602120] Compaction of waste rock on Pit 1/Stage 13 results incorporated into Material Movement Plan. [971916] Contour ripping in high erosion areas. [602119] Controls on Material Movement to ensure built landform matches design. [504478] Final designed landform does not contain slopes > 4%. [504480] Flood study informs erosion control design. [504482] Landform Evolution Model (LEM) has climate change scenarios and a synthetic rainfall data set for 10,000 years. [504477] Landform Evolution Model (LEM) model has informed both landform design, erosion controls and sediment traps. [504476] Monitoring of backfill during landform construction [1047338] Revegetation handover checklist [1092062] Revegetation plan updated with outcomes of Pit 1 and Stage 13 trails [1047339] Revegetation strategy tailored to landform elements (e.g slopes, gullies, etc). [602118] Ripping Management Plan. [971917] Scheduling of landform to decrease erosion output and landform design includes no gully formation over tailings. [971915] Traffic and logistics management plan [1047340] Updated consolidated model with Pit 1 validation from monitoring data and CPT testing. Ongoing updates. [504481] Validation of consolidation models. [504479]	Good	Number of controls in place, contingency addressed in ongoing monitoring and ongoing rectification works during post closure.	Stable	Class III	Develop detailed plan for catchment management (inc. catchment conversion). Develop a water management plan for bulked and final landform construction, and a post closure sediment management plan. Ensure components are in line with BMM schedule. Ensure revegetation strategy tailored to landform elements (e.g slopes, gullies, etc). Incorporate stage 13 results into revegetation plan. Update final landform to include concave slopes and first order drainage lines. Update MNP126 Specification for Design and Construction of Mine Roads Procedure to ensure erosion is highlighted. Update scarification/ripping plan to incorporate contour ripping in high erosion areas and pit 1 learnings.	8/03/2022
504409	Requirement for more extensive remediation / removal of contaminated plumes than planned.	TSF plume management plan to leave in situ not accepted by stakeholders. (Legacy commitment) Fuel farm plume mobility not fully understood. Stakeholders have not accepted no plume remediation as of yet. Inaccuracies in modelling.	Additional unplanned cost to treat plumes. Inability to meet closure schedule. Loss of trust with stakeholders.	Application of BPT processes [602095] Closure Contaminated sites management plan. [504381] Engagement underway with regulator on remediation plan. Contaminated sites management plan. [504421] Existing audits of LAA, wetland filters provide an accurate indication of potential scope and contamination level. [504420] Ground water monitoring program for mill and fuel farm has provided specific information. [504410] Initial TSF plume characterisation and impact assessment completed (Intera). [504412]	Good	Controls are considered appropriate at this time. Pending outcomes of the solute transport modelling.	Stable	Class III	Characterise contamination of wetland filters and billabongs. Conduct an Independent Assurance Audit on TSF deconstruction methodology (post-FR). Conduct stakeholder engagement and obtain stakeholder acceptance on plume remediation plan. Develop the TSF deconstruction methodology/plan. Ensure this risk is reviewed in detail under the Feasibility Reforecast. Following a risk based approach determine remediation required for PFAS contamination.	8/03/2022

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				Ranger conceptual model developed and accepted by stakeholders. (Confirms Mill plume can stay in situ, TSF plume needs further investigation) [504411] Surface water pathway risk assessment [936463]						
504385	Tailings Storage Facility wall breached during deconstruction works or while still in use.	Draw down rates within the facility cause instability and slumping of the walls. Wall demolition sequencing causes uncontrolled release of material. Seepage of water occurs through or under wall during water storage; potential for piping erosion leading to failure. Damage to wall rock armouring during tailings removal (dredge/machinery). Excessive erosion on dam walls. Over topping of dam leading to failure. Seismic event.	Significant compliance impact and legal prosecution. Reputation severely impacted. Clean up and remediation costs. Environmental impact. Schedule impact.	Additional monitoring and instrumentation for drawdown [602112] Advanced notice through bore monitoring. [504392] Compliance and auditing against compliance to RT D5 Standard. [504391] Dedicated dam engineer oversiting and approving all plans (Coffey). [504386] Downstream raise dam constructed with clay core [602113] Engineering supervision of construction works. [1092028] Independent review of all engineering. [504387] Interception trenches installed around west wall of the TSF. [504390] Maintain appropriate MOL. [504395] Modelling to understand impact [602114] Process safety CCMP's include TSF failure which references drawdown rates on facility. [504389] Process safety controls for dredging. [504393] Successful completion of Eastern wall notch. [504394] Technical review complete for use of TSF as a water storage facility. [504396]	Good	Risk decreasing in line with inventory. Technical oversite under D5 standard.	Decreasing	Class III	Conduct an Independent Assurance Audit on TSF deconstruction methodology (post-FR). Develop the TSF deconstruction methodology/plan.	18/05/2022
504373	Unplanned contaminated materials found on RPA.	Unknown asbestos materials. Unknown radioactive material. Unknown hydro-carbons plume. Unknown PCBs. Use of PFAS	Additional closure scope required to manage material, may impact achieving 2026 closure date. Cost overrun to manage contaminated materials. Reputational Damage	Asbestos Register available for consultation. [1101007] FS generated Contaminated Sites Management Plan. [989604] PFAS is no longer used on the RPA. [989600] Resources available to manage circumstance. [989602] RT PFAS specific E15 Guidance note. [989601]	Satisfactory	Controls are weighted towards PFAS.	Stable	Class III	Consultant undertaking PFAS Assessment.	8/03/2022
504367	Inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), leads to inadequate water treatment tactics.	Water Model does not directly duplicate real-world scenarios. Water Model assumptions are inaccurate (only includes assumptions not included in other risks). Inaccurate tailings density assumptions. Groundwater inflows to process water are greater than expected.	Process water inventory reduction does not meet the closure schedule. Longer than planned process water treatment increases schedule beyond closure date - cost + legal/regulatory & reputational impacts. Increased cost from additional process water treatment through the BC. Increased cost from requirement to implement process water contingency (large scale HDS). Delay in rehabilitating the TSF/RP6 due to need to use for process water storage for longer.	Consolidation model. [506949] Regular bathymetric surveys of free process water inventory used to validate model. [504368] Water Model validation (external assurance). [504369]	Satisfactory	Controls are considered appropriate at this time.	Decreasing	Class III	Assurance plan to be developed for water model for FR. Complete a concept level study to determine a suitable location and design for RP7, including in TSF options for contingency. FR to document, in an auditable form, the basis of water model, setting out the inputs, constraints and assumptions for water model. Stage and/or phasing plans to better detail catchments and simplifications for input into the water model.	29/04/2022
504188	Tailings consolidation is slower than expected.	Poor management of deposition of tailings causes segregation effects. Poor installation of wick drains. Poor performance of under drain pump. Delay in back-filling Pit 3. Tailings consolidation outcomes do not match modelling behavior. Inadequate characterisation of tailings properties. Delays to tailings transfer from the tailings dam. Stakeholders do not agree that 97% consolidation has been achieved and dewatering is required for longer. Stakeholders do not accept groundwater modelling. Inability to validate consolidation model to required confidence. Inaccurate consolidation model.	Process water treatment required beyond closure date to achieve 97% consolidation. Landform subsidence causes delays and impacts to the success of revegetation. Differential settlement of final landform. Solute transport different to predicted. Changes to waste rock volumes in Pit, resulting in changes to landform design. Increased cost from additional process water treatment through the BC. Requirement for another process water treatment process to treat water post-BC. Additional water treatment duration - treating for longer causing additional cost.	Assurance of completion of consolidation model to stakeholders (2 independent reviews). [1105989] CPTu, sampling and test work to inform consolidation model and wick design. [1105992] Norwegian Geotechnical Institute separate 2D consolidation model. [1105990] Ongoing presentations to stakeholders through MTC and RCCF platforms. [1105993] Pit 1 actual consolidation rates understood with adjustment to model ; ongoing monitoring. [1105991] Specialist consultant employed for consolidation modelling. [1105988]	Marginal	Further work ongoing.	Stable	Class III	Continue to monitor and update model as required.	19/08/2022
	Uncertain terms of access to RPA from 9th January 2026, including Traditional Owner Access to significant areas	ERA's current tenure of the Ranger Project Area expires in 2026 Atomic Energy Act amendment not passed New section 44 is not agreed beyond 2026. Terms of associated instruments is not yet agreed.	Disruption to the rehabilitation schedule. Varying rehabilitation requirements ERA forced to concede ground on the environmental obligations Stakeholders seek to impose access arrangements on onerous terms.	General agreement to proposed amendment (i.e. GAC, Traditional Owners, cross government, DISER) [1046045] Multiple mechanisms for stakeholder discussion (i.e. MTC, ARRTC, ARRAC, Relationship Committee). [1046048] Supportive letter from Minister received [1046046]		Conditions of access are determined by external parties.			Continued engagement with Commonwealth, GAC and NLC on term sheets for section 41, section 44 and mining agreement.	

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504069			 Impact to community confidence in ERA and associated reputational impact Negative media attention. Adverse impact to shareholders due to increase in schedule or forecasted costs Amendments to act and associated instruments could go beyond the existing legislative framework and impose new requirements on ERA and do not provide the necessary flexibility to meet future requirements.	Atomic Energy Eact amendment bill	Marginal		Stable	Class III		8/03/2022
504047	Closure of Ranger Mine impacts on local economics causing reputational damage.	Removal of subsidies. Removal of services. Cessation of royalties. Lack of consultation. Lack of understanding of timeline of closure. Lack of understanding of impact on population of Ranger closure. No future plan for the region by government.	Businesses become unviable. Social dislocation. Loss of leasehold to operate business. GAC reduced income. Reputational impact.	Engagement with stakeholders on future state. [504049] SIA (social impact assessment) [504048] Stakeholder Engagement and Communications Plan [1033370]	Satisfactory	Controls adequate at this time.	Stable	Class III	Complete SIA review and communicate any changes to the relevant stakeholders. Continue local employment programs to build a future employable workforce.	8/03/2022
503403	Perception amongst local community of downstream contamination from Ranger closure impacting ability to engage in traditional activities. Includes radiation, contamination.	Poor/lack of communication with stakeholders. Historical incidents and lack of trust.	Traditional Owners not able to collect bush foods and/or interact with country for cultural practices. Damage to relationship with key stakeholders. Loss of community trust.	ARRAC meeting discussed and presented by DITT and SSB. [1101057] Community and Stakeholder Engagement plan. [1092018] Cultural reconnection steering committee [1046097] Management Actions included in the Communities and Stakeholder Engagement Plan. [1069955] Relationship committee meetings. [503405] Water monitoring program. External Relations team is on mailing list for enviro water monitoring to proactively manage media. [503404]	Good	Controls adequate at this time.	Stable	Class III	Develop and implement internal communications to address perceptions on Ranger Mine's potential impact to the environment. Include water quality model in 3D landform model. Undertake aquatic vegetation investigation as a part of the Bushtucker Investigation & Assessment study. Undertake faunal bushtucker investigation as a part of the Bushtucker Investigation & Assessment study. Undertake flora assessment of on-site fruit as a part of the Bushtucker Investigation & Assessment study.	8/03/2022
500614	Site condition does not meet Stakeholder expectations resulting in rework.	Previous commitments made are not embedded within scope. Insufficient stakeholder engagement or consultation. Insufficient scientific basis to support closure criteria. Inconsistent expectations from different stakeholders. Misalignment SSB closure elements viewed as not meeting "Best Practicable Technology" (BPT). Poor environment performance onsite. Closure Studies and the outcomes presented in reports, undertaken by relevant experts are complex and difficult to communicate to stakeholders. Significant changes to pre-communicated/approved closure strategy. The community may be concerned about what infrastructure is retained or lost as a result of the closure. Community expectations for the retained infrastructure are different to that remaining. Misunderstanding of the Authorisation by the community. RPA perceived to be contaminated. Perception of ERA failing to comply with UN conventions, for instance those relating to Tradition Owners/ World Heritage Sites. Broad definition in the legislation interpreted differently by authorities. Landform may block the view of Mt Brockman.	Traditional owners do not return to country. Landform does not meet the values (e.g. land uses) that are expected from the Traditional Owners. Community dissatisfied with final land-form. Inability to obtain final closeout. Regulator agrees with stakeholders causing additional unplanned scope and cost to meet uncertain or changing closure criteria. Additional scope added late in schedule leads to inability to meet closure schedule milestones. Extended care and maintenance phase (possibly in perpetuity). Inability to gain closure certificate and relinquish RPA. May result in prosecution action from not adhering to requirements of Authorisation. Increased liability post-2026. ERA is not be released from the legal responsibilities.	Site specific recognised scientific research undertaken against identified knowledge gaps. [500615] 3D printed physical model of final landform used to demonstrate final landform topography. [693665] Alligator Rivers Region Technical Committee (ARRTC) process and Key Knowledge Needs developed. [1092006] Application of BPT processes [1092007] BPT and approvals process. [500625] Agreed closure criteria Closure Plan updates to incorporate stakeholder recommendations [500630] Communication fora (e.g. ARRTC, ARRAC,MTC,stakeholder workshops). [1092016] Continued stakeholder engagement via ongoing presentations to stakeholders through MTC and RCCF. [504195] Early engagement with stakeholders [602094] GIS study undertaken to model the potential view lines which has been approved by stakeholders. [602100, 693666] Iterations of the Mine Closure Plan with updated closure criteria are submitted to Minister for approval annually. [936465] Landform design cultural closure criteria. [693663] Physical site visits undertaken by stakeholders i.e. Pit 1, Trial landform [936464] Rehabilitation Animation [608175] Socio-economic impact assessment [602098] Stakeholder communication strategy and management e.g. Traditional Owners (TOs), Minesite Technical Committee (MTC), Alligator Rivers Region Advisory Committee (ARRAC), Alligators Rivers Region Technical Committee (ARRTC), technical working groups, community engagement. [1092073] Stakeholder engagement has occurred to understand their needs and the ability to meet these needs [602099] Stakeholder Engagement Plan developed. [500621] Tiered assessment framework. [500628] Trial landform established and results transparent to TO's. Jabiluka rehabilitation provides precedent. [500622]	Satisfactory	Overall progress across raft of controls is reasonable.	Stable	Class III	Continue to engage with TOs on site conditions post closure. Investigate opportunities to demonstrate the construction of a stable landform to stakeholders.	13/05/2022

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1106000	Dust from rehabilitation works enters environment.	Dry surface plus prevailing winds transports dust from surface (TSF learnings). Trucking and dumping of waste rock during BMM.	Dust deposition into Magela Creek. Breaches of license conditions. Reputational impact.	Significant corporate knowledge and experience. [1106005] Water carts for dust suppression. [1106004] Air quality assessment completed [604171]	Unrated	Not officially rated but well understood	Stable	Class II		19/08/2022
1064162	Sediment from surface water from rehabilitated landform impacts billabongs resulting in the need for subsequent remediation.	Inappropriate release of water. Downstream closure criteria do not protect upstream billabongs on RPA.	Additional cost and schedule delay associated with billabong remediation. Stakeholder concerns should smothering of aquatic plant species occur due to sediment (cultural bush tucker aspect).	RWMP001 Ranger Water Management Plan includes release water quality monitoring and is approved by external stakeholders . [1064178] Stakeholder approved Closure Criteria. [1064174] Turbidity monitoring in onsite billabongs for early indication. [1064176]	Satisfactory	On site and offsite monitoring in place that should provide an early indication of the need for potential remediation (if necessary).	Stable	Class II	Catchment conversion planning to incorporate modelling of sediment leaving the landform to sediment found in the creek. Develop detailed plan for catchment management (inc. catchment conversion). Develop a water management plan for bulked and final landform construction, and a post closure sediment management plan.	8/03/2022
1049198	Unable to extract expressed tailings pore water.	Decant towers not located in the lowest point of the tailings. Decant towers collapse or otherwise fail.	Increased solute load to environment. Solute transport outcomes are not as expected and unable to attain license.	Ability to drill bores post capping completion to target new areas/replace failed towers. [1049209] Ability to monitor tailings surface using settlement towers. [1049205] Ability to monitor water quality across the pit using settlement towers. [1049204] Ability to use settlement towers for decanting. [1049208] Multiple decant towers. [1049203]	Good	Design in place. Contingency known. Monitoring controls not yet embedded.	Stable	Class II		13/05/2022
868244	Larger scale failure of the capping surface.	Areas of large differential settlement.	Tailings heave, potentially resulting in tailing being above maximum level. Delays to installation of secondary capping.	Factors of safety in capping design. [1049190] Settlement column monitoring of tailings surface. [1049193] Surveys of top of capping surface. [1049191]	Marginal	Continued monitoring of Pit 1 surface will increase comfort in control effectiveness	Stable	Class II		8/03/2022
868243	Localised failure of the geotextile or capping surface.	Uneven tailings surface. Areas of large differential settlement. Inexperienced contractor. Poor geotextile/capping material choice or quality. Weaker tailings than expected. Utilization of inappropriate capping methodology. Inadequate testing of capping strength. Errors in understanding of tailings properties. Errors in understanding of deposition history.	Health and Safety impacts (e.g. heavy equipment sinking, injury to personnel). Delays to subsequent capping activities. Localised tailings boils.	Access to the initial capping to be restricted and addressed in the traffic management plan for implementation. [1049176] Comprehensive geotechnical testing regime to determine timing of placement of secondary capping over initial capping. [1049179] Comprehensive geotechnical testing undertaken before placement of secondary capping. [1049177] CPT testing during and after tailings deposition to provide tailings properties. [1049178] Engagement of a design consultant. [1049180] Field supervision. [1049181] Peer review by geotechnical expert on geotechnical design. [1049182] Review and verification of tailings consolidation model. [1106635] Technical assurance of final Geotech design. [1049183]	Satisfactory	Controls considered suitable	Stable	Class II		8/03/2022
730288	Failure to consider closure impacts on downstream customers, hauliers or other communities	The transition from operations to closure combined with the peaking demand in individual closure packages results in varying demand on ERA suppliers. Lack of transparency with suppliers leads to poor business planning.	Financial instability for businesses. Reputational impact. 	CDM.03-0000-PL-PLN-00003 Procurement and Contracts Management Plan [508037] CDM.03-0000-PL-SCH-00001 Ranger Closure Contract and Procurement Schedule [1092013]	Satisfactory	Controls considered suitable	Stable	Class II		8/03/2022
694661	Total above baseline radiation dose to plants and animals exceed UNSCEAR values.	Dust transported to local soils (terrestrial). Waste rock on final landform (terrestrial). Land application area (terrestrial). Run-off from the landform to creeks (aquatic). Controlled water releases to creeks (aquatic) during stabilisation phase. Groundwater contaminants expressed to surface water (aquatic).	Increase in radionuclide concentrations in soil affecting terrestrial biota. Increase in radionuclide concentrations in water and/or billabong sediments affecting aquatic biota.	Dust control during decommissioning. [1092025] Erosion structures are incorporated into landform design - e.g. ripping and armouring where required. [1092029] Establishment of vegetative surfaces to reduce erosion. [1092031] Iterative/adaptive landform design based on landform stability modelling. [1092043] Material movement planning and stockpile resource model to identify location of 1s and 2s rock. [1047361] Only 1s waste rock used for final landform [1092054] Radiological dose assessment [1046061] Stormwater and erosion control, design and management structures. [1092076]	Satisfactory	Controls are considered satisfactory at this time.	Stable	Class II		8/03/2022
694625	Feral animals occur at higher densities than in surrounding KNP.	Lack of management. Open disturbed area. Weed infestation.	RPA becomes a source of feral animals to KNP. Impacts natural recruitment of fauna. Impacts revegetation success. Spreads weeds. Impact to waterways (eg buffalo).	Active feral animal management aligned with current operational practices. [694626] Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [602396]	Satisfactory	Solid management practices are in place.	Stable	Class II		8/03/2022
694597	Major native fauna does not return to landform.	Fire damage to habitat. Competition from feral animals and weeds. Acutely toxic onsite waterbodies. No appropriate habitat types preventing adequate shelter food and/or breeding opportunity. Insufficient diversity and abundance of flora and fauna to meet defined trajectories. Changes in biodiversity survey techniques. Lack of artificial habitat to encourage fauna. Natural disturbance events i.e. pests,	Reduced representation in functional groups. Unable to meet cultural criteria for a sustainable food and medicinal source. No fertilization of some animal pollinated flora groups. Lack of sustainability of established ecosystems. Breach of authorization conditions leading to significant reputation damage (social license to operate). Additional cost of rehabilitation	CDM.03-0000-NH-PLN-00002 Ranger Closure Revegetation Plan (Final Landform). [1092010] Creation of faunal habitats on the landform, including nesting boxes [694620] Eventual removal of site fence (physical barriers) allowing egress on to site. [694619] Implementation of rocky habitat areas. [694617] Ongoing discussion held through Cultural Reconnection Steering Committee. [1049167]	Satisfactory	Controls are effective at this time.	Stable	Class II	Complete fauna, habitat nestbox trials and undertake fauna monitoring trials.	8/03/2022

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		cyclones. Poor recruitment of key flora species.	of deviated states and maintaining artificial habitats for up to 200 years.	Specific cultural closure criteria agreed with stakeholders. [1049165] Specific fauna closure criteria agreed with stakeholders [936400] Weed Management Plan [1092079] YFM001 Fire Management Plan [694615]						
693671	Erosion and gully formation across landform surface exposes contained tailings.	Rainfall is greater than anticipated (eg Climate Change scenarios) Failure of proposed erosion controls. Erosion rates do not match modelled Final landform not constructed to design	Non-compliance with ER 2.1, ER 5 and ER 11.3(i). Potentially increases solute transport on/off site. Potentially increases radiation dose to members of the public. Limits access by traditional owners to post decommissioning site.	Design of Pit backfill has tailings low in the Pit with thick waste rock cap. [693681] Erosion structures are incorporated into landform design. [693677] Establishment of vegetative surfaces to reduce erosion. [693676] Implementation of a QA program for landform construction and erosion controls. [693679] Iterative/adaptive landform design based on landform stability modelling. [693675] Landform designed with drainage channels diverted away from in Pit tailings. [693683] Ongoing maintenance of erosion structures and mitigation of gully formation, post decommissioning. [693678] Hazardous Materials Management Plan. [505828]	Satisfactory	Controls are considered satisfactory at this time.	Stable	Class II		8/03/2022
597545	Insufficient infrastructure and capability to manage offsite discharge of release water.	Lack of maintenance and replacement of pumping infrastructure (pumps, generators etc). Loss of LAA's. Inability to build and commission turbomisters in time. Inappropriate pump capacity for catchments. Poor management of constructed wetlands.	Breach of authorisation conditions leading to significant reputation damage (social license to operate). Cost of replacement if maintenance is not continued. Localised erosion and flooding. Increased pond water inventory due to mismanagement of wetland filter.	Completion and submission of the annual groundwater management plan [1057828] Water management inspections [597551] Engineering assessment of new catchments [597550] Regular assessment of groundwater conditions [597548] Turbomisters [597549] Water Infrastructure Maintenance Plan [597547]	Satisfactory	Controls are mature.	Stable	Class II		8/03/2022
506028	Direct and indirect impact to cultural heritage sites during post closure - especially if signage /demarcation is decommissioned.	Inappropriate access on RPA by contractors Remediation works carried out without consideration of cultural heritage (process not followed)	Breach of NT Heritage Act and Sacred Sites Act. Reputation impacted. Cost of remediation. Fines. Civil/criminal action. Loss of trust.	AAPA certificate [506030] Land disturbance process [506031]	Marginal	Could include further stakeholder engagement to finalise handover expectations post closure.	Stable	Class II	Continue to build cultural heritage capacity with Djurrubu Rangers. Triannual Cultural Heritage audit. Identify protection measures to remain in place based on post-rehab monitoring plan. Update the management plan with information from Triannual Cultural Heritage audit outcomes.	8/03/2022
506000	Radiation doses from the final landform exceeds dose constraint and annual dosage limit to the public, post closure.	Mineralised material left on surface (gamma, dust and radon). Exposed tailings. Solutes expressed to surface water and mobilised. Elevated levels of contaminants (metals) in bush tucker.	Non-compliance with ER 5. Increased dose to public.	Air quality assessment completed [604171] Data from trial landform studies has informed the landform design and LEM. [506007] Dust control during decommissioning. [506002] Engineering dose constraint of 300 µSv per year will be applied. [1046078] Final landform thickness reduces the likelihood of exposing tailings and radon emanation from tailings. [506003] Only 1s waste rock used for final landform [506001] Stormwater and erosion control, design and management structures. [506005] Surface Water Model [1046079]	Satisfactory	Controls are considered adequate at this time.	Increasing	Class II	Bush tucker monitoring assessment. Radiological dose assessment. Undertake aquatic vegetation investigation as a part of the Bushtucker Investigation & Assessment study. Undertake faunal bushtucker investigation as a part of the Bushtucker Investigation & Assessment study. Undertake flora assessment of on-site fruit as a part of the Bushtucker Investigation & Assessment study.	8/03/2022
504500	Low plant survival rates in the field during establishment and vegetation decline after/at establishment.	Low plant available water in waste rock substrate. Competition from weedy species. Seasonal availability of landform is not optimum for planting. Plant disease or poor health in nursery stock e.g. disease or root:shoot ratio. Lack of nutrient cycling. Lack of local accumulation of litters and fines (sediments). Fauna grazing on tube stock/seedlings. Elevated magnesium sulfate concentrations in groundwater. Inadequate irrigation during first few days and weeks following planting.	Species composition, abundance and richness does not meet closure criteria. Delay in revegetation schedule or resources taken from primary planting to support additional infill planting requirements. Revegetation does not support fauna diversity. Unable to meet cultural criteria for a sustainable food and medicinal source. Increased mortality rate.	Compliance with National Standard for Nursery Management [504510] Construction of landform using various techniques to make sure particle size distribution is to design and paddock dumping to get better compaction. [504504] Criteria established with stakeholders on species and seed gathering area. [1092021] Future studies to close out KKN's scoped. [499996] Irrigation for first 6 months post-planting. [504508] NESP study into magnesium sulfate concentration in ground water impacting vegetation. [936399] Nutrient Cycling Study [936394] Ongoing improvement of nursery practices including seed preparation, potting mix, irrigation, fertilizing and other treatments. [971911] Optimize seedling age and root-shoot ratio at time of planting to reduce water stress. [971912] Plant available water modeling predictions indicate sufficient walter holding capacity of wase rock to support vegetation [504503] Revegetation handover checklist [1092064] Revegetation management plan. [1092065] Stockpile drilling to inform perched water table [936398]	Good	Recent survival rates for Stage 13 were very high (90-95%), indicating current controls good.	Decreasing	Class II	Complete study / trial on understorey development on waste rock (CDU and ERA studies). Incorporate stage 13 results into revegetaton plan. Update revegetation plan following experience from Pit 1.	13/05/2022

Risk ID	Risk Description	Causes	Consequences	Existing Controls	Overall Control Effectiveness	Overall Control Effectiveness Rationale	Risk Trend	Risk Class	Actions (beyond the ongoing and successful implementation of existing controls)	Risk Last Updated
				Sub-surface compaction layers increase water holding capacity of waste rock [504513] Trial landforms completed to demonstrate viability of vegetation in waste rock. [504501] Understanding mortality rates contributing factors [936397] Use of biodegradable pots. [504507] Water crystal use for seedlings planted during monsoon without irrigation. [971913] Watering of plants (irrigation) in early stages but not long term. [504505]						
1106647	Remnant mineralised material discovered in stockpiles after Pit 3 bulk backfill completed.	Mineralised material not identified by previous stockpile drilling/assessment. Material movement plan not followed.	Mineralised material ends up in shallower part of final landform.	Availability of RP2 for mineralised material. [1106652] Material movement plan based on available stockpile grade information. [1106649]	Good		Stable	Class I		19/08/2022
1106596	Spillage of hazardous material during rehabilitation works in Pit 3.	Transportation of hazardous material. Deconstruction works. Failure of storage vessel.	Local environmental impact.	Existing operational environmental and hazardous substances management controls. [1106599]	Good	Mature controls in place.	Stable	Class I		19/08/2022
1106578	Loss of process water containment during Pit 3 activities.	Ruptures of pipelines. General spillages from vehicles/equipment. Hydrocarbon spill. Tank and/or bund overflow. Mechanical damage to pipeline by contact by vehicle or other object.	Local (environmental) impact. Offsite impact not envisaged.	Existing hydrocarbon spill response. [1106580] Process safety system. [1106581] Termite spraying program. [1106582] Testing and inspection of pipelines. [1106579]	Good		Stable	Class I		19/08/2022
1106008	Disposal location for contaminated material not available following backfill of Pit 3.	Pit 3 no longer available for disposal of contaminated material (water treatment plants, heavy mobile equipment (HME), construction facilities). Inability to agree upon location with stakeholders. Water treatment infrastructure is required post backfill of Pit 3.	Schedule overruns. Cost overruns. Potential offsite disposal (higher cost).	Closure schedule. [1106011] Decontaminate and transport materials off-site. [1106012] Retention Pond 2 (RP2) planned for Phase 2 demolition material. [1106013]	Good	Contingency planned and available.	Stable	Class I		19/08/2022
694628	Increased aquatic weed establishment in RPA billabongs impacts KNP	Transfer from surrounding environment, vehicles, transient fauna. Transport of weeds from surrounding KNP.	Decrease in downstream aquatic biodiversity / habitat leading to Ramsar status and aquatic biodiversity of ARR being compromised.	Early warning monitoring and subsequent adaptive management. [694635] Weed Management Plan [1092078]	Unrated		Stable	Class I		8/03/2022

8 Post-mining land use, closure objectives and closure criteria

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GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Benchmark dose rate	Also referred to as environmental reference level, a chronic radiation dose rate received by the most highly exposed individuals of non-human biota that would be unlikely to have significant effects on terrestrial or aquatic populations.
Bininj	Bininj means many things depending on context: 1. Bininj means 'Aboriginal person' as opposed to a non-Aboriginal person. 2. Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent (as opposed to say, a Yolngu person from north eastern Arnhem Land or 'Mungguy' which is the Jawoyn language equivalent). 3. Bininj means a man as opposed to a daluk (a woman). 4. Bininj means a human being as opposed to a non-human animal. In the context of the mine closure Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent.
Closure criteria	Performance criteria that will be used to measure the achievement of the rehabilitation closure objectives.
Constituents of potential concern	Chemical elements identified through scientific studies as being of potential concern to the receiving environment.
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary 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.
Ranger Project Area	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976.*

ABBREVIATIONS AND ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
BPT	Best Practicable Technology
CCWG	Closure Criteria Working Group
COPC/COPCs	Constituent of Potential Concern / Constituents of Potential Concern
DEM	Digital Elevation Model
ER	Environmental Requirement(s)
ERA	Energy Resources of Australia
ERISS	Environmental Research Institute of the Supervising Scientist
GAC	Gundjeihmi Aboriginal Corporation
GV	Guideline Values
IAEA	International Atomic Energy Agency
ICRP	International Commission of Radiological Protection
KKN	Key Knowledge Needs
LAA	Land Application Area
LEM	Landform Evolution Model
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
NEPM	National Environment Protection Measure
NLC	Northern Land Council
NOHSC	National Occupational Health and Safety Commission
NP	National Park
RDP	Radon Decay Product(s)
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
SSB	Supervising Scientist Branch
TBC	To be confirmed
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
W/SQO	Water or Sediment Quality Objectives

Abbreviation/ Acronym	Description
WoNS	Weeds of National Significance
WQMF	Water Quality Management Framework

8 POST-MINING LAND USE, CLOSURE OBJECTIVES AND CLOSURE CRITERIA

8.1 Post-mining land use

An understanding of the post-mining land use allows for the development of specific closure objectives, which are used in the development and formalisation of closure criteria. In accordance with industry guidance (DMIRS 2020), the proposed post-mining land use for the Ranger Mine is to be:

- relevant to the wider regional environment;
- achievable in the context of post-mining land capability;
- acceptable to Energy Resources of Australia (ERA) stakeholders; and
- ecologically sustainable in the context of the local and regional environment.

The Environmental Requirements (ERs) (*Section 3 Closure Obligations and Commitments*) specify that the Ranger Project Area (RPA) must be rehabilitated:

> *…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.*

It is noted that any decision on the actual incorporation of the RPA into Kakadu National Park (Kakadu NP) will be made by the relevant authority and may not eventuate until sometime after closure, if at all.

Thus, the predetermined post-mining land use of the rehabilitated RPA is the 'potential incorporation into the Kakadu NP'. To meet this land use, the closure of the Ranger Mine is required to meet a number of closure objectives, which are discussed below (Section 8.2).

Whether the RPA is incorporated into Kakadu NP or not, the rehabilitated site will most likely be utilised for both recreational and cultural use by the local Aboriginal people. ERA has a long history of engagement with the Mirarr people through consultation with the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC). In 2014, ERA formalised the engagement regarding post-mining land use and closure criteria through extensive consultation with Traditional Owners via the consulting linguist and anthropologist Murray Garde (Garde, 2015). This report was summarised by Paulka (2016) and refined for habitation, use of traditional plants and animals, and the assumed post closure bush food diet.

8.1.1 Future occupancy intentions

Consultation with Bininj, Aboriginal people of the West Arnhem region, including the Mirrar, has established there is an enthusiastic intention to continue visitation post-rehabilitation on the condition that Bininj are satisfied that the area is safe to enter and occupy (Garde, 2015). Over the past 35 years there have been restrictions on visitation to this significant area of the Mirarr clan's estate and people are keen to reconnect with the country and the places of cultural significance to them. Intended visitation can be grouped into the following purposes:

- hunting, fishing, bush food gathering;
- recreation;
- land management activities; and
- cultural site visitation, ritual responsibilities.

The following sections outline the intentions to occupy or visit the rehabilitated RPA in terms of average number of days per person per year. These are estimates based on consultations with Bininj combined with knowledge about current occupation patterns for each of the four visitation purposes. It is highly likely that these four categories will not be discrete or mutually exclusive. For example, hunting may occur during visits originally associated with a different purpose (e.g. a monitoring or management visit).

Based on this information ERA has estimated occupancies at various locations to enable the calculation of radiation doses post closure and the development of appropriate closure criteria. A summary of the estimated occupancy times for the various activities are provided in Table 8-1 with an estimate of the typical locations expected to be occupied shown in Figure 8-1.

The table of estimated occupancies contains the original Garde (2015) estimated days per activity and a breakdown over various locations. The table also provides an estimate of percentage of time for each location and an estimate of hours per year.

As can be seen in both the figure and table, the majority of area estimated to be occupied will be in the Magela riparian zones. With the exception of land management and monitoring, Garde (2015) details that occupancies will be centred on the Magela creek and site billabongs (Georgetown and Coonjimba). It is expected that hunting and gathering (and to a lesser extent other activities) will also extend into the previously disturbed water management areas, including the old Retention Pond 1 (RP1) area, Land Application Areas (LAAs) and Corridor Creek. As the landform evolves into a self-sustaining ecosystem, vegetated drainage lines will reform and fauna will reinhabit the landform. It is estimated that occupancy at these locations, mainly in the form of hunting and food gathering, will occur (Figure 8-1). It is likely that infrequent hunting will occur on the remainder of the landform, however this has been estimated to be minimal. The fauna detailed by Garde (2015) are either aquatic based or likely to gather in the riparian areas around water and food sources.

Table 8-1: Estimates of occupancy periods at various locations on the rehabilitated RPA

Purpose of visit	Estimated time[1]	Location	%	Estimated hours per year
Hunting and food gathering (day trips)	30 days per person per year[2]	Magela riparian zones (undisturbed)	70	126
		LAA, RP1, water management areas and site billabongs	20	36
		Landform waste rock	10	18
Seasonal camping (extended camping)	20 days per person per year[3]	Magela riparian zones (undisturbed	75	360
		Site billabongs	20	96
		LAA, RP1 and water management areas	3	14
		Landform waste rock	2	10
Recreation	10 days per person per year[3]	Magela riparian zones (undisturbed)	90	216
		Site billabongs	7	17
		LAA, RP1 and water management areas	2	5
		Landform waste rock	1	2
Land management and monitoring	10 days per person per year[4]	Site billabongs	25	20
		LAA, RP1 and water management areas	25	20
		Landform waste rock	50	40
Ritual	5 days per year[5]	Magela riparian zones (undisturbed)	90	54
		Site billabongs	5	3
		LAA, RP1 and water management areas	5	3

1 – Estimated time from Garde 2015
2 – A 6 hour day has been assumed (Garde estimated both half and full day trips)
3 – Full 24 hour day assumed (conservatively assume camping overnight for bush walks)
4 – Land management assumed to be conducted on an 8 hour day
5 – Rituals assumed to last for 12 hours on average (some may be overnight, some very short)

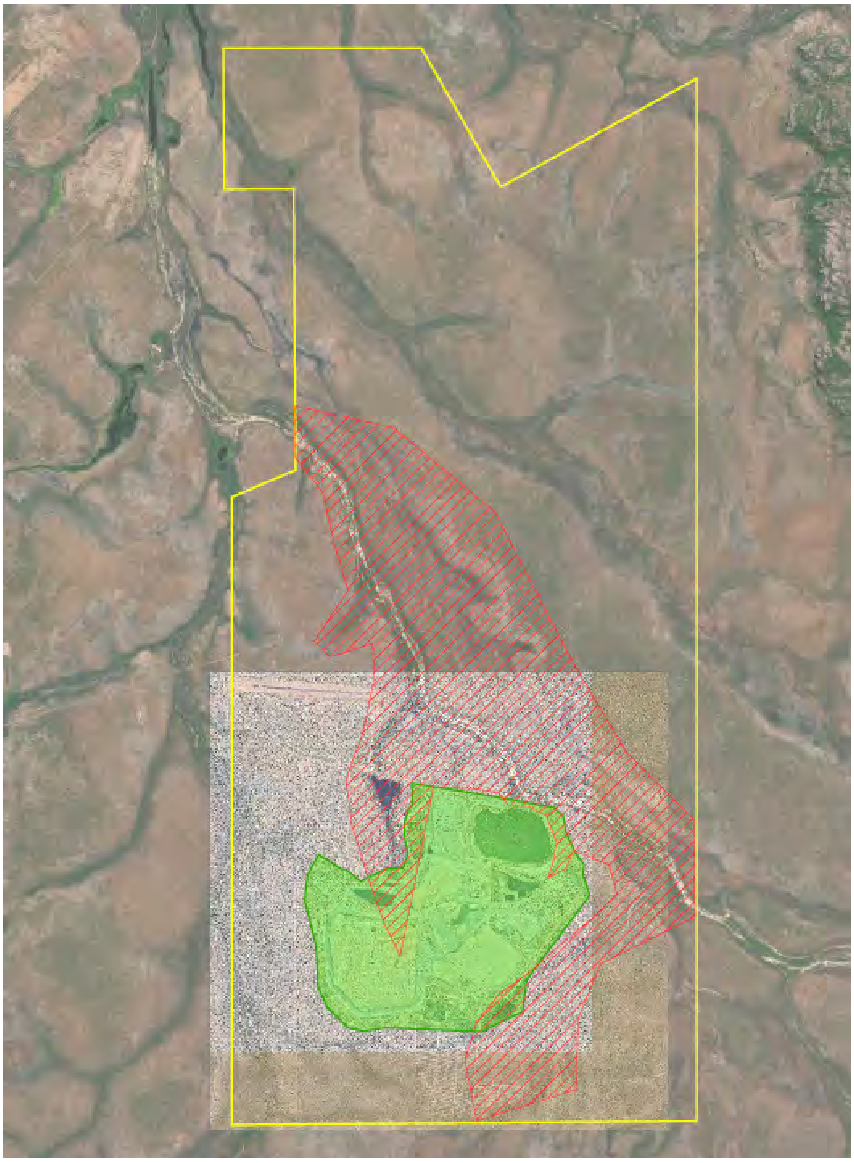

Figure 8-1: Estimated location for occupancy post closure

8.1.1.1 Hunting and gathering

Customary harvesting by local people of terrestrial bush foods from former mine impacted areas is likely to become more prevalent as the rehabilitation of the RPA progresses.

Garde (2015) notes that the most popular of excursions usually involve fishing in Magela Creek, but also that Bininj regularly hunt macropods, pigs, buffalo, waterfowl (mostly magpie geese) and emus, mostly with guns. The estimates of potential visitation periods for hunting, fishing and food collection purposes are based on the following observations:

- hunting visitation is likely to be more frequent on weekends as people combine hunting/food collection with recreational purposes;
- hunting and gathering visits are frequently day trips (that extend for either a half-day or the full duration of the day);

- hunting and gathering trips usually depend on the availability of transport (4WD vehicle), a firearm, seasonal access conditions (i.e. road not inundated) and the seasonal availability of the intended resource; and
- Seasonal camping or extended occupation for seasonal resource exploitation is also highly likely.

Extended seasonal camps are common in the region and are linked with the concentration of food resources at various times, including the late dry/early wet season for waterfowl such as magpie geese, ducks and other bird life. These resources will mostly attract Bininj from Jabiru to places such as Georgetown Billabong, Coonjimba billabong, the rehabilitated RP1, and Magela Creek mainly from MAG009 and upstream as far as the Magela Falls region.

Estimate of time spent on hunting and gathering, day trips:

Average of three times a month (less with lack of access in wet season) = 30 days per year.

Estimate of time spent on hunting and gathering, extended seasonal camping:

= 20 days.

Notional estimate of number of people accessing the rehabilitated RPA:

50 people— mostly from local resident areas.

8.1.1.2 Recreation

When consulted about intended recreational activities, the Bininj listed the following possibilities:

- intergenerational knowledge transfer visits;
- residential college and school trips;
- camping trips along Magela Creek;
- bushwalking trips along traditional walking routes; and
- weekend swimming, ‘get out of town picnics’.

Some Bininj said they would like young people (Bininj) to become familiar with certain cultural sites on the RPA post-rehabilitation. Estimates of such activities are about 2 days per person per year. These may be either sponsored by one of the Bininj organisations or they could be private trips (e.g. a family outing).

Other Bininj said that if they could be assured that it was safe to do so, they would consider camping at traditional or well-known camping places. Examples would include various billabongs along the Magela and associated tributaries. There is also an historical precedent for some long term residence at sites along the Magela, for example 009 camp, where Bininj have spent some years in residence. The area at 009 on the Magela remains a popular recreational site where weekend visits are still popular. In recent years however, the increase in the crocodile population has meant that people are only swimming there in isolated waterholes that appear in the late dry season.

The advent of local rangers is likely to see a program of bush walking and other site visits as the young rangers become familiar with places that have been closed or difficult to access due to mining over the past 35 years. There are plans to include these bushwalks as annual or biannual events, which will form part of a land management program on the Mirarr estate. These will follow the traditional Aboriginal walking routes. Further documentation of these routes took place in 2013 with assistance of the Indigenous Heritage Program and the results have been archived on an online content management database. Robert Layton (1981) documented traditional walking routes on the RPA and Magela Creek area. Whilst they have a recreational aspect to them, bushwalking programs by indigenous ranger groups are also considered as important activities discussed in Section 8.1.1.3 'Land management and monitoring'.

Estimate of time spent on or transit through rehabilitated RPA for recreation:

10 days, on average, per person per year.

Locations:

Gulungul Creek road crossing, Georgetown Billabong, Coonjimba Billabong, the rehabilitated RP1 area, and Magela Creek mainly from Mudginberri to MG009 and then upstream in the area just north of Georgetown Billabong.

8.1.1.3 Land management and monitoring

An ongoing program of monitoring and management in relation to cultural criteria for closure will be required following the rehabilitation of the RPA. 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. It is difficult to fix the frequency of these visits at this early stage. Notionally, annual visits would be undertaken.

Fire and weed management will result in regular visits to the site once vegetation has matured. The time needed to conduct site monitoring and management is estimated to be 10 days per person each year. Specific locations requiring the majority of effort are currently difficult to determine.

8.1.1.4 Rituals

Many traditional ceremonies are no longer performed in Kakadu National Park as it is a national park full of tourists and inquisitive non-indigenous people. Garde (2015) outlines some of the historic major and public ceremonies that still occur in Arnhem land.

Bininj in Jabiru and Kakadu are required to undertake certain rituals associated with the recent death of a family member. An example is the painting of ochre on trees, buildings and vehicles with which the recently deceased person has been associated. This ritual also involves visits by the family to sites in the country of the deceased so that the ochre can be placed on trees at important camping places. Bininj may need to access the rehabilitated area for this purpose. The time needed to conduct such activity is estimated to be one day per person each year. Locations would include established seasonal camps and other sites of frequent visitation (e.g. favourite fishing places or goose hunting places near billabongs).

Bininj also have the responsibility in this region to perform increase rituals at certain key sites, especially sacred sites that are totemic centres for particular natural species. These kinds of rituals are performed throughout Australia and are well documented in anthropological literature. The rituals are performed within a matter of minutes and in some cases (depending on the site) they can take longer. A half day or day trip to the relevant area would be typical to 'throw the dreaming totem'. The sacred sites on the RPA may be locations where such rituals might be carried out in the future as Bininj attempt to reconnect with the rehabilitated land. It is estimated that one day per person per year could be dedicated for this purpose.

Locations:

The recorded sacred sites, but possibly also at any of the archaeological scatters.

Bininj in the Kakadu and West Arnhem Land region also visit sites to introduce new visitors or young people (Bininj) to such places. They may also wish to communicate with the spirits of deceased kin at certain sites. It is difficult to determine how frequently site visits for this purpose may be undertaken. Two or three days per year is assumed.

Locations:

Mostly along the Magela Creek, but possibly also at the gravesite and the other recorded sacred sites.

8.1.2 Bush food diet

Establishing how much bush food is consumed by Bininj in the northern region of Kakadu NP informs the post rehabilitation radiological dose assessment. Sources for bush meat are generally defined by three categories:

- hunted by Bininj in Kakadu;
- delivered as a community service by other agencies or non-indigenous individuals; or
- shared by more distant kin (e.g. relatives visiting from Gunbalanya or Western Arnhem Land outstations).

A more exact study based on detailed quantitative analysis from fieldwork is now deemed impractical, not only for the diverse Aboriginal communities and residences within Kakadu NP, but probably for anywhere in Australia. Measuring the weights of all bush meats and plant foods consumed across the dozen or so communities/outstations/ranger stations in northern Kakadu where bush foods are still a significant element of the diet would require a large number of teams to record all harvested food over an annual cycle.

This would create an unacceptable intrusion into the lives of bush food consumers. This impracticality was confirmed by economic anthropologists during a conference at the Australian National University in September 2014 and based on work by anthropologist Jon Altman.

Altman's 1987 study is one of two studies in Australia that focused on the quantitative collection of nutritional data for Aboriginal people living remotely on their own estates. The second study by Betty Meehan's was conducted with coastal Burarra people near the mouth of the Blyth River near Milingimbi (Meehan, 1982).

As part of his late 1970s doctoral research, Altman resided at Mumeka outstation on the Mann River south of Maningrida for about 18 months. Over ten-months during his residency, Altman collected daily data from hunting and gathering (as well as market goods delivered by the store) for the outstation community, employing Bininj assistants to help when more than one production team was absent from the camp on any one day. Altman's data is represented in kilocalories and protein rather than pure weight of food resources collected. In 1980 he calculated for this remote western Arnhem Land community, that forty-six per cent of total kilocalorie per capita, and eighty-one percent of total proteins were provided by bush foods (Altman, 1987).

Comparisons to contemporary northern Kakadu communities some 35 years later was difficult. Bininj in the Kakadu region have higher cash incomes to spend and have greater access to market foods throughout the seasonal cycle. Bush foods still represent a significant economic, nutritional and cultural element of current diets.

An absolute quantitative measurement of bush food consumption is not feasible. Therefore, estimates based on long term and extensive data collection by survey and interview are utilised. This methodology is undertaken by the Supervising Scientist Branch (SSB) (Ryan *et al.*, 2011) as the basis for the proposed post closure diet.

The estimated annual intake of bush food by local Aboriginal people residing in northern Kakadu is provided in Table 8-2. The diet has been adapted from that compiled by Ryan and others (2011). The Gundjeihmi names for these foods have been added with some additions of missing items. Anecdotal evidence based on interviews with residents from Bininj communities in northern Kakadu and long term participatory observation of food collection trips by Murray Garde since 2003, indicate the SSB data is still accurate. Specific differences from historical diets compared to current information includes:

- Emu periodically hunted in the area south of the RPA.
- Flying fox consumed regularly in some communities, occasionally or never in others. Communities that consume flying fox do so between one to two months taking an average of a dozen animals (by shotgun). Sometimes flying fox have been supplied to Bininj by other agencies or individuals including Dave Lindner.
- Various water fowl including plumed whistling ducks, wandering whistling ducks, Radjah shelduck, white ibis and straw-necked ibis, and less frequently brolga and the black-necked stork. Consumption of other birds (i.e. sulphur-crested cockatoos and corellas) is rare.
- Typical crocodile consumption is approximately five or six combined fresh and estuarine species. The observed 2 kg/a per person by ERISS has therefore been increased to 3 kg.
- Goanna consumption excludes frilled neck lizards, now more commonly eaten than goanna. Frilled neck lizard populations appear unimpacted by cane toads compared to goannas. The 2 kg/a per person appears reasonable.

Although there is no quantifiable evidence other than direct comparison to the Australian diet, buffalo consumption used in the SSB diet seems possibly over-estimated at 146 kg/a per person. Agricultural commodity statistics (ABARES, 2013) indicate per capita meat consumption in the Australian population as approximately 100 kg/a per person with beef/veal constituting 32.2 kg.

The Supervising Scientist proposed value was not updated during the Garde review; however, the values presented in Table 8-2 represents bush food consumed over the full year in Northern Kakadu. The buffalo consumed as a bush food in Northern Kakadu often comes from Anbarrawarrgu (the Buffalo Farm), as such this would not be included in the diet consumed on the RPA. Buffalo consumption on the RPA has been reduced to 5 kg/a per person. This has been based on an assumption that Buffalo will be hunted and shot 5 times during the year, that a single person will not consume more than 0.5 kg of Buffalo in a single sitting and that the Buffalo meat will last for two days, being shared among the community (i.e. 1 kg meat per Buffalo per person). The weight of organs consumed has been reduced accordingly to 0.5 kg of each.

Table 8-2: Estimate of annual intake of bushfood of local Aboriginal people in northern Kakadu

Food item	Flesh eaten	Organs eaten	kg/a per person
Buffalo flesh	X		146*
Buffalo kidney		X	18*
Buffalo liver		X	18*
Wallaby	X	X	20
Pig	X		25
Magpie goose	X	X	20
Other water fowl	X	X	3
Fish group 1	X	X	10
Fish group 2	X		20
Mussels	X		4
Turtle flesh (3 species: pig nose, long neck and snapping)	X		5
Turtle liver (long neck only)		X	0.5
File snake	X		3
Crocodile flesh	X		3
Goanna	X	X	2
Yams	X		20
Fruit	X		3
Water Lilly	X		3
Flying fox	X		5

Food item	Flesh eaten	Organs eaten	kg/a per person
Emu	X	X	2
Food total			*330.5*

* this reflects annual intake but see comments above table about Buffalo consumption on the RPA

Significant variables include the fact that some communities engage in hunting and bush food collection more often than others and some people consume certain bush foods that others do not. There are also seasonal variables that affect the availability and access to certain species. Certain foods may be favoured by particular age groups (e.g. internal organs of some animals are favoured by the elderly and flying fox is not always eaten by some younger people).

Organs of certain animals are still regularly eaten. The most frequently consumed are those of buffalo (liver, kidneys, tongue), magpie geese (most organs), macropods (liver, kidneys) and long-neck turtle (liver). The organs of these animals have cultural significance in terms of the preparation of a meal. Bininj usually spend considerable time hunting these animals and the organs are removed quickly and eaten as an entrée dish whilst the main parts of the animal are then prepared for the longer cooking process. Organs such as liver are also considered important food for the elderly.

8.1.3 Culturally important flora and fauna

There are various criteria for establishing the cultural importance of a plant. The widest framework is linguistic reference. If it has a name and can be referred to, it must have some significance in the cultural life of Aboriginal people. A further criterion is utility. If it is used as some form of resource (e.g. food, medicinal, aesthetic, material culture, ritual) it is culturally important. On a number of occasions Bininj have indicated that culturally significant plants also include those that link animals together with other animals (including people). Plants that have flowers, seeds or fruit that attract birds and other animals are important for rehabilitation because they encourage the rapid re-establishment of biodiversity, for example Owenia trees (*Owenia vernicosa*). Although Owenia seeds can take up to five years to germinate, they will grow in very rocky habitats, even in cracks of bare sandstone, their fruit is favoured by black cockatoos and emus and the sap is eaten by sugar gliders. People use the crushed leaves as an ichthycide (fish poison).

It may not be possible for all the floristic species identified in the Garde report to be sourced, propagated and established, or suitable for the Ranger site (for example some rainforest species). The plants listed are those found across the three relevant ecological zones of the RPA – watercourses and billabongs, riparian margins and savanna woodland.

8.2 Closure objectives

Closure objectives set out the long-term goals for closure and are to be based on the post-mining landform and use (DIIS 2016). Closure objectives are an essential component of the rehabilitation process, providing transparency for stakeholders as to what the proponent commits to achieve at Authorisation relinquishment. Development of closure objectives should consider each of the environmental factors impacted by the operation (DMIRS 2020).

The ERs of the section 41 Authority, issued under the *Atomic Energy Act 1953,* and now annexed to the Ranger Authorisation issued under the *Mining Management Act 2001*, also provide specific closure objectives that align to the post-closure land use already discussed. A table of these ERs as closure objectives is provided as Table 8-3. These objectives were developed at the time of the authorisation of mining with the post-mining land use in mind. The objectives have been reviewed with stakeholders throughout the project and have been agreed to as being appropriate for the project impacts and proposed land use.

Section 8.3 presents the current status of closure criteria, as informed by the project impacts, supporting studies and stakeholder engagement.

Table 8-3: Closure objectives

Closure objective	**ER reference**
Landform	
The tailings are physically isolated from the environment for at least 10,000 years.	11.3 (i)
Erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas.	2.2 (c)
Radiation	
Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice and guidelines; and there is a minimum of restrictions on the use of the area.	2.2 (b) and 11.3 (iii)
In particular, the company must ensure that operations at Ranger do not result in: • change to biodiversity, or impairment of ecosystem health*, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing and subsequently during and after rehabilitation.	1.2 (d, e)
Water and sediment	
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: • protect the health of Aboriginals and other members of the regional community. The company must ensure that operations at Ranger do not result in: • an adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice and guidelines.	3.1, 1.1(c) and 1.2(c)

Closure objective	ER reference
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: • change to biodiversity, or impairment of ecosystem health*, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: • any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	3.1, 1.2(d) and 11.3 (ii)
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	3.1,1.2(e) and 2.1
Flora and fauna	
Revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu NP, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.	2.1, 2.2 (a)
Soil	
The company must ensure that operations at Ranger do not result in: • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	1.2 (e)
Cultural	
The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: • maintain the attributes for which Kakadu NP was inscribed on the World Heritage list.	1.1 (a)
The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	2.1

*Ecosystem health means the ability to support and maintain a balanced, integrative, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region

8.3 Closure criteria

Closure criteria represent direct measurable and quantifiable values, or tiered assessment processes based on industry best practice frameworks, such as the International Commission of Radiological Protection (ICRP), Inventory Multi-tiered Assessment and Prioritisation (IMAP) and National Environment Protection Measure (NEPM). Closure criteria will be used as the basis for determining the successful fulfilment of closure objectives to enable issuance of close-out certificates. It is acknowledged that further work is required to define quantifiable monitoring parameters necessary to confirm that closure criteria have been met.

The mechanisms and processes by which closure criteria are developed are outlined in the Terms of Reference for the Closure Criteria Working Group (CCWG) (Paulka 2012). The closure criteria address the broader objectives described in the ERs and Ranger Authorisation and consider the views of relevant stakeholders (e.g. the Ecosystem Restoration Forum has recently agreed closure criteria).

To identify closure criteria, key themes were developed by the CCWG (Stage 2), which include: landform, radiation, water and sediment, flora and fauna, soils, and cultural. More recently the flora and fauna theme has been renamed to ecosystem. The topics for cultural closure criteria closely align with each of the closure criteria themes. In this MCP, cultural criteria have been presented as a separate section with links provided via a numbering system to show the relationships.

The closure criteria for each theme are based on stakeholder consultation (Section 4), substantial research and studies (Section 5), Best Practicable Technology (including ALARA approach) (Section 6) and risk assessments (Section 7).

The closure criteria presented in this MCP have been through extensive stakeholder consultation. The majority of criteria have now been agreed. Those where some additional studies are required prior to agreement and finalisation have been noted. The proposed closure criteria may continue to undergo review and refinement, based on new studies and consultation with Minesite Technical Committee (MTC) members with updates provided in future MCPs if required.

Each closure theme is presented in following sections including:

- summary of relevant objectives and outcomes;
- closure criteria summary table; and
- justification for outcome, parameter, criteria and method to assess achievement.

Figure 8-2: Fungi on Trial Landform

8.3.1 Landform

2022 Status Update
All seven landform criteria were finalised and received Ministerial approval on 30 September 2021. However, an adjustment to one criteria is required (denudation rate).

There are two objectives derived from the ERs relating to the landform theme (Table 8-3). For each objective, the outcome derived from that objective and explanation are described.

Landform Objective 1:

The first objective comes from ER 11.3 (i) and relates to the isolation of tailings:

The tailings are physically isolated from the environment for at least 10,000 years.

As it will not be physically possible to monitor and measure this over the defined period of 10,000 years, a model will be required to show that this can be achieved. The outcome derived is based on best available modelling demonstrating that the tailings remain isolated.

Any modelling predictions should be conservative to give confidence that the objective will be achieved, however any worst-case scenarios developed will need to be realistic and reasonable.

Landform Objective 2:

The second objective comes from ER 2.2 (c) and relates to erosion of the landform:

> *Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas.*

Three outcomes have been derived from this objective.

First outcome – derived directly from the objective relating to erosion rates being comparable to natural landscapes. It is expected the erosion rates will be initially high then trend slowly on a trajectory towards the natural denudation rates of the region. As these timeframes are expected to be quite long, best available modelling will be used to demonstrate that the denudation rate will approach that of the background rate.

Second outcome – to ensure sediments created through erosion of the landform do not cause bedload to be transported away from the constructed landform and impact local waterways.

Third outcome – applies the concept that turbidity can be used as an indicator of fine suspended sediment. On an annualised basis, the difference between up and downstream can be used as an indicator of site-scale erosion characteristics.

The proposed landform closure objectives, outcomes, parameters and closure criteria are set out in Table 8-4. Section 8.3.1.1 provides justification for the outcomes, parameters and closure criteria that were derived for each of the key elements of the landform theme. The typical rocky surface of the Trial Landform is shown in Figure 8-3.

Figure 8-3: Typical rocky surface of the Trial Landform

Table 8-4: Final Closure criteria – Landform

ER	Objective	Outcome	Parameter	Summary of criteria[2]
11.3 (i)	The tailings are physically isolated from the environment for at least 10,000 years	Best available modelling demonstrates that tailings will remain isolated for at least 10,000 years.	Digital elevation model (DEM)	A high-resolution digital elevation model of the constructed landform matches the approved landform design, within applicable construction standards.
			Landform Elevation Model (LEM) predictions of gully erosion	Modelling of erosion on the constructed landform matches results of erosion modelling conducted on the approved landform design and confirms tailings will not be exposed for 10,000 years.
			Gully erosion	Gully formation will not expose buried tailings.
2.2 (c)	Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	The denudation rate on the landform is on a trajectory towards the regional background rate.	LEM model predictions of denudation rate	Modelling of erosion on the constructed landform demonstrates that the denudation rate will approach the background rate of 0.07 mm/a.
		No bedload is transported away from the constructed landform.	Bedload	Bedload is not being transported from the constructed landform, in the absence of active management.
		Total fine suspended sediment concentrations in receiving water downstream of the landform have returned to background concentrations.	Turbidity	For Magela and Gulungul Creeks, the difference in net annual turbidity between sites located upstream of the mine-site and downstream at the boundary of the RPA, is similar to background values over five consecutive wet seasons in the absence of active sediment control.

[2] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.1.

8.3.1.1 Justification for outcome, parameter and criteria

The following subsections explain how the outcomes of closure were derived from the objectives, the parameters used to measure outcomes, and the proposed closure criteria for each of the key elements of the landform theme (infrastructure, isolation of tailings and erosion characteristics).

Isolation of tailings

The method used to demonstrate achievement of tailings isolation criteria will be based on the Landform Evolution Model (LEM) predictions, using the CAESAR-Lisflood landform evolution model. The criteria will be achieved if the model demonstrates tailings will not be exposed. The modelling of climate change scenarios and the inbuilt conservatism will mean there is no tolerance assigned to the output and therefore it will confirm the criteria either has or has not been achieved.

Once constructed, the as built topography will be compared to design to confirm it is within the construction tolerances expected. These are currently expected to be in the order of +/- 0.5 m at drainage channels and +/- 1 m elsewhere (Section 9.3.5).

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. Significant erosion such as gully erosion is more likely to occur in the initial stages of the life of the landform. Following the initial settling of the landform, significant unplanned erosion should not occur. Gully erosion detected over Pit 1 and 3 will be remediated prior to the following wet season. It is expected that after the first five years, the landform will stabilise and less erosion will occur. This criterion is considered to be achieved when gully erosion, beyond that would ordinarily occur in the region, could not expose tailings occurs after this period.

Erosion characteristics

Denudation rate is the measure of the weathering or erosion of a landform surface by forces such as water and wind and expressed in terms of millimetres per year. This parameter is considered the most suitable parameter for comparing erosion characteristics of landscapes over time. The denudation rate of the waste rock landform is unlikely to be comparable to natural landscapes in the short term; therefore, a LEM will be used to predict denudation rates. The model needs to demonstrate that the long-term predictions of denudation rate from the designed landform are on a trajectory towards background rate, which was reviewed to be 0.075 ± 0.013 mm/a (Wasson *et al.,* 2021).

Sediments from erosion of the landform will be measured through both coarse sediment (bedload) and finer sediment (sedimentation).

For coarse sediment, the criteria will be to make sure that bedload is not being transported from the constructed landform, in the absence of active management. This parameter will be measured through post wet season observations after the active post closure management has been completed and the sediment controls structures have been removed.

Suspended sediment loads from the rehabilitated landform to Magela and Gulungul creeks are expected to be high initially, and then trend progressively towards background. Work completed by the SSB has demonstrated that turbidity can be used as an indicator for suspended sediment. The method developed involves the comparison of annual difference in turbidity between upstream and downstream site. Achievement of this criteria will be through demonstration of similar to background over five consecutive wet seasons once the active sediment control structures have been removed.

8.3.2 Water and sediment

2022 Status Update
Agreement with stakeholders has been achieved for many water and sediment quality objectives.

8.3.2.1 Water quality management framework

ERA is using the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018) Water Quality Management Framework (WQMF) for developing agreed water and sediment quality objectives (Figure 8-4).

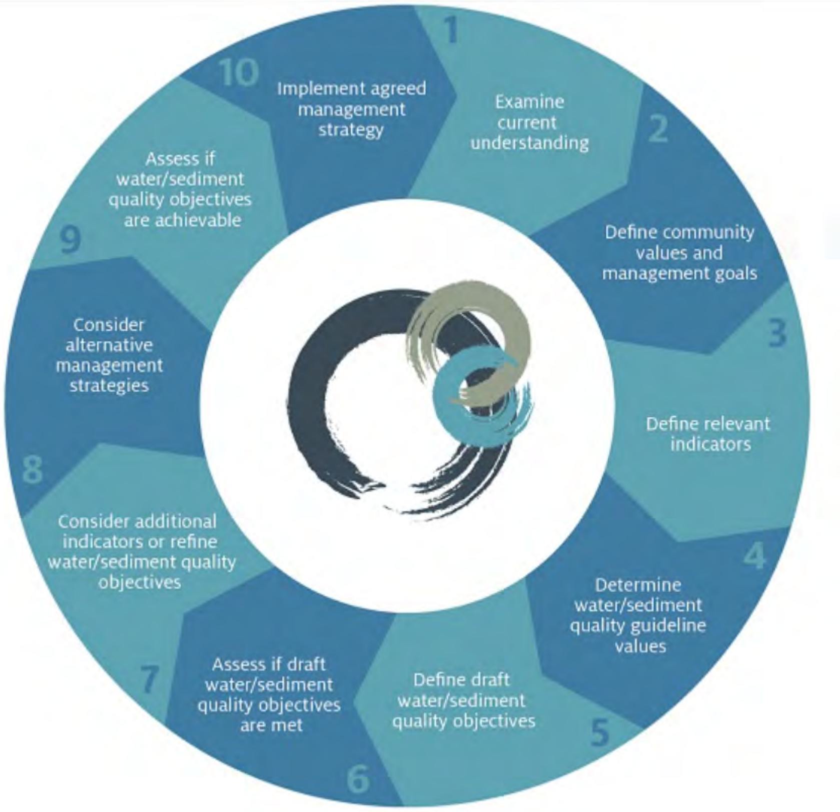

Figure 8-4: The Water Quality Management Framework (ANZG, 2018)

The language of the WQMF differs from that used by ERA and stakeholders in other closure criteria themes. In this section the *outcome* has been replaced with the term *management goal* from the WQMF, *parameter* replaced by *indicator* and *criteria* has been replaced with the term *water or sediment quality objectives (W/SQO)*. As explained in Section 8.3.2.2, under the WQMF, water/sediment quality guideline values (GVs) are identified for each management goal. The most stringent of these GVs is then chosen as the draft or final W/SQO.

The water and sediment *management goals* and *indicators* are set out in Table 8-5. The same indicator appears against several management outcomes but with different GVs (e.g. a higher GV value for drinking water than for ecosystem protection for a given indicator). In most cases the ecosystem protection GVs are more stringent than GVs for other management objectives. The GVs for ecosystem protection are therefore proposed as the final W/SQO for application off the RPA and as draft W/SQO for on the RPA. This is indicated in Table 8-5 by underlined italicised type with the final provided in a separate column for ease of interpretation. This reflects progress against steps one to five in the WQMF.

Steps six to ten in the WQMF provide a framework for assessing if draft W/SQO can be met, gathering more information, revising the draft W/SQO if appropriate, and eventual agreeing on a final W/SQO for each indicator to adopt as closure criteria. This process is important to derive and agree on final W/SQO for waterbodies on the RPA where impacts are to be ALARA. As this final process has yet to be agreed with stakeholders, including Traditional Owners, these remain in a separate table, Table 8-6.

8.3.2.2 Objectives and management goals

There are three objectives derived from the ERs that relate to the water and sediment theme (Table 8-3). These are discussed below and captured in Table 8-5 and Table 8-6. Stakeholder discussions may identify additional goals. Some work has progressed on identifying community values for different water types on and off the RPA. This and other information will be discussed further with stakeholders.

Environmental Requirement 3.1 is central to the first three management objectives:

> *The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.*

This ER directs ERA to ensure that the primary environmental objectives must apply off the RPA to the period following rehabilitation for any surface or ground waters discharged from the RPA. The various primary environmental objectives are then separated into the separate objectives for this closure criteria theme.

Water and sediment objective 1:

The first objective groups ER 1.1(c) and 1.2(c) as both relate to human health:

> *The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:*
>
> *1.1(c) Protect the health of Aboriginals and other members of the regional community*
>
> *The company must ensure that operations at Ranger do not result in:*
>
> *1.2(c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.*

Two pathways were identified for the assessment of the potential risk to human health from chemical pollutants in water (radiation is addressed separately in the radiation theme). Each pathway is the basis of the management goal.

- **Pathway 1**: through ingestion of water and bush food that has bio-accumulated mine derived analytes. The management goal is that diet consumption limits are not exceeded as a result of mine derived contamination.
- **Pathway 2**: through recreational activities. The management goal is that recreational water resources remain safe for their designated use.

Water and sediment objective 2:

The second objective is derived from ER 1.1 (d), ER 1.2(d) and 11.3(ii) and relates to protection of the Alligator Rivers Region, including protection of the environment from tailings contaminants for 10,000 years:

1.1 The company must ensure that operations at Ranger are undertaken is such a way as to …:

(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes

1.2 The company must ensure that operations at Ranger do not result in:

(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region.

11.3 Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:

ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.

Two management goals have been derived from this management objective:

First management goal – mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health off the RPA, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.

Second management goal – mine sourced solutes do not increase contaminants in sediments off the RPA to levels that would be detrimental to ecosystem health off the RPA.

These two outcomes cover the three pathways for contaminant transport for this theme, groundwater, surface water and sediments.

Water and sediment objective 3:

The third objective is from ER 1.2 (e) and ER 2.1. ER 1.2 (e) relates to protection inside the RPA, focusing on impacts to be as low as reasonably achievable

The company must ensure that operations at Ranger do not result in:

(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.

ER 2.1 relates to incorporating the rehabilitated site into Kakadu NP.

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 management goal for this objective is that impacts on the RPA (water and sediment quality) ALARA.

Table 8-5: Agreed guideline values for each management goal. The most stringent for each indicator (underlined and italicised) is the draft water/sediment quality objective proposed as closure criteria

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme [3]	Draft Water/Sediment Quality Objectives [4] (Closure Criteria)
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community. The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Drinking water: Mn, NO_3, NO_2, SO_4^{2-}, U.	Water quality off the RPA meets the national drinking water health guidelines (at those water bodies and times used by Traditional Owners for drinking). SO_4^{2-} 500 mg/L, Mn 500 µg/L, NO_3 50 mg/L, NO_2 3 mg/L, U 17 µg/L (NHMRC, 2011; v3.5 updated 2018).	NO_2 ≤ 3 mg/L
		Mine derived hazards will not cause unacceptable visual amenity or water quality to exceed recreational guideline values for secondary contact at sites identified for recreational value.	Toxic or irritant chemicals: NO^3, NO_2, U, SO_4, Mn.	Water quality off the RPA meets the national recreational guidelines for secondary contact (at those water bodies and times used by Traditional Owners for drinking). NO_3 500 mg/L, NO_2 30 mg/L, U 170 µg/L, Mn 5 mg/L (i.e., drinking water COPC x 10: NHRMC, 2008). SO_4^{2-} 400 mg/L (ANZECC & ARMCANZ, 2000 irritants, no guidelines for irritants/toxicants in NHRMC, 2008).	-
			Visual clarity and surface films.	No mine related change causes turbidity to be statistically significantly increased over natural background values. Oil and petrochemicals not to be noticeable as a visible film on the water or be detectable by odour.	-
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Turbidity, ammonia, manganese, uranium, magnesium, (magnesium: calcium mass ratio), sulfate, copper & zinc.	SSB Rehabilitation Standards are met in Magela and Gulungul creeks off the RPA: *Dissolved total ammonia nitrogen; 0.4 mg/L (pH and temperature dependant)* *Dissolved magnesium; 2.9 mg/L (72-hour moving average)* *Dissolved magnesium to calcium (Mg:Ca) mass ratio; no greater than 9:1* *Dissolved sulfate; 10 mg/L (seasonal average)* *Dissolved uranium; 2.8 µg/L (72 h moving average)* *Dissolved manganese; 75 µg/L (72 h moving average)* *Turbidity: no statistically significant increase over natural turbidity* *Dissolved copper; 0.5 µg/L (72 h moving average)* *Dissolved zinc; 1.5 µg/L (72 h moving average).*	Dissolved total ammonia nitrogen ≤ 0.4 mg/L (pH and temperature dependant) Dissolved magnesium ≤ 2.9 mg/L (72-hour moving average) Dissolved magnesium to calcium (Mg:Ca) mass ratio no greater than 9:1 Dissolved sulfate ≤ 10 mg/L (seasonal average) Dissolved uranium ≤ 2.8 µg/L (72 h moving average) Dissolved manganese ≤ 75 µg/L (72 h moving average) Dissolved copper ≤ 0.5 µg/L (72 h moving average) Dissolved zinc ≤ 1.5 µg/L (72 h moving average) Turbidity – no statistically significant increase over natural turbidity.

[3] Most stringent GV are taken as the draft W/SQO. These have been underlined.

[4] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.2.

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme [3]	Draft Water/Sediment Quality Objectives [4] (Closure Criteria)
	ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine sourced solutes do not increase U in sediments off the RPA to levels that would be detrimental to ecosystem health.	Uranium in sediments.	*Uranium in sediments does not exceed 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method)*	Uranium in sediments ≤ 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method).

Table 8-6: Draft water and sediment quality objectives under review

ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Diet parameters TBC with expert opinion	Local diet model demonstrates that ingestion of mine derived constituents of potential concern (COPC) via aquatic and terrestrial bush foods and drinking water does not cause annual intakes to exceed any relevant national/international tolerable intake levels.
3.1, 1.2(e) and 2.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	Surface water and sediment quality on the RPA is demonstrated to be as low as reasonably achievable.	As for off the RPA listed above.	The predicted water quality for the closure scenario demonstrated (and accepted by stakeholders) to be ALARA following the WQMF and the process outlined in Section 6.
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Nutrients	Nutrient criteria for preventing eutrophication are still under review.

8.3.2.3 Justification for outcome, parameter and criteria

ERA is following the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) WQMF to provide a process for stakeholders to develop agreed water quality objectives that apply both on and off the RPA.

The WQMF provides a sequential stepwise approach (Figure 8-4) to setting management goals through to assessing, refining and deriving W/SQO. Steps 1 to 5 are relevant to developing closure criteria for both on and off the RPA. Steps 6 onward are relevant for developing criteria for impacts that are ALARA, which only applies to waterbodies on the RPA.

It is important to note that Traditional Owners have reported concerns about trying to integrate cultural values with the 'scientific, legal and technical domains of a process that will take place within a framework controlled by those from the dominant non-Indigenous culture' (Garde 2015). The application of this framework has been, and will continue to be, discussed with stakeholders, including the representatives of the Traditional Owners through working groups, consultative forums and site visits. This is particularly important for agreeing on management goals for waterbodies on the RPA at step 2 and reviewing the following steps to align with and meet the agreed values for these on-site waterbodies.

The following sections describe the ten-step framework, and a high-level description of information available, for developing a water management plan and assessing a remediation strategy (ANZG, 2018). Both are relevant to deriving closure criteria.

Step 1. Examine current understanding

To inform decisions at subsequent steps, develop conceptual models of how the waterway systems work, the issues they face and how to manage them.

The understanding of how the Magela Creek system works and mine related issues is well advanced after almost 40 years of research and monitoring related to the Ranger Mine and surrounds (refer to studies listed in the SSB bibliography[5] and throughout this document).

Several key assessments and conceptual models relevant to the closure phase for water and sediment inform this step. For example:

- Revised Key Knowledge Needs (KKN) for closure (Supervising Scientist 2017) have been based on source, pathway, receptor models and environmental risk assessments of the Ranger Mine (Pollino *et al*. 2013, Pollino 2014, Bartolo *et al.* 2013). The knowledge base is updated as progress against the KKNs is reported (Section 5).
- An assessment of important ecological processes in the Alligator Rivers Region, to inform an ecological risk assessment (Bartolo *et al*. 2018).

[5] https://www.environment.gov.au/science/supervising-scientist/publications#bibliography

- Peer reviewed groundwater and surface water assessments and models (e.g. ERM 2020a, INTERA 2019, 2020 & 2021a, Water Solutions 2018 & 2021).
- Linkages between ground and surface water (INTERA 2021b) and between hydrological processes and ecosystem dynamics (BMT 2018).
- A site wide Acid Sulfate Soil (ASS) source, pathway, receptor conceptual model (ERM 2020b) and characterisation of ASS on the RPA and in receiving downstream waterbodies (ERA 2021a).
- Assessments of soil and sediment contamination (ERA 2021b, ERM 2020c).
- Discussions of Indigenous world views on the environment, including water (Garde 2015).
- The water pathways risk assessment conducted in early to mid-2021 (report in preparation; refer to Section 5).
- A review by SSB (currently underway) of emerging contaminants.

Step 2. Define community values and management goal

Define community values and establish or refine more-specific management goals (including level of protection) for the relevant waterways at stakeholder involvement workshops.

Environmental requirements specific to the protection of water quality and decommissioning strategies specify:

- waters leaving the RPA do not compromise the achievement of the primary environmental objectives (ER 3.1) related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds (ER 1 and 2);
- impacts on the RPA are ALARA (ER 1.2e);
- all aspects of the Ranger ERs and those environmental matters not covered by the ERs must use Best Practicable Technology (BPT) (ER 12); and
- the RPA must be rehabilitated to a state to allow incorporation into Kakadu NP (ER 2.1).

These ERs provide high-level management goals for rehabilitation of the mine site. Water quality guideline values have been set for some of these goals (Table 8-5).

Additional management goals for water and sediment have been identified that need to be considered by stakeholders. For example:

- The Traditional Owners and the SSB have indicated that a goal of no change to biodiversity on the RPA is preferred.
- Garde (2015) describes the community's cultural expectations and expected uses of the rehabilitated mine. Hunting, cultural and recreational use of water is included.

- Garde (2015) states the waters contained within all riparian corridors (i.e. rivers and billabongs), must be of a quality that is commensurate with non-affected riverine systems and health standards. The ALARA principle should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and level of contamination must be as low as technically possible.
- The NLC and GAC reiterated this and provided additional (draft) information on their position on ALARA for onsite water bodies (Chris Brady, personal communication, 8 April 2020).

  In the response to the 2019 Mine Closure Plan draft, the Traditional Owner representatives emphasise the importance of waterways on the RPA to Traditional Owners. These areas were previously, and should again be, a focus of activity for Traditional Owners. The main focus of activity is likely to be focussed on Georgetown and Coonjimba Billabongs and the Magela Creek channel.

  The ALARA principle therefore should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and the level of contamination must be as low as technically possible.

  In recognition of this, the BPT process established by ERA for determining water quality of these key waterbodies is adjusted such that cost is not considered, whilst the weighting of cultural value is doubled.

  Additionally, to ensure that the aim is for these key waterways to be utilised by Traditional Owners, for example as seasonal camping area where people fish and come into contact with the water, the water quality at an absolute minimum, will not exceed the Australian recreation water quality guidelines as a result of mine related activities.

  In other water bodies (e.g. sumps, minor drainage lines) Traditional Owners expect that management during the monitoring and maintenance period pending final rehabilitation will be such that they do not pose a credible risk to people or wildlife.

ALARA is discussed in *Section 6 Best Practicable Technology* and Appendix 6.3.

A stakeholder workshop identified the water types on and surrounding the RPA and the environmental values for each water type based on the environmental requirements and stakeholder expectations (BMT WBM, 2017).

During 2021 and 2022 Traditional Owner’s visited water bodies on the RPA as part of the cultural reconnection program. Information exchanged at these visits is important for refining the management goals for the waterbodies on the RPA.

The current natural World Heritage Values that occur on the RPA have been recently documented (Everett *et al.* 2021). Plans are in progress to update this work to include cultural values. Aspects of this for water bodies on and off the RPA have commenced (Garde 2015, BMT WBM 2017).

Step 3. Define relevant indicators

Select indicators for relevant pressures identified for the system, the associated stressors and the anticipated ecosystem receptors.

Indicators have been identified for the operational phase of the mine through many years of research, monitoring and application of the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) water quality guidelines. (e.g. Brown *et al.* 1985, Turner & Jones 2010, Frostick *et al*. 2012).

Iles and Humphrey (2014) reviewed the literature on release standards for constituents of potential concern (COPC) present in ore, process water and waste rock sources, and identified those needing a hazard assessment and/or requiring closure criteria.

Other work relevant to selecting indicators for closure water quality management are:

- The development of endpoints and indicators for the protection of biodiversity (Supervising Scientist 2002) and that they reflect the environmental values of water bodies both on and off the RPA. These include indicators for health and cultural uses and the Ramsar and Kakadu NP World Heritage values (BMT 2018, BMT 2019).
- The review of conceptual model endpoints and important ecological processes (Bartolo et al. 2018).
- The definition of key ecological components underpinning the environmental requirements of the RPA and surrounds and the interactions with underpinning processes (BMT 2018).
- The development, in consultation with Traditional Owners, of indicators for cultural closure criteria, including some for water (Section 8.3.6). Specific indicators for remediation goals for wet landscapes on the RPA will need to be identified with Traditional Owners.
- The identification of uranium as the COPC in reports on accumulation of metals in contaminated sediments on the mine site. Other metals showed limited enrichment even in the sediments of the waste water treatment wetlands (Iles et al. 2010, Parry 2016, Esslemont & Iles 2017, ERA 2021b).
- The selection of indicators for drinking water and recreation from NHMRC and NRMMC (2011; v3.5 updated 2018) and NHMRC (2008) based on the surface water COPCs identified by Frostick and others (2012).
- Expert advice will be sought on indicators relevant to a diet assessment. This will include an expert review of the indicators and GVs for drinking water.

A review of COPC for all sources on the Ranger Mine was conducted by ERM Ltd as part of the *Background concentrations of COPC in groundwater* project. No new COPCs have been added to the closure criteria list as a result of this review. COPCs will be reviewed again as a component of the contaminated sites sampling campaign. The list of indicators for W/SQO will be reviewed when outcomes from this project are available.

Radionuclides are discussed in Section 8.3.3.

Step 4. Determine water/sediment quality guideline values

Determine the water/sediment quality guideline values for each of the relevant indicators required to provide the desired level of protection (if applicable) for the management goals for relevant waterways.

Diet and recreation

Guideline values for drinking water are from the Australian drinking water guidelines NHMRC and NRMMC (2011; v3.5 updated 2018).

In addition to comparing predicted COPC concentrations to these guideline values, an assessment of risk from water quality to the traditional diet, including drinking water, will be undertaken. This assessment will be based on the water quality predictions from the surface water model. Radioactive contaminants are dealt with separately under the closure criteria for radiation (Section 8.3.3).

The Australian recreation guidelines (NHMRC 2008) provide recreation water quality guidelines for chemical hazards, pH and dissolved oxygen, and suggest using ten times the drinking water guidelines as a simple screening approach to identify COPC that may merit further consideration where waters might be swallowed during recreation. NHMRC (2008) also says *"… waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes…"* However the NHMRC (2008) guidelines do not provide a list of irritants or guideline values for such chemicals, whereas ANZECC and ARMCANZ (2000) do. The recreational GV for sulfate was therefore taken from ANZECC and ARMCANZ (2000). The same parameters identified for drinking water are used as suggested above. It is noted that the recreational guideline values for sulfate is more restrictive than using the drinking water times ten approach.

The lower range in Magela Creek is less than the pH guideline suggested for poorly buffered low ionic strength waters by NHMRC (2008). Turner and others (2015) demonstrated that the natural range of pH in Magela Creek is 4.7 to 7.9, and highly variable, and considered it *"highly unlikely that a quantity of mine derived water sufficient to significantly alter the pH in Magela and Gulungul creeks could be released"* and removed pH from the list of compliance parameters. Considering this, pH is not considered a parameter that requires a GV for recreation purposes. Should future acid sulfate soils studies indicate a potential risk, consideration will be given to the inclusion of a GV for pH.

Dissolved oxygen is also highly variable in the seasonal waterbodies on and off the RPA and there has been no requirement for compliance monitoring of dissolved oxygen for several decades at Ranger Mine. Dissolved oxygen is also not considered a parameter that requires a GV for recreation purposes.

Ecosystem protection

GVs for high-level ecosystem protection have been derived by the SSB and reported in their Rehabilitation Standard Series[6]. These are identified as being applicable at the lease boundary in Magela and Gulungul creeks. Meeting these GVs at the lease boundary provides an assurance that no change will occur to the offsite biodiversity. The scientific basis for the SSB water quality rehabilitation standards for ammonia, manganese, uranium, magnesium, (magnesium:calcium ratio), sulfate, copper, zinc, turbidity and sedimentation is described in each standard. The GV for uranium in surface water was found to protect against sediment toxicity effects considering the potential for accumulation and de-adsorption from sediment back to surface waters at unacceptable concentrations. This could negate the need for a uranium GV for sediment (SSB 2019). However, ERA has adopted the SSB site-specific guideline values for uranium in both water and sediment as closure criteria.

GVs based on ecotoxicity studies of the SSB are available for species protection levels of 99 %, 95 %, 90 % and 85 %. Guideline values for 99 % species protection are used as the SSB rehabilitation standard for application off the RPA. These are adopted as closure criteria for protecting the ecosystem off the RPA. The closure objective for water quality on the RPA (Table 8-7), reflecting ER 1.2e is *Impacts on the RPA are ALARA (derived following the WQMF and the ALARA process outlined in Section 6, with input from stakeholders).* The following steps of the WQMF are important for deriving the ALARA criteria.

Step 5. Define draft water/sediment quality objectives

Use the guideline values or narrative statements chosen for each selected indicator as draft water/sediment quality objectives to ensure the protection of all identified community values and their management goals (ANZG 2018).

Choose the most stringent of the guideline values for the water/sediment quality objectives (ANZG 2018).

For water, the same indicator appears against several management objectives in Table 8-5. The ecosystem protection GV are more stringent than GVs for the same parameter for other management objectives. The most stringent of the GVs for each indicator is italicised and underlined.

This step of the WQMF would select the most restrictive of the GVs to be proposed as draft water or sediment quality objectives and in the later steps of the WQMF these can be reviewed if not achievable. This is a relevant process for deriving closure criteria that are ALARA for on the RPA. However, for closure criteria off the RPA the most stringent GV is proposed (identified in Table 8-6 in the column draft water/sediment quality objective). It is still relevant to retain less stringent GVs against the relevant management options to support an assessment of each goal.

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[6] https://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards

ANZG (2018) supports narrative statements (as opposed to numeric values) as GVs and W/SQO. For waterbodies on the RPA some narrative draft W/SQO are used (Table 8-5 and Table 8-6) to state both the objective and the process by which the numeric criteria for ALARA impacts are being derived.

Step 6. Assess whether draft water/sediment quality objectives are met

Use measurements from the monitoring of each relevant indicator to assess whether current water/sediment quality meets the draft water/sediment quality objectives (ANZG 2018).

ERA has engaged consultants to use numerical models to predict the concentration and loads of a range of contaminants in surface water on, and downstream of, the Ranger Mine after mine closure (Section 5.2). The predicted concentrations of these COPCs were compared to GVs for each theme in the *Water pathways risk assessment project* (see Section 5).

Predicted concentrations of several COPCs (Water Solutions, 2021) are higher that the ecosystem and/or human health GVs at some locations on and off the RPA. The models are being reviewed and mitigation actions have been identified to reduce the concentration of contaminants reporting to the water bodies on and off the RPA (see Section 5).

If concentrations exceed the GVs, this does not necessarily imply that impacts will occur. Rather, further assessment is required to understand the implications of exceeding the GVs. This type of tiered assessment is common to many guideline frameworks (e.g. EnHealth 2012, NHMRC 2008, NHMRC & NRMMC 2011) and is also recommended in the following steps of the WQMF.

The sediment monitoring program (ERA, 2021b) showed that, of the waterbodies sampled, GVs for all metals were met except for three samples in a section of Retention Pond 1 where the GV for uranium was exceeded.

Step 7. Consider additional indicators or refine the water/sediment quality objectives

Assess the need to revise or add to the lines of evidence or indicators and the water/sediment quality guideline values (ANZG 2018).

Guideline values for different levels of species protection are available for most COPC from the ecotoxicity studies of the SSB or from ANZG (2018). Additional indicators and lines of evidence are being reviewed or are already available.

BMT Ltd has been working with ERA and stakeholders since 2017 in a three-phase project to:

- Identify preliminary ecological and cultural endpoints for each of the primary environmental objectives (BMT WBM, 2017).
- Map environmental values for different water types on and off the RPA (BMT, 2018).

- To develop a risk-based vulnerability assessment framework considering impact components such as duration, geographic extent and resilience, to determine how different concentrations of magnesium—potentially the most restrictive contaminant of concern—might affect these endpoints. This involves considering direct sensitivity of multiple ecosystem component indicators to magnesium concentrations and indirect sensitivity via other factors affecting vulnerability, such as habitat, diet, reproduction and dispersion (BMT, 2019) (Section 5 provides a description of the project).

A review of local nutrient data and a risk assessment of eutrophication is being conducted by ERA and SSB to address KKN WS6.

The sensitivity of the following ecosystem components to mine impacted water has been assessed: riparian species, migrating fish, macroinvertebrates at different stages of creek flow, and stygofauna in the sandy creek beds (Hutley *et al.* 2021, Crook *et al.* 2021, Mooney *et al.* 2020, Chandler *et al.* 2021).

Step 8. Consider alternative management strategies

Evaluate the effectiveness of current management strategies to address the identified water quality issues and recommend possible improvements. Improved or alternative management strategies are to be formulated, assessed and prioritised.

The recent *Water pathways risk assessment* project identified risks to the aquatic ecosystem and people related to contaminant levels from the current mine closure strategy. Actions have been identified to assess options to manage the contaminant sources creating these risks.

Consideration of alternative management options, considering community, environmental and cost aspects are common to both ALARA and BPT assessments used at ERA.

The BPT assessment (Section 6) process compares different management options and ranks them against each other based on scores for each of the BPT criteria. This includes criteria categories for water quality and environment protection. All scores are combined to form a single value, and the different options are ranked. The option with the best score is typically deemed the best practicable technology.

ERA has identified a process that iteratively combines management/mitigation options assessments with a risk management framework to identify a closure strategy based on BPT and demonstrates impacts that are ALARA (Figure 8-5 (bottom)). This is a process that is followed as part of the combined ERA BPT process and risk management framework.

ERA proposes that the analyte concentration associated with the option that is considered BPT-ALARA is the water quality proposed ALARA criteria for on the RPA. This aligns with the ALARA approach for radiation protection described by Oudiz and others (1986), shown in the top process chart in Figure 8-5.

Step 9. Assess whether water/sediment quality objectives are achievable

Use information gained from Steps 6 to 8 to assess whether the water/sediment quality objectives are achievable.

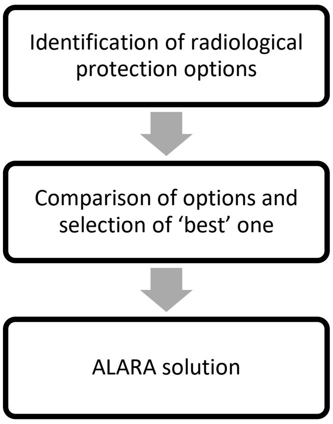
As discussed, at step 6 predicted water quality post-closure will be compared with the agreed objectives for ecosystem protection onsite and offsite. This was done in the *Water pathways risk assessment* project and management/mitigation actions identified where GV exceedances resulted in high or critical risks (Section 5). The risk assessment will be conducted again as updated information on predicted water quality for different management options becomes available. As shown in Figure 8-5 this is an iterative process.

Step 10. Implement agreed management strategies

Document and implement agreed management strategies, including, in some cases, a suitable and agreed adaptive management framework.

The results of the iterative management options assessments and proposed management strategies will be discussed with stakeholders through consultative fora. Proposed management strategies will be documented in applications to stakeholders and regulators for approval for key activities. Monitoring and adaptive management frameworks will be developed with input from stakeholders. This is a topic being advanced with guidance from the Alligator Rivers Region Technical Committee. Applications will include descriptions of mitigations and management actions and the results of BPT and risk assessments to demonstrate the proposed strategy and resulting water quality results in impacts that are ALARA.

Stakeholder feedback will occur again at this stage. Future MCPs will be updated with a record of progress.



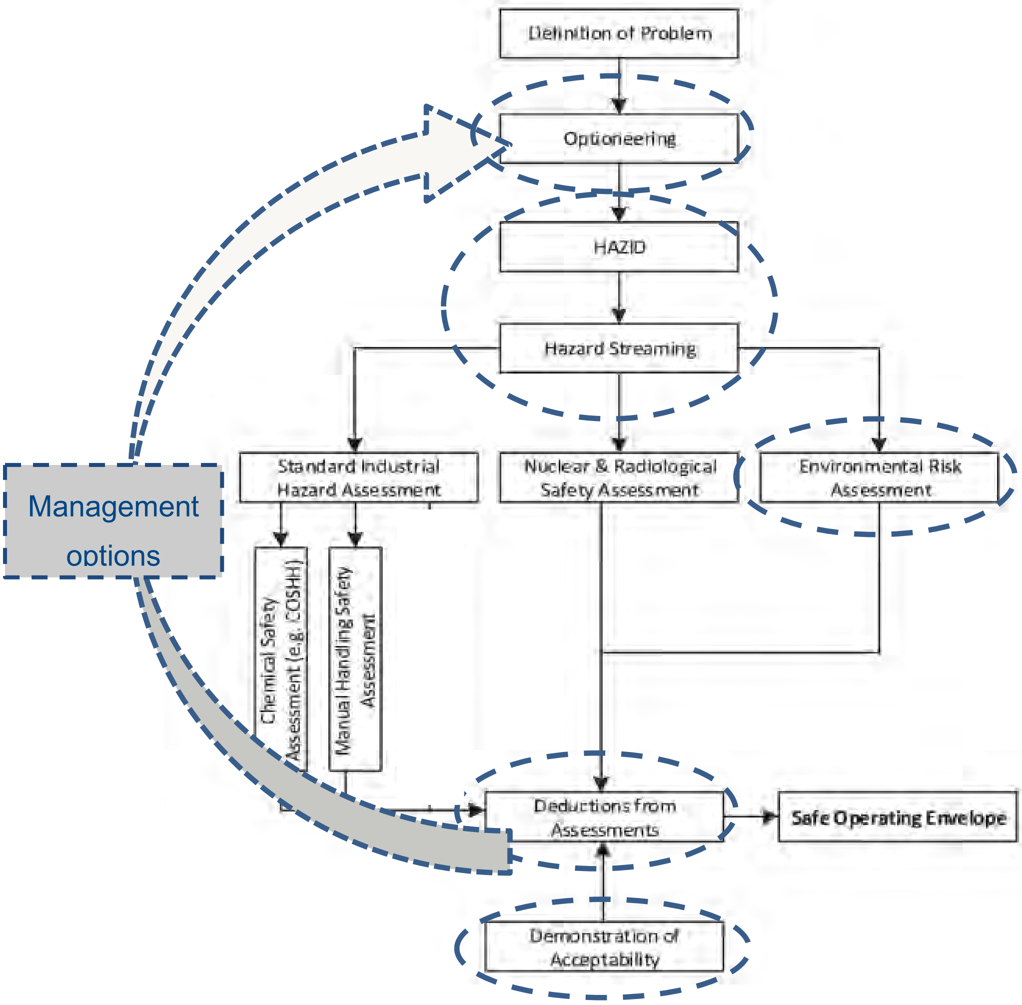


Figure 8-5: (Top) The main features of the ALARA procedure (Oudiz *et al*. 1986) and (Bottom) Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (from Bryant *et al.* 2017). Aspects related to the surface water risk assessment are circled.

8.3.3 Radiation

2022 Status Update
All radiation criteria have now been finalised, receiving ministerial approval on 30 September 2021.

There are two objectives derived from the ERs relating to the radiation theme (Table 8-3).

Radiation objective 1:

The first objective comes from ER 2.2 (b) and 11.3 (iii):

> *Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area*

Radiation objective 2:

The second objective comes from ER 1.2 (d and e):

In particular, the company must ensure that operations at Ranger Project Area do not result in:

> *(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and*
>
> *(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.*

Two outcomes have been derived from these objectives (Table 8-7), one related to the terrestrial environment and one for the aquatic. This division is based on the guidance for assessment provided within the ICRP document. Both outcomes are based on the potential risk to the environment (plants and animals) from above background radiation exposures sourced from the mine. The outcomes have been derived from the guidance provided by the ICRP in its publication 124 *Protection of the Environment under Different Exposure Situations* (ICRP 2014). 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. The biological endpoints of most relevance are therefore those that could lead to changes in population size or structure.

Table 8-7 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcomes and the proposed closure criteria. In some cases, corrective action is also provided in the event that the expected outcome is not accomplished. Some criteria also have linkages to cultural criteria. Where this occurs, reference has been made to the cultural criteria section for more details. These criteria are all consistent with the SSB Rehabilitation Standards on radiation (SSB, 2018a; SSB, 2018b)

Reflecting the guidance of the International Atomic Energy Agency (IAEA) (2006) and the ICRP (2014), radiation closure criteria are provided as radiation dose rates. To confirm that the radiation closure criteria proposed in Table 8-7 will be met in the post-closure phase, ERA commissioned a radiological impact assessment to be undertaken, which commenced in the third quarter of 2017. The radiological impact assessment considers potential radiation exposure to members of the public, as well as terrestrial and aquatic biota. The finalisation of this radiation assessment is dependent upon the outputs of the surface water model that is undergoing review and refinement based on the feedback received from the Pit 3 application. The outcomes of the radiation assessment are expected to be available for the 2023 MCP.

Section 8.3.3.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of the radiation theme: radiation doses to members of the public and radiation doses to terrestrial and aquatic biota.

Table 8-7: Closure criteria – radiation

ER	Objective	Outcome	Parameter	Summary of criteria[7]
2.2 (b) and 11.3 (iii)	Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area.	Radiation dose constraints to members of the public are ALARA.	Using the agreed restrictions on land use the total above-baseline radiation dose from pathways: External gamma Inhalation of Radon decay products (RDP) Inhalation of dust Ingestion of bush food (including water).	0.3 mSv/a.
		Radiation dose constraints to members of the public are below limits.	Should land use restrictions fail, the total above-baseline radiation dose from pathways: External gamma Inhalation of RDP Inhalation of dust Ingestion of bush food (including water).	1 mSv/a.
1.2 (d,e)	In particular, the company must ensure that operations at the Ranger do not result in: (d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	Minimise the deleterious radiation effects on terrestrial 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.	Total above-baseline absorbed dose rates to the most highly exposed terrestrial plants and animals.	100 μGy/h to the most highly exposed terrestrial species.
		Minimise the deleterious radiation effects on aquatic 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.	Total above-baseline absorbed dose rates to the most highly exposed aquatic plants and animals.	400 μGy/h to the most highly exposed aquatic species.

[7] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.3.

8.3.3.1 Justification for outcome, parameter and criteria

Radiation doses to members of the public

Two outcomes have been derived from this objective, the first relates to the requirement to have radiation doses to members of the public remain below limits, and the second to also keep these doses as low as reasonably achievable.

The premier international body for radiation protection is the ICRP. The limits for exposure to radiation and recommendations of the ICRP have been generally adopted worldwide.

The primary aim of the ICRP is to contribute to an appropriate level of protection for people and the environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure.

The ICRP has recommended 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 ICRP.

The recommendations of the ICRP are taken by the IAEA to develop radiation safety standards and guidelines that are then used internationally to protect human health and the environment.

The recommendations of the ICRP have no regulatory power in Australia; but are adopted in a joint Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and National Occupational Health and Safety Commission (NOHSC) document. Likewise, the various standards and guidelines published by the IAEA are adopted in Australia through various codes of practice and safety guides published by ARPANSA. The recommendations are also applied to the mining industry through the Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing. This Code is applied to the Ranger Mine operation by Commonwealth and Northern Territory legislation and implemented at site through the Ranger Authorisation.

In the international standards, human activities that add radiation exposure to that which people normally incur due to background radiation, or that increases the likelihood of their incurring exposure, are termed ‘practices'. For uranium mining and processing, the various stages of the practice are: design; construction; operation; decommissioning; and release of regulatory control.

The radiation protection principles of justification, dose limitation and optimisation apply to all these stages of the practice.

ERA has adopted a radiation protection policy and developed a Radiation Management System, based on the justification, optimisation and limitation principles established by the ICRP. The policy and system will be applied to the decommissioning phase through the Radiation Management Plan. During the post-closure phase, the principles will be applied through the development and demonstration of compliance with closure criteria. The closure criteria presented in Table 8-7 have been set so that radiation exposures to the public, and risk to the environment, post-closure are ALARA.

The IAEA guidance document *Release of Sites from Regulatory Control on Termination of Practices* (IAEA, 2006) 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 ARPANSA National Directory for Radiation Protection (ARPANSA, 2017). For members of the public this will be 1 mSv/a, determined from the sum of effective doses from all possible combinations of exposures.

The optimisation process for decommissioning and release from regulatory control starts with the setting of a dose constraint. The IAEA recommend that the dose constraint should take into account multiple pathways of exposure and should not exceed 300 µSv/a above background; however, each dose constraint should be site specific. When setting a public dose constraint, consideration must be given to the potential for other exposure pathways in the region. Given the Koongarra lease has been relinquished, the only remaining uranium mining lease in close proximity is Jabiluka. Based on the limited exposure pathways in the region, a dose constraint of 0.5 mSv (500 µSv/a) would be in keeping with the principles for setting dose constraints. However, ERA has elected to keep the recommended 300 µSv/a from the IAEA.

The IAEA system recommends that the final dose to members of the public is to be optimised below the dose constraint. If this is not achievable without any restrictions on the use of the land, then these may be applied with the additional requirement that the dose to members of the public should not exceed the dose limit of one milli-Sievert per year in case the restrictions fail. This process is illustrated in Figure 8-6 and forms the basis for setting the radiation criteria for protection of human health outlined previously in Table 8-7.

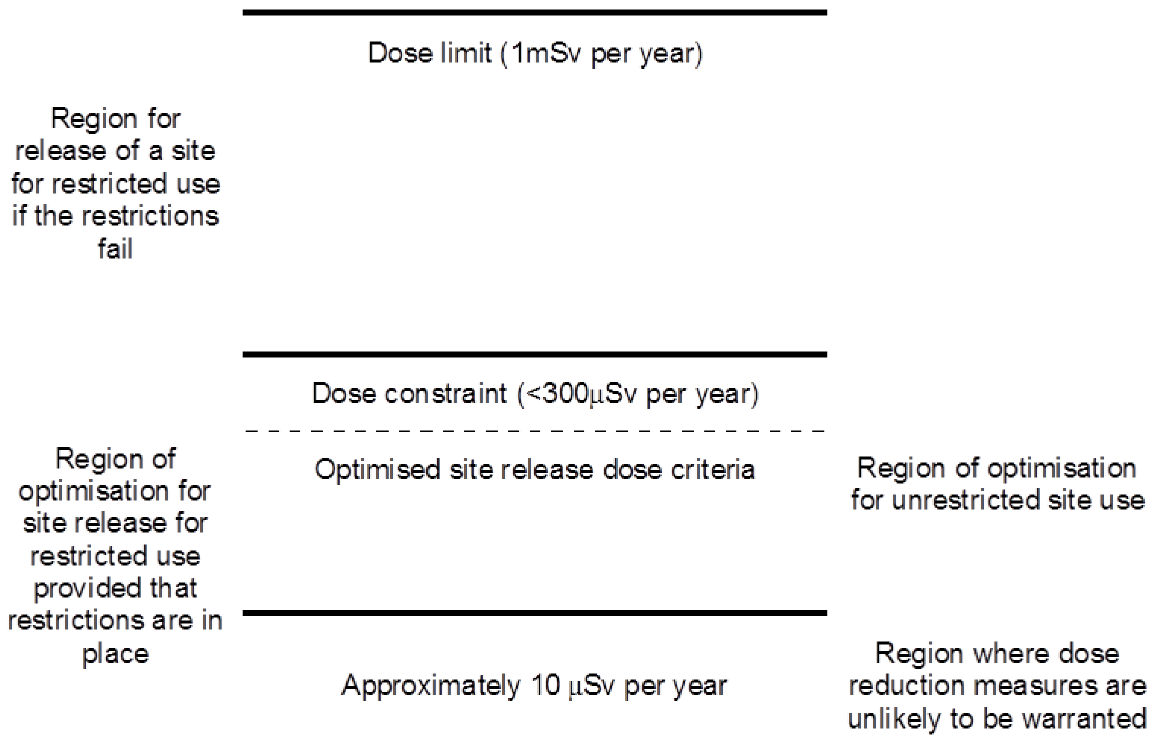


Figure 8-6: Constrained optimisation and regions of effective dose for members of the critical group in the release of sites (IAEA, 2006)

To assess if the radiation criteria for human health have been achieved, the following process will be undertaken:

- documentation of baseline radiological conditions for the site;
- identification of the representative person;
- definition of the probable habitation scenarios and identification of the exposure pathways;
- compilation of data for these scenarios and pathways, including definition of all sources; and
- development of radiation dose model for rehabilitated site.

The four main exposure pathways for human exposure to radiation will be direct external radiation, inhalation of dusts, inhalation of radon and its decay products, and ingestion of food stuffs (including ancillary ingestion of soil and drinking of water). Member of the public dose assessment will therefore consider the following exposure pathways:

- inhalation of long-lived alpha activity (e.g. radioactive dust);
- inhalation of radon decay products;
- ingestion of radioactive material in (or with) food or water;
- external irradiation from gamma radiation.

Given the anticipated post-closure use of the landform, the representative person will be an Aboriginal person using the site for traditional activities including transient camping and the gathering of traditional bush foods for consumption. Details of the land use, occupancy and diet was discussed in Section 8.1.

To assist with estimating the dose, and subtraction of natural background, several radiological studies have been undertaken on the RPA, these include:

- pre-mining, area-wide radiological conditions, as a first step to assessing post-mining changes and the success of rehabilitation from a radiological perspective (e.g. Bollhöfer *et al.* 2014, Bollhöfer *et al.* 2011, Esparon *et al.* 2009); and
- above background radiation doses through different pathways, to the public that may access the RPA post-closure (e.g. Akber & Lu 2012, Akber *et al.* 2011a, b & c, Akber & Marten 1991, Lu *et al.* 2009). These studies have primarily focused on potential post-closure occupation in the LAAs on the RPA.

A summary of the pre-mining background levels is provided in *Section 5 KKN Supporting Studies*.

Radiation effects on biota

Two outcomes have been derived from the objectives in relation to radiation effects on biota (Table 8-7), with both based on the potential risk to the environment (plants and animals) from above background radiation exposures sourced from the mine. The outcomes have been derived from the guidance provided by the ICRP in its publication 124: *Protection of the Environment under Different Exposure Situations* (ICRP, 2014). This document describes the framework for protection of the environment and how it should be applied within the ICRP system of protection.

As noted in objective 2, 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.

The risk assessment and management of radionuclides entering or present in the environment has historically been based on human health considerations alone. This approach has been underpinned by the ICRP (1991) recommendations that state: *"… if man is protected then it can be assumed that the environment is protected."*

More recently there has been increasing awareness of the potential vulnerability of the environment and of the need to be able to demonstrate that it is protected against the effects of industrial pollutants, including radionuclides. The ICRP, in its publications (ICRP 2007, 2008 & 2014), has addressed this by recommending that assessments be undertaken of the risk from radiation to animals and plants.

Recommendations for assessment of radiation risk to the environment have been published by multiple international organisations, including the ICRP, IAEA and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). These detail frameworks for assessment of risk through the comparison to a benchmark dose rate value that is considered to provide an acceptable level of protection to the environment (i.e. prevention of deleterious impacts to wildlife populations and ecosystem biodiversity). Studies conducted by ERISS have reviewed the international literature relating to benchmark dose rates and determined that the values published by UNSCEAR were considered to be the most appropriate to apply to the Ranger closure criteria (Doering & Bollhöfer, 2016).

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

- determine the radiation dose rate to a reference set of both terrestrial and aquatic biota; and
- compare this to the benchmarks documented as the closure criteria.

The benchmark dose rates documented as closure criteria are based on the recommendations of UNSCEAR (2008) and recommended for use under the SSB rehabilitation standard for the Ranger uranium mine - Environmental Radiation (SSB, 2018a). If the dose rates are below the benchmark dose rate, it can be concluded that there is an acceptable level of protection to the environment (i.e. that deleterious impacts to wildlife populations and ecosystem biodiversity will be prevented).

If dose rates are above the benchmark dose rate, a more detailed review of the doses to that 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.

8.3.4 Soils

2022 Status Update
All soil criteria have now been finalised, receiving ministerial approval on 30 September 2021.

There is one objective derived from the ERs relating to the soils theme (Table 8-3), which is one of the primary environmental protection objectives, ER 1.2 (e).

1.2 In particular, the company must ensure that operations at Ranger do not result in:

(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.

The outcome derived from this objective is that impacted soils are remediated to as low as reasonably achievable to protect the environment.

Table 8-8 provides a summary of the closure objectives, the outcome, parameters used to measure the outcome, and a summary of the proposed closure criteria. Section 8.3.4.1 provides justification of the outcomes, parameters and closure criteria that were derived.

8.3.4.1 Justification for outcome, parameter and criteria

The objective and outcome for closure is that, where needed, soils will be remediated to a level where the environmental impact is ALARA. This is adopted in relevant BPT assessments where the preferred option (I.e. the highest ranking option against specified criteria) will be progressed. Outcomes of contaminated sites assessments will be included in future versions of the MCP.

Achievement of the outcome will either be through demonstration that contamination levels are currently, or remediated to be, low enough that no action is required or through development of a site management plan based on ALARA.

Table 8-8: Closure criteria – soils

ER	Objective	Outcome	Parameter	Summary of criteria [8]
1.2 (e)	The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	Impacted soils are remediated to as low as reasonably achievable to protect the environment.	Contaminated soil assessment for uranium and manganese in LAA.	Demonstrate risk is ALARA.
			Contaminated assessment of identified COPCs for other soils identified as not being part of the larger decommissioning works.	Demonstrate risk is ALARA.

[8] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.4.

8.3.5 Ecosystem

2022 Status Update
Ecosystem criteria have been developed for both revegetation and fauna which have changed in structure and detail since receiving Minister approval.

There is one objective derived from the ERs relating to the ecosystem theme (previously termed flora and fauna). This is one of the primary rehabilitation objectives, ER 2.2 (a):

> *Revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.*

There are two aspects to this objective. The first, referred to as the 'ecosystem similarity', requires the flora and fauna species composition and community structure of revegetated areas within the RPA to be similar to Kakadu NP. The second, referred to as 'ecosystem sustainability', requires rehabilitated areas to contain functioning ecosystems that are long-term viable and require a maintenance regime similar to those in adjacent areas of Kakadu NP.

The qualitative criteria relating to this objective cover these two aspects of ER 2.2 (a) and were finalised with SSB, NLC and ERA input in August 2022. These criteria are provided in Table 8-9. The table provides a summary of the attribute, sub-attribute, goal and indicator (or criteria) that will be used to measure the outcome. These criteria include both ecosystem similarity as well as ecosystem sustainability elements.

Table 8-9: Closure criteria – Ecosystems

Attribute	Sub-attribute	Goal	Indicator
Ecosystem Similarity			
Species composition and relative abundance	Species composition of vegetation	The assemblages of overstorey species and understorey functional species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of species in overstorey assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
			Functional composition of understorey species refers to the following lifeforms: Legumes: Minimum number of legume species and variety of lifeforms. Perennial grasses: Minimum number of perennial grass species, including specified species. Annual grasses: Minimum number of annual grass species. Forbs: Minimum number of forb species from a minimum number of families. Climbers and vines: Minimum number of climber and vine species used as a food source. Non-legume woody species (shrubs): Minimum number of non-legume woody species and specified species (including woody ground cover species).
	Species richness of vegetation	Species richness of overstorey and understorey are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species abundance of vegetation	Abundance of overstorey and understorey species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total abundance of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Community structure	Structure	Vegetation structure similar to, or on a trajectory towards that of the reference ecosystem(s).	Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

Attribute	Sub-attribute	Goal	Indicator
	Vegetation strata	Overstorey and midstorey cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The distribution of percentage canopy cover is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
		Understorey vegetation cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	Percentage cover of understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of native vertebrate species	Species composition of native vertebrate species	The assemblages of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species richness of native vertebrate species (number of species)	Species richness of mammals, birds and reptiles is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of: i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native vertebrate species	Abundances of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total abundance of i) mammals (including bats); ii) birds; and iii) reptiles are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of threatened species	Species composition of threatened native vertebrate species	The assemblage of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of targeted threatened fauna species is statistically similar to, or on a trajectory towards, that of the reference ecosystem.
	Abundance of threatened vertebrate species	Abundance of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem.	Total abundance of targeted threatened vertebrate species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of ants	Species composition of native ant species	The assemblages of native ant species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of species in native ant assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

Attribute	Sub-attribute	Goal	Indicator
	Species richness of native ant species	Species richness of native ants is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native ant species	Abundance of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of individuals of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem Sustainability			
External exchanges	Key vegetation-dispersing fauna	Abundances of nectivorous and frugivorous bird species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	Total number of individuals of: i) nectivorous; and ii) frugivorous bird species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem function	Habitat availability for fauna	Habitat for fauna is present, or is forming.	Habitat for fauna is, or indicators of habitat formation are, present.
	Nutrient cycling	Chemical, physical and biological indicators provide evidence that nutrient cycling will sustain ecological processes.	Litter decomposition rates necessary for supporting ecological processes are consistent with, and within the ranges of, those reported for northern savanna ecosystems.
			Appropriate soil microbial community functions that support nutrient cycling are present.
			Soil organic carbon and nitrogen are accumulating at a rate necessary for supporting ecological processes.
			Soil mineral nitrogen and soluble organic nitrogen stocks and rates of mobilisation are at a level necessary to support ecological processes.
	Resilience to fire	Ecosystem resilience to the appropriate fire regime.	Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.
			Post-fire mortality rates of juvenile and adult overstorey species do not exceed those of the reference ecosystem.

Attribute	Sub-attribute	Goal	Indicator
	Resilience to extreme weather events, pests and disease	Ecosystem resilience to natural disturbances (wind, drought, disease) is similar to the reference ecosystem.	In the event of natural disturbances (e.g. wind, drought, or disease), all other closure criteria must be shown to have been met, demonstrating recovery.
Threats	Weeds	No Class A weeds or Weeds of National Significance (WoNS).	Class A and/or Weeds of National Significance are either absent from the Ranger Project Area (RPA), or have been eradicated from within the RPA for a period of time that exceeds the seed bank longevity of any given species.
		Abundance of Class B weeds no greater than the reference ecosystem(s).	The incidence and abundance of all Class B weeds within the RPA is no greater than the reference ecosystem, at a landscape-scale.
		Abundance of other introduced flora species would not require a maintenance regime different from that appropriate to adjacent areas of Kakadu NP.	The presence and abundance of other introduced flora within the RPA is no greater than those in adjacent areas of Kakadu NP.
	Abundance of exotic fauna species	Abundances of buffalo, horses, pigs, cats and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.	The total abundance of: i) buffalo; ii) horses; iii) pigs; iv) cats; and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.

8.3.5.1 Justification for outcome, parameter and criteria

Derivation of the qualitative ecosystem criteria is underpinned by an understanding of general ecological restoration principles (SERA, 2021), ecosystem dynamics in northern Australia, and the knowledge gained through over 30 years of flora and fauna studies, revegetation trials and research on RPA and surrounding areas. The ecosystem criteria were developed through a process of stakeholder consultation, benchmarking against relevant contemporary practices at other operations and within other jurisdictions, as well as consideration of information from appropriate reference sites and rehabilitation trials.

Work is ongoing regarding reference site selection for indicators and the overall Ranger conceptual reference ecosystem (CRE, for more information see *Section 5 KKN ESR1*). This work is key to defining the target ecosystem(s) and will determine the quantitative closure criteria for assessment of success. It is generally understood that the ecological attributes and parameters proposed for the assessment by ERA are sound, however the criteria may be further revised once the CRE(s) are further developed and/or finalised.

Further information on the justification for each component of the ecosystem theme is provided below.

8.3.5.2 Ecosystem Similarity

The first outcome is that species composition and community structure is similar to adjacent areas of Kakadu NP.

The ecosystem similarity aspects of the ecosystem closure criteria have been grouped under vegetation similarity and fauna similarity attributes

Vegetation Similarity

Species composition of vegetation

Species composition is the array and relative proportion of organisms, in this case vascular plants, within an ecosystem (Gann *et al.* 2019). This measure is valuable for understanding how an ecosystem works and how important different species are to an environment. In mature, successful revegetation, these criteria should indicate that a good diversity of characteristic species (based on the agreed CRE) have been established and/or that there is improved potential for colonisation of more species over time (SERA, 2021). Species composition is generally expressed as a percent (so that all species components add up to 100 %) and can be considered on either an individual species basis, or by species groups depending on the objectives of the revegetation or monitoring program (e.g. Eucalyptus spp., perennial grasses, etc.). For closure criteria it is commonly expressed using similarity measures which quantify the similarity in the species and their relative abundances between two vegetation.

Despite the functional importance of dominant species for the long-term sustainability and stability of plant communities, they are not the major components of species diversity in the eucalypt-dominated open woodlands typical of the region. Annual and perennial grasses and forbs in the ground layer often dominate total plant species diversity (measured as species richness, abundance etc). However, these components can be very ephemeral in nature, resulting in considerable year-to-year variation in both species diversity and composition, even at a single natural woodland site (e.g. Fensham, 1992, Williams *et al.* 2003). In particular, the frequency, timing and intensity of fire can cause large changes in the composition of the ground stratum in these woodlands within a single year. As a result, measures of understorey species composition can be quite dynamic and variable in a manner that is largely unrelated to the overall functional performance of the plant community. Recognising this, it was agreed that understorey composition should be assessed based on functional groups rather than species. At an understorey-dedicated workshop held on the 24th of June 2021 involving ERA, SSB, NLC, as well as experts from Charles Darwin University and Kakadu Native Plants Pty Ltd, six functional understorey groups were identified for the understorey composition indicator based on the ecosystem services each group provides (draft report Bellairs, 2021).

The relevant criteria are:

- *The contribution in relative abundance of species in overstorey assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *Functional composition of understorey species for each functional group as follows:*
  - *Legumes: Minimum number of legume species and variety of lifeforms.*
  - *Perennial grasses: Minimum number of perennial grass species, including specified species.*
  - *Annual grasses: Minimum number of annual grass species.*
  - *Forbs: Minimum number of forb species from a minimum number of families.*
  - *Climbers and vines: Minimum number of climber and vine species used as a food source.*
  - *Non-legume woody species (shrubs): Minimum number of non-legume woody species and specified species (including woody ground cover species).*

Minimum numbers and specified species for each understorey functional group are yet to be agreed on. It is likely that minimum numbers will be a threshold defined by the lowest number of species in that lifeform across the set of reference sites. Specified species will be determined based on characteristics such as ubiquitousness across the reference ecosystem, its critical role for fauna food or habitat, and/or cultural significance.

Species richness of vegetation

Species richness is simply a count of the number of different species represented in an ecological community, landscape or region, and is a key component of species diversity (along with relative abundance of each species).

The relevant criterion is:

- *The total number of i) overstorey species, and ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Species abundance of vegetation

Species abundance can mean the number of individuals per species (density), or the percent cover per species, within a given area.

The relevant criterion is:

- *The total abundance of i) overstorey species, and ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Community Structure

Community structure refers to the architecture and spatial patterns of vegetation strata (SERA 2021), and can include height, diameter and size class distribution of stems, or the depth and total leaf area of each stratum. The Ranger rehabilitated site will have a very simple structure during the initial stages of ecosystem establishment because tubestock will be similar ages and sizes when planted. However, as the ecosystem matures, localised conditions (e.g. substrate properties, topography, weather and disturbance events etc.) will result in different rates of tubestock growth, self-recruitment and external colonisation of new species, resulting in a more complex community structure.

The relevant criteria are:

- *Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *The distribution of percentage canopy cover is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *Percentage cover of understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Two previously contemplated closure criteria related to vegetation structure are no longer proposed due to these aspects being adequately addressed through other criteria. Basal area of overstory is closely correlated with vegetation cover and is considered to be effectively assessed through the measurement of canopy cover (noting that this can also be measured remotely). The measurement of basal area will continue to form part of the monitoring within rehabilitation and reference site plots as an explanatory/diagnostic metric but will not be used as a separate closure criteria. The distribution of vegetation or “naturalness” had also previously been considered as a possible sub-attribute however all stakeholders have agreed that this attribute is difficult to measure objectively and the core diagnostic features relative to naturalness are covered in other ecosystem metrics. Cultural closure criteria (which necessarily include subjective considerations) are also considered to capture aspects of ‘naturalness’.

Fauna Similarity

It is recognised that the rehabilitated landform will not replace the pre-mining landscape with an identical ecological system, and will have no real analogue in the natural surroundings (due to the topographic, hydrological and substrate properties of the waste rock landform). However, in consideration of fauna, it should be recognised that the surrounding fauna communities form the only source for fauna recolonisation, and thus comparison of fauna communities within rehabilitation with suitable reference populations is a valid approach. Closure criteria have been developed for both invertebrate and vertebrate fauna. Invertebrates are important indicators for ecosystem reconstruction as they are abundant, respond to ecological system changes relatively quickly and many species have important roles as ecosystem engineers (e.g. Anderson *et al.* 1996, Andersen & Sparling 1997, Folgarait 1998). Invertebrates have been studied in Kakadu NP, and at Ranger specifically (Andersen 1993, Anderson *et al.* 1996, Andersen & Oberprieler 2019). Much of the vertebrate fauna is expected to recolonise later in the recovery trajectory of the site, in response to the development of invertebrate and vegetation resources. Vertebrates have been monitored across Kakadu NP over the last 25 years as part of Department of Environment and Natural Resources' Three Parks Fireplot Monitoring Program (reviewed by Einoder *et al.* 2018) and a series of more recent surveys have been conducted within and surrounding the RPA (Eco Logical Australia 2014, Eco Logical Australia 2016, SLR Consulting 2019).

Assessment of the development of invertebrate and vertebrate fauna communities, designed to demonstrate progress toward communities similar to those in adjacent areas of Kakadu NP, will be based on a combination of metrics.

Composition and abundance of native vertebrate species

The similarity of fauna richness and diversity with pre-mining or reference ecosystems is the most frequently studied indicator of fauna responses to mine rehabilitation globally (see reviews by Cristescu *et al.* 2012, Cross *et al.* 2019b). Empirical evidence demonstrates that fauna richness and diversity can be expected to increase over time, and that values approach (or in some cases exceed) values in reference ecosystems for a range of fauna groups (e.g., Nichols & Grant 2007, Brady & Noske 2010, Gould 2011, Frick *et al.* 2014, Triska *et al.* 2016, Houston *et al.* 2018).

In addition to measures of diversity, comparison of the similarity of fauna community assemblages to reference ecosystems provides a more sophisticated assessment of the development of faunal communities. In contrast to the evidence suggesting that fauna species diversity approaches reference values, similarity of community composition is generally more difficult to achieve (e.g., Woinarski *et al.* 2009, Brady & Noske 2010, Gould 2011, Craig *et al.* 2012, Cristescu *et al.* 2012, Triska *et al.* 2016), although some studies have recorded rehabilitated sites with community composition approaching that of reference sites (Nichols & Grant 2007).

Criteria for abundance, richness and community composition are being proposed for birds, mammals (including bats) and reptiles. Separate criteria are also included for threatened vertebrate species within the rehabilitated areas. The relevant criteria are:

- *The contribution in relative abundance of i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of: i) mammal (including bats); ii) bird; and iii) reptile species are similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of individuals of: i) mammals (including bats); ii) birds; and iii) reptiles are similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *The contribution in relative abundance of targeted threatened fauna species is statistically similar to, or on a trajectory towards, that of the reference ecosystem.*
- *Total abundance of targeted threatened vertebrate species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Composition and abundance of ants

Ants have been widely used as ecological indicators of habitat disturbance in the Australian tropics (King *et al.* 1998, Andersen *et al.* 2002, Hoffmann & Andersen 2003, Lawes *et al.* 2017), and were the dominant ground-active invertebrates on the Ranger Trial Landform and reference sites surrounding the mine surveyed by Andersen and Oberprieler (2019). As such ants are being proposed as the indicator for invertebrate species.

As with vertebrates, the criteria being proposed are composition, richness and abundance. The relevant criteria are:

- *The contribution in relative abundance of species in native ant assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s)*
    - *Total number of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of individuals of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).*

8.3.5.3 Ecosystem Sustainability

As discussed earlier, ER 2.2(a) requires the rehabilitated areas to contain long-term, viable ecosystems ‘which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park’. The following components relate to the long-term viability/ functioning of the established ecosystems.

External exchanges

Edible fruit-bearing trees and shrubs provide resources for a range of bird and mammal fauna, which in turn facilitate dispersal of plant species across and into the rehabilitated ecosystem (Caves *et al.* 2013, Frick *et al.* 2014). Vertebrate pollinators and frugivores perform key ecological functions as vegetation dispersing fauna. Nectivorous and frugivorous bird species (which both indicate that suitable habitat resources are available, and facilitate dispersal and pollination of plant species) are thus considered important to include for closure criteria.

The proposed key vegetation-dispersing fauna closure criteria is:

- *Total number of individuals of: i) nectivorous; and ii) frugivorous bird species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Although previously considered, closure criteria covering recruitment or regeneration of species and the presence of flowing and fruiting material in vegetation are no longer deemed necessary. This is due to other closure criteria relying on these attributes to be present to be satisfied (e.g. criteria on flora species composition, relative abundance and community structure, as well as nectivorous and frugivorous bird criterion). Ongoing monitoring of flowering, fruiting and recruitment attributes will still be undertaken for early warning/explanatory/diagnostic purposes.

Fauna habitat

Fallen timber, rocks, bushy vegetation (eg. *Livistona* and *Heteropogon tricieus*) and tree hollows provide important habitat for amphibian, bird, mammal and reptile species. Many species are hollow-using or hollow-dependent (Taylor *et al.* 2003, Goldingay 2009, Goldingay 2011, Lindenmayer *et al.* 2014), and generally use multiple hollows selected on a number of characteristics, which potentially include tree size, height of hollow, entrance size, hollow form and position, hollow aspect and/or hollow depth (Goldingay 2009 & 2011). Hollows (particularly uncommon large hollows) occur most frequently in large, old trees and Goldingay (2011) estimated that most trees used as mammals dens (including those in the NT) were >100 years of age. The development of a self-sustaining array of tree hollows (where recruitment of new hollows balances attrition of existing hollows) suitable to support hollow-using or dependant fauna is therefore predicted to occur far beyond the 25-year timeframe for achievement of closure criteria. Recognising this limitation, it was agreed by ERA, SSB and NLC in an August 2022 forum that if key habitat formation attributes are present (eg. hollow-forming tree species, termites and an appropriate fire regime) that is an indication that hollows are likely to form over time.

The relevant criteria are:

- *Habitat for fauna is, or indicators of habitat formation are, present.*

Nutrient cycling

The process of nutrient cycling will be important for the ongoing sustainability of revegetation. Insufficient cycling of nutrients (due to limited availability and/or amounts of nutrients) can directly affect ecosystem attributes, including community structure, species composition and biodiversity. Nutrient cycling relies on a synergistic combination of physical, chemical and biological changes, therefore a range of factors require monitoring to ensure sustainable cycling is occurring.

The waste rock substrate that will form the Ranger final landform has significantly different physical, chemical and biological characteristics to the ancient soils of the unmined surrounding savanna (Section 5). Considering this, most of the nutrient cycling indicators are focussed on supporting essential ecological processes necessary for a sustainable ecosystem rather than returning to reference levels.

The relevant criteria are:

- *Litter decomposition rates necessary for supporting ecological processes are consistent with, and within the ranges of, those reported for northern savanna ecosystems*
- *Appropriate soil microbial community functions that support nutrient cycling are present.*
    - *Soil organic carbon and nitrogen are accumulating at a rate necessary for supporting ecological processes.*
    - *Soil mineral nitrogen and soluble organic nitrogen stocks and rates of mobilisation are at a level necessary to support ecological processes.*

Soil physical structure attributes are no longer proposed as a closure criteria due to the long duration required for waste rock substrate to become 'similar' to surrounding natural soils through weathering and biological processes. This attribute is not determinative of ER 2.2(a) being satisfied, and instead, soil physical properties will be monitored as key diagnostic variables for the other nutrient cycling indicators.

Resilience

A resilient ecosystem can experience the range of reasonably anticipated, 'natural' disturbance events and maintain (or return to) its pre-disturbance condition (given natural degrees of inherent variation). Resilience to prevailing disturbances is an important ecological characteristic of Australia's tropical savannas as they experience various fire regimes, periods of prolonged drought (due to distinct but variable wet and dry seasons) and destructive wind events including powerful storms and cyclones. The rehabilitated ecosystem will be exposed to these conditions, and therefore needs to demonstrate resilience and recovery to be considered sustainable.

Fires are frequent in the surrounding Kakadu NP and most local native woodland species have inherent attributes that enable them to persist after fire (*Section 5 KKN ESR8*). However, developmental stages also influence resilience. The rehabilitated ecosystem will be vulnerable to fire during the initial establishment phase when all stems are still relatively small. Following an exclusion timeframe, fire will be introduced in a controlled manner appropriate to the ecosystem's stage of development.

The relevant criteria are:

- *Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.*
- *Post-fire mortality rates of juvenile and adult overstorey species do not exceed those of the reference ecosystems.*
- *In the event of natural disturbances (e.g. wind, drought, or disease), all other closure criteria must be shown to have been met, demonstrating recovery.*

Threats – Exotic flora and fauna

In order to have a maintenance regime that is not significantly different from that of the surrounding Kakadu NP, the presence of introduced species will need to be comparable or better.

The closure criteria for weeds are based on the applicable Federal and Northern Territory legislation. In addition to the prescribed weeds, other, non-legislated introduced species have the potential to require considerable management, and therefore need to be present at levels not requiring a maintenance regime significantly different than adjacent areas of Kakadu NP.

The relevant criteria are:

- *Class A and/or Weeds of National Significance are either absent from the RPA, or have been eradicated from within the RPA for a period of time that exceeds the seed bank longevity of any given species.*
- *The incidence and abundance of all Class B weeds within the RPA is no greater than the reference ecosystem, at a landscape-scale.*
- *The presence and abundance of other introduced flora within the RPA is no greater than those in adjacent areas of Kakadu NP.*

Feral animals are present within surrounding areas of Kakadu NP and are subject to different management practices depending on specific species. Due to the population of feral animals in the park and their highly mobile nature, presence of introduced species on the RPA (in particular buffalo, horses, pigs and cats) is expected. The ERA revegetation and post-closure land management program will continue to actively control feral animals whilst revegetation establishes and develops to a mature, resilient ecosystem. Thereafter, the revegetated ecosystem should have the same degree of resilience to these pressures as the adjacent areas of Kakadu NP, and therefore should not require a significantly different management regime.

In addition to the currently known feral animals both on the RPA and within Kakadu NP, there may be the potential for additional introduced species, both vertebrate and invertebrate, that may have a future legislative requirement for control. The criteria have allowed for this future proofing.

The relevant criterion is:

- *Total number of individuals of: i) buffalo; ii) horses; iii) pigs; iv) cats; and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.*

8.3.6 Cultural

2022 Status Update The cultural criteria presented in this MCP have been developed in consultation with the GAC and NLC.

There is one objective for closure under the cultural closure criteria theme, which is the combination of two ERs: ER 1.1 (a); and ER 2.1:

> *1.1 The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:*
>
> *(a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list;*
>
> *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.*

ER 1.1 (a) requires that ERA maintains the attributes for which Kakadu NP was inscribed on the world heritage list. These world heritage values have multiple criteria that are based on the cultural values in the park. ER 2.1 is the overall objective for closure of Ranger Mine, stating that it must be rehabilitated to a standard that could be incorporated into Kakadu NP, linking rehabilitation to the requirement that there is no impact on the World Heritage Values of Kakadu NP.

Several outcomes have been extracted from these objectives. These outcomes were all based on consultation work completed by Murray Garde in 2014 (Garde, 2015) and finalised by the GAC and NLC (Brady *et al.,* 2021). This work built upon a large body of previous consultation work and studies into cultural closure criteria completed by ERA, NLC and GAC.

A summary of the closure objectives, the outcomes derived from the objectives, parameters used to measure the outcome and the proposed closure criteria are provided in Table 8-10. Section 8.3.6.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of the cultural theme.

ERA have been working closely with the GAC and NLC to ensure that closure execution meets the expectations and needs of the Mirarr Traditional Owners. This is being facilitated through a cultural reconnection committee of Bininj. The committee has been facilitated by the NLC with the objective of promoting the achievement of the Cultural Closure Criteria for the mine by giving Bininj an opportunity for input into closure planning and monitoring (Brady *et al.,* 2021).

The committee has been working a landform and ecosystem re-establishment design that is informed by a view of country that recognises the interrelationship, via local kinship and moiety systems, of all things — the rocks, plants, animals, people, stories, weather, ceremonies and tradition. Incorporating an Indigenous view of the landscape provides an opportunity to better integrate the rehabilitation into the surrounds, with co-benefits from a Western science perspective, such as increasing species diversity of plants and animals.

Table 8-10: Closure criteria – cultural

ER	Objective	Outcome	Parameter	Summary of criteria[9]
1.1 (a) 2.1	The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list; 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.	Landform design supports cultural land use: An-berrk, savanna woodland An-bouk, riparian margins An-gabo, water courses An-labbarl, billabongs Traditional Owners satisfied with the landform.	Size of rocks.	≥7 Surface rock suitability verified by Bininj monitoring - confirm mostly correctly sized.
			Presence / absence of erosion.	≥7 Erosion verified by Bininj monitoring – limited to very minor concerns and only small areas.
			Accessibility, traversability[10].	≥7 Traversability verified by Bininj monitoring – limited to minor difficulties only and few in number.
			General aesthetics (does it look 'natural').	≥7 Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory.
		Traditional Owners are observing improvement in the progression of revegetation on the landform.	Vegetation growth rate.	≥7 Growth rate verified by Bininj monitoring – relative to the number of seasons, the growth of plants across all areas is satisfactory and is improving.
			Vegetation diversity.	≥7 Diversity verified by Bininj – all of the expected species are present in a natural combination in nearly all of the area.
			Correct species for ecological zone.	≥7 Species verified by Bininj – all of the species are correct for nearly all ecological zones.
			Presence of weeds.	≥7 Weeds verified by Bininj – weeds are present in only a minor portion of the area, low level of concern.
		Traditional Owners are satisfied that there are not additional water bodies present.	Presence or absence of artificial water bodies.	Absence of water bodies verified by Bininj monitoring – no artificial water bodies present.
		Traditional Owners satisfied with the water quality and that no silting or sedimentation is occurring.	Visual impressions of water quality (colour, flow, expected clarity, visible contaminants), silting, sedimentation.	≥7 Water quality verified by Bininj monitoring – water appears to be of high quality in most areas, only very minor water quality concerns.
		Traditional Owners satisfied that the riparian zones are in good condition.	Condition of water course margins, creek banks.	≥7 Watercourse margins and creek banks verified by Bininj monitoring – appear to be in a natural condition in most of the area, only minor concerns.
		Traditional Owners are observing improvement in biodiversity on the landform.	Natural species numbers and diversity appropriate for stage of rehabilitation.	≥ Species numbers and diversity verified by Bininj monitoring – natural species occurring according to expectations for natural rate relative to the number of seasons and is improving.
		Traditional Owners are satisfied with the final landform and state of key landmarks.	Line of sight assessment prior to finalising landform design.	Visual connection with key cultural sites verified by Bininj monitoring – sites visible from the same areas and to the same extent as prior to disturbance.

[9] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.6.

[10] Bininj may agree that ripping of landform will lead to a better revegetation outcome, therefore there will be a need to consider and consult on 'pathways' through the landscape.

8.3.6.1 Justification for outcome, parameter and criteria

The success of the rehabilitation over time will be measured against the specified closure criteria (Table 8-10), including the presence of culturally important flora and fauna on the final landform at the appropriate stage of rehabilitation. Garde (2015) speaks to the importance of social organisation, moieties, and conceptions of landscapes, all of which, if not satisfactorily addressed, will ultimately influence the assessment by Mirarr of the rehabilitation.

Garde (2015) also describes a process by which to monitor the success of rehabilitation using a set of cultural health indices. The following discussion is provided as an example only and should not be considered the final agreed mechanism for cultural criteria monitoring.

The cultural health indices described in Garde (2015) have been taken as the parameters for cultural closure criteria with proposed final endpoints presented in Table 8-11. Garde (2015) states that there are very few established models or methodologies to inform such a program. One notable example comes from New Zealand: *Cultural Health Index for Streams and Waterways: Indicators for Recognising and Expressing Maori Values* (Tipa & Teirney, 2003 & 2006). The index attempts to apply indicators that Maori land owners use to assess the health of waterways.

The proposed indicators that could be used to reflect the attitudes of Traditional Owners towards the progress of rehabilitation are largely based on visual and aesthetic factors proposed in Garde (2015), provided in Table 8-11.

In addition to the cultural health indices, one additional criterion has been included at the request of GAC, being that traditional burning practices have resumed.

Table 8-11: Suggested indicators of cultural health of rehabilitated site (Garde, 2015)

Aspect	Suggested indicators
Landscape surface	Size of rocks; presence/absence of erosion; accessibility; general aesthetic (does it look ‘natural’).
Vegetation	Growth rate; botanical diversity; correct species for ecological zone; presence/absence of weeds.
Riparian zone	Presence or absence of artificial water bodies; visual impressions of water quality, sedimentation, silting of rehabilitated water courses; condition of water course margins, creek banks.
Biodiversity	Natural species numbers and diversity; impressions of hunting potential; impressions of vegetable food availability.

Assessments of attitudes and opinions of Traditional Owners will occur at the appropriate time to determine whether or not the Traditional Owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.

Measurements of impressionistic responses are scalar and individual indices are averaged out to provide a score. Scalar numeric assessment will also be accompanied by discursive data that provides a rationale for the score given. There is provision to provide other comments; these are hoped to provide an indication of areas that require management. Scores are to be calculated annually and then compared to determine whether perceptions of rehabilitation are moving in a trajectory that demonstrates achievement of cultural objectives as determined by Traditional Owners.

There are several options for determining final scores. The first option is for sites to be individually assessed by a number of Indigenous stakeholders (barriredweleng 'Traditional Owners' and djunggai 'mother's country managers') and their scores collated and averaged. The second option is for the assessment to be done as a group activity where consensus on a score is established by the group at each site during visitation. This will be determined closer to the completion of decommissioning in consultation with GAC.

The assessment scale will be in a bilingual format that includes information in both Gundjeihmi and English. Each site will not necessarily be assessed for all indicators as some may not be relevant. For example, an indicator such as size of rocks will only be relevant at those sites where high levels of disturbance requires reconstruction of the landform with waste rock. Riparian sites will be assessed for relevant indicators which will not apply to other areas (e.g. condition of watercourse margins will obviously not apply to assessment of areas away from watercourses). An example of the scalar measurement tool is provided in Table 8-12.

Table 8-12: Example of scalar measurement tool for cultural criteria monitoring

ga-djalbolkwarre yerre	ga-bolkwarre yiga ga-bolkmakmen gun-yahwurd	kareh ga-bolkmakmen gare lark	ga-bolkmakmen wurd	bon, ba-bolkmakminj wanjh
no improvement yet noticed	some minor improvements	some areas improved, some areas not	noticeable return to healthy state in most areas	satisfactory return to natural state
1 | 2	3 | 4	5 | 6	7 | 8	9 | 10

Work is continuing to ensure the final landform delivers the appropriate cultural outcome, and ensure the right species are planted in the right places. This includes 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. The GAC and NLC have created a cultural reconnection working group to progress this work. The group has held several visits to Ranger to provide feedback on the rehabilitation, revegetation and habitat recreation plans.

Closure monitoring for cultural criteria will be conducted at a number of sites that collectively provide a cross section of the range of site types where rehabilitation has been undertaken.

An assessment of cultural criteria will need to be completed at each of the selected sites on an annual basis. The approach to monitoring of cultural criteria is described in Section 10.5.

Figure 8-7: Georgetown Creek

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9 Closure implementation

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GLOSSARY

The following key terms are used in this section of the Ranger Mine Closure Plan

Key term	Definition
Bulk material movement	Abbreviated to BMM, he movement of stockpiled waste rock for the purposes of backfill and the construction of the final landform
Capping	Initial and secondary. The placement of waste rock above the tailings in Pit 3. Capping layers provide drainage and act to dissipate the bearing pressure of construction equipment.
Closure domain	Areas with similar features, decommissioning and/or rehabilitation requirements for closure.
Conceptual Reference Ecosystem	Abbreviated to CRE, a conceptual model of a natural reference ecosystem adjusted to accommodate changed or predicted environmental conditions, synthesised from numerous natural reference sites and modified based on evidence from research, trials, experience, benchmarking, and historical and predictive records
Digital Elevation Model	Digital representation of the land topography
Georgetown Billabong	Abbreviated to GB. The statutory surface water monitoring point for Georgetown Billabong, which is located downstream of Corridor Creek and the Corridor Creek wetland filter.
Land Application Area(s)	Abbreviated to LAA. An area on the RPA used as an evapotranspiration disposal method polished and unpolished pond water from the constructed wetlands filters and, more recently, permeates from the water treatment plants. However, irrigation of unpolished pond water ceased at the end of 2009. The concept of land application is to retain metals and radionuclides in the near-surface soil profile.
Maximum Operating Level	Maximum height permitted for process water in the RWD and Pit 3. Maximum operating level also applies to the maximum deposited height of tailings in Pit 3.
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321%.
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Processing	Processing is the mining term to describe all phases of the ore treatment from milling through to the final product packaging of uranium oxide.
Ranger Project Area	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth Aboriginal Land Rights (Northern Territory) Act 1976.
Ranger Water Dam	Abbreviated to RWD. Surface dam used to hold tailings and process water at Ranger. Commonly referred to as "tailings storage facility" or "RWD" in other ERA material. The Ranger Water Dam was one of three tailings storage facilities at Ranger, the others being Pit 1 and Pit 3.

Key term	Definition
Reference level	Abbreviated to RL. Denotes a specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the Ranger Water Dam, depth of Pit 3.
Retention Pond	Abbreviated to RP. A large constructed storage facility that collects runoff and stores pond water for treatment (RP2 & RP6) or release water post-treatment (RP1).
Revegetation domains	Areas of disturbance, to be revegetated, differentiated on their likely physical and chemical constraints that will influence both the initial establishment and the long-term growth, development and functioning of revegetated plant communities.
Subaerial tailings deposition	Deposition of tailings in air, e.g. from spigots or pipes above the surface of the water
Subaqueous tailings deposition	Deposition of tailings below the surface of the water
Tailings Dam / Tailings Storage Facility (TSF)	The Ranger Water Dam (RWD)
Expressed Pond Water	Process water squeezed from reducing pore spaces during the consolidation of tailings formerly known as the Pit Tailings Flux (PTF)
Underfill	Initial fill of waste rock placed in the base of Pit 3.
U3O8	The most stable form of uranium oxide and the form most commonly found in nature. Uranium oxide concentrate is sometimes loosely referred to as yellowcake. It is khaki in colour and is usually represented by the empirical formula U3O8. Uranium is normally sold in this form.
Vadose zone	Abbreviated to VZ. The portion of the sub-surface that lies between ground surface and the water table or saturated zone.
Waste rock	Abbreviated to WR. The mineral waste produced in the mine but is stockpiled due to its low grade i.e. material which does not enter the processing plant. For example, 1s waste rock is typically material that has a grade of less than 0.02% U3O8; 2s waste rock (or low-grade ore) is typically material that has between 0.02% and 0.12% U3O8.
Wetland filter	A man-made system that is purpose built to emulate the ecosystem services provided by natural wetlands as a low cost, efficient means to polish/remediate/clean-up effluent.
Wicks / Prefabricated Vertical Drains	Abbreviated to PVD. Drains inserted vertically into unconsolidated tailings material in Pit 1 and 3. The drains consist of plastic strips wrapped in geofabric with extruded channels that allow water to drain upwards from the tailings as it consolidates

ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used in this section of the Ranger Mine Closure Plan.

Abbreviation/ Acronym	Description
1s rock	Waste rock material that typically has a grade of less than 0.02% U_3O_8
2s rock	Waste rock (or low grade ore) material that typically has between 0.02% and 0.12% U_3O_8
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ALARA	As Low As Reasonably Achievable
BC	Brine Concentrator
BMM	Bulk Material Movement
BPT	Best Practicable Technology
C&M	Care and Maintenance
CCD	Counter Current Decantation
COPC	Constituents of Potential Concern
CRE	Conceptual Reference Ecosystem
CRF	Cemented Rock Fill
CSIRO	Commonwealth Scientific, Industrial Research Organisation
DEM	Digital Elevation Model
DISR	Commonwealth Department of Industry, Science and Resources (formally DIIS)
DITT	Department of Infrastructure, Tourism and Trade
DPIR	Now DITT formerly the Northern Territory Department of Primary Industry and Resources
ER(s)	Environmental Requirements
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
FLF	Final Landform
GAC	Gundjeihmi Aboriginal Corporation
GCMBL	Georgetown Creek median bund leveline
GPS	Global Positioning System
H2	Second Half
HDPE	High Density Polyethylene
HDS	High Density Sludge
LAA	Land Application Area(s)
MCP	Mine Closure Plan

Abbreviation/ Acronym	Description
MOL	Maximum Operating Level
mRL	Metres Reference Level
MTC	Minesite Technical Committee
NLC	Northern Land Council
NP	National Park
PAW	Plant Available Water
PMP	Probable Maximum Precipitation
PSD	Particle Size Distribution
PTF	Expressed process water formerly termed Pit Tailings Flux (PTF)
PVD	Prefabricated Vertical Drains (wicks)
Q1	Quarter 1, as in first quarter of the calendar year. Also Q2, Q3 & Q4
R3D	Ranger 3 Deeps
RL	Reference Level
RMV	Ranger Mine Village
ROM	Run-of-mine
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
RWD	Ranger Water Dam formerly the Tailings Storage Facility or Tailings Dam
SSB	Supervising Scientist Branch; formally the Supervising Scientist Division
SX	Solvent Extraction
TDS	Total Dissolved Solids
TLF	Trial Landform
TSF	The Ranger Water Dam (RWD) formerly known as the Tailings Storage Facility or Tailings Dam
WTP	Water Treatment Plant

9 CLOSURE IMPLEMENTATION

9.1 Introduction

This chapter provides:

- a description of the closure work program for each closure domain; and
- a description of the closure activities that are required across multiple closure domains.

Within the description of closure works for each domain, the status of completion for each closure activity is provided. This chapter details the ‘what’, ‘where’ and ‘when’ of closure activities at the Ranger Mine. Studies used to inform the closure strategy for a domain are the ‘why’ and have been previously described in *Section 5 KKN Supporting Studies*.

9.2 Closure domains

Closure domains for the Ranger Mine are areas with similar closure features, decommissioning and/or rehabilitation requirements (DMIRS, 2020). The location and spatial extent of each closure domain is shown in Figure 9-1. Table 9-1 identifies the area of disturbance that has occurred within each domain, whilst

Table 9-2 identifies the area that has been progressively rehabilitated.

For each domain, discussion is included about the tasks that have already been completed, those currently underway, those planned, and relevant contingency plans. Closure activities that apply across more than a single domain, such as revegetation, or activities that do not fit into a specific domain, such as the treatment of the process water inventory, are discussed in Section 9.3.

Table 9-1: Land disturbance by domains

Domain No.	Domain Description	Disturbance (ha)	
1	Pit 1	41.40	41.40
2	Pit 3	107.12	107.12
3	Ranger Water Dam (formerly the Tailings Storage Facility)	185.18	185.18
4	Land Application Areas		
4A	Corridor Creek LAA	13.50	
4B	Magela LAA	45.56	
4C	Djalkmarra LAA	12.50	
4D	Djalkmarra LAA ext.	5.80	
4E	Retention Pond 1 LAA	36.0	
4F	Retention Pond 1 LAA ext.	0.9	
4G	Jabiru East Land Application Area	43.0	158.00

Domain No.	Domain Description	Disturbance (ha)	
5	Processing plant, administration buildings and Water Treatment Plant	39.86	39.86
6	Stockpiles	268.65	268.65
7	Water Management Areas		
7A	Retention Pond 1	53.89	
7B	Retention Pond 2 & 3	21.80	
7C	Retention Pond 6	12.85	
7D	Retention Pond 1 wetland filter	11.43	
7E	Corridor Creek wetland filter	9.48	
7F	Georgetown Creek Mine Bore	13.84	
7G	Sleepy Cod Dam	2.33	125.61
8	Linear Infrastructure (tracks, service corridors)	40.79	40.79
9	Miscellaneous		
9A	Gagudju Yard	1.80	
9B	Ranger Mine Village (temp)	3.04	
9C	Nursery/Coreyard	4.05	
9D	Levee	2.82	
9Ei	Borrow Pits	2.32	
9Eii	Borrow Pits	16.40	
9Fi	Landfill Sites	3.62	
9Fii	Landfill Sites	6.79	
9G	R3 Deep Decline	2.63	
9H	Magazine	0.95	
9I	Trial Landform	10.60	55.02
10 A & B	Airport & ERISS	44.08	44.08
11	Residual RPA	0	0
Total			1062.53

Table 9-2: Area of progressive revegetation at RPA

Site	Area
Trial landform	6.38
Borrow pit	1.39
RPI Site 3	0.12
Closed track at RMV	0.31

Site	Area
RMV revegetation track	3.34
RMV (Ranger Mine Village)	1.40
Drill pad east of Djalkmarra 1	0.13
Drill pad east of Djalkmarra 2	0.22
Drill pad east of Djalkmarra 3	0.19
Magela B drill pad 1	0.06
Magela B drill pad 2	0.04
Drill pad	0.16
Stage 13.1	4.00
Pit 1	40.00
Total	*57.74 ha*

Figure 9-1: Ranger Mine closure domains

9.2.1 Pit 1

Figure 9-2: Pit 1 (June 2021)

9.2.1.1 Completed rehabilitation

Upon the completion of mining in December 1994, ERA commenced activities for the closure and rehabilitation of Pit 1 (Figure 9-2). A summary of the activities that have taken place from 1995 to present is provided in Table 9-3.

Table 9-3 Completed Pit 1 rehabilitation

Year	Closure activity
1995-96:	Preparation of the pit to receive tailings included the construction of an underdrain in the base of the pit of approximately 10,000 m2 in area, and construction of a horizontal rock-filled adit from the base of the pit to intercept a vertical dewatering bore. Tailings deposition into the pit began in August 1996.
2005	Installation of a seepage limiting barrier in the south-eastern part of the pit occurred to seal permeable wall zones and ensure the effective containment of process water.
2006	Grouting and ongoing monitoring of the seepage limiting barrier.
2008	Tailings deposition in Pit 1 ceased in Quarter 4. The void volume of Pit 1 is 24.0 Mm3. The volume of unconsolidated tailings in Pit 1 was approximately 18.9 Mm3 and the average level of the tailings was less than +12 mRL, in accordance with the interim approval to store tailings in Pit 1 (Marshall, 2014).
2012	The installation of 7,554 prefabricated vertical drains (PVDs) occurred to assist with dewatering the pit prior of capping and rehabilitation. The wicks were installed within the top 40 m of the tailings mass. The purpose of the wicks was to dewater the upper level of the tailings and promote tailings consolidation, thus establishing a stable surface upon which to commence backfill activities.
2013-14	Installation of a geotextile layer occurred across the exposed tailings surface area and, subsequently, a 2.5 m thick rock initial capping was placed across 97% of the pit. The rock placement was designed to activate the vertical wick drains and promote porewater expression. A laterite layer was placed over the northern half the pit to form the pond water interception layer, to prevent rainwater adding to the process water inventory.

Year	Closure activity
	Prior to the placement of the initial capping layer in the fourth quarter of 2013 and in 2014, 28 settling monitoring plates were installed across the pit to enable regular verification and updating of the consolidation model.
2015	A geotextile layer was installed across the remaining exposed tailings surface (3% of total surface).
2016	In January, the remaining 2.5 m thick rock initial capping[1] and laterite layers were placed so the entire pit surface was covered. Two decant towers were installed to remove the expressed process water from the pit. A subsequent decant well was installed in 2017. Bulk backfill of Pit 1 commenced in May following regulatory approval of the final average tailings level of +7 mRL.
2018	Bulk backfill was halted in July, pending regulatory approval for final backfilling works.
2019	In May the final backfill commenced following regulatory approval of the final landform design.
2020	The final backfill and landform contouring was completed in August, with scarification of the final landform occurring in November. Works on the Interim Water Management System (IWMS) are completed prior to the commencement of the wet season.
2021/22	Initial planting on the final landform (Figure 9-3)

Key elements of Pit 1 closure were (these are further described in the sections that follow):

- construction of an underdrain across the floor of the pit, connected to a vertical dewatering bore via a horizontal rock filled adit;
- deposition of unconsolidated mill and RWD tailings in the base of the pit;
- installation of vertical wick drains to assist with dewatering;
- installation of an initial capping layer of geotextile and waste rock;
- ongoing removal of pit tailings flux during tailings consolidation to reduce the risk of contaminants entering groundwater or surface waters and potentially impacting the RPA or offsite aquatic ecosystems;
- placement of Grade 2 (2s) waste rock material below the water table to reduce the risk of contaminants impacting RPA or offsite aquatic ecosystems, and below a layer of Grade 1 (1s) material to ensure any gamma radiation from the 2s material is sufficiently attenuated;
- construction of a surface layer of non-mineralised 1s material, with consideration given to the physical characteristics and thickness of the material required to support a self-sustaining native ecosystem similar to target reference ecosystems;

[1] Note: “Initial capping layer” and the term “Preload” has been interchangeably been used in numerous studies for Pit 1

- construction of drainage channels to manage erosion of the surface layer and reduce the risk of mobilised sediments or other contaminants impacting RPA or offsite aquatic ecosystems;
- revegetation to initiate the establishment of a self-sustaining ecosystem; and
- monitoring and research to continue to improve on the trials and modelling already completed. This will further reduce the risks associated with aspects of the Pit 1 closure and inform the closure planning for the rest of the final landform.

Tailings preparatory works

It was recognised that the shape of Pit 1 would result in rapid filling of the lower benches, with little opportunity for beaching and air drying of the tailings during deposition. The intent of the pre-deposition works was to maximise the rate of consolidation of the tailings by providing a hydraulic gradient towards the base of the deposited tailings (Knight Piesold, 1997).

Preparatory works consisted of an underdrain, constructed from the base of the pit to around -142 mRL and approximately 10,000 m^2 in area. A horizontal rock filled adit, was also installed, from the base of the pit to intercept a vertical de-watering bore. Process water from the rock filled adit, was pumped to the Ranger Water Dam to maintain a zero head at the level of the underdrain (Coghill *et al*., 2003).

Tailings deposition

ERA commenced the deposition of tailings within the mined-out Pit 1 in August 1996. Between 1996 and December 2008, ERA deposited approximately 18.9 Mm3 (25.6 Mt) of tailings into the pit (ATC, 2012, CSIRO, 2014). Concurrent with tailings deposition, Pit 1 was also used to store process water.

The original tailings application specified a maximum tailings level of 0 mRL (ERA, 1995). This allowed for approximately 15.2 Mm^3 of unconsolidated tailings to be deposited into the pit (Kenny, 2003). To maximise the volume of tailings able to be stored in Pit 1, ERA constructed a seepage-limiting barrier in the southeast section of the pit. The barrier sealed permeable sections of the pit wall and formed part of ERAs successful application to increase the tailings deposition level to an interim +12 mRL, in 2005 (ERA, 2005).

The deposited tailings undergo a geotechnical process called consolidation. Consolidation causes the volume of the tailings to decrease as the mass compresses, due to self-weight and the application of capping and backfilling loads (Fitton, 2020). Consolidation in Pit 1 is measured using 28 settlement monitoring plates, installed as part of the initial capping works.

Consolidation of tailings, in Pit 1, has proceeded in accordance with modelled outcomes in ATC (2012) and Fitton (2015a) (Fitton, 2021). Based on the predicted ultimate settlement of 4.52 m the degree of consolidation at the time of the last survey is approximately 98 to 99% (Fitton, 2021).

Wicking

Prefabricated vertical drains or wicks were installed over the period May to September 2012 (ATC, 2012). A total of 7,554 wicks, covering an area of approximately 18.4 ha, to depths between 18 m and 34 m, were installed on the tailings surface in Pit 1 (Figure 9-3, ATC, 2012; ERA, 2013a). The purpose of the wicks was to facilitate consolidation of the upper 40 m of tailings in order to release water and densify the tailings (ERA, 2013b).

Figure 9-3: A view of some of the 7,554 vertical wick drains installed in Pit 1 in 2012

Geotextile placement and initial capping

Following the installation of wick drains and the draining of water from the surface of Pit 1, a geotextile layer was placed across the exposed tailings surface area. An initial waste rock cover, called a pre-load at the time, accompanied this and was designed to activate the vertical wick drains and promote porewater expression. Initial capping works were carried out during the last quarters of 2013, 2014 and 2015.

Backfill

Following the construction of the initial capping layer, ERA commenced works to complete the remainder of the backfill and construction of the final landform in Pit 1. The two types of waste rock used in rehabilitation are termed 1s and 2s (Table 9-4). Waste characterisation is further discussed later in this chapter. Placement of bulk backfill into Pit 1 by Ranger's mining production fleet commenced in 2017 and was completed in 2020. The backfill progressed in two distinct phases (ERA 2019a):

- Placement of mineralised (low 2s) and un-mineralised (1s) rock fill up to the '2's Cap' between April 2017 and November 2018; and
- Placement of un-mineralised (1s) material as the surface layer, up to the Final Landform (FLF) level.

Table 9-4: Type of waste rock used in rehabilitation

Type	Term	Uranium oxide grade (U3O8) %wt
Non-mineralised waste rock	1s (Grade 1)	Less than 0.02
Mineralised waste rock	2s (Grade 2)	0.02 – 0.05

The design for the backfill of Pit 1 prioritised maximising the volume of mineralised (low 2's) material placed in the pit (Fitton, 2018a). Therefore the key to the backfill design of Pit 1 was to place fill to an elevation so that, after the potential settlement due to tailings consolidation, the 2s material is below the height of 20 mRL with minimal need for modification of the surface levels.

The bulk backfill design also aimed to minimise the potential disturbance to the decant towers, settlement plate upstands and future drainage patterns. ERA placed the 2s waste rock in seven stages using three metre paddock-dumped layers. This dumping method allowed for the raising of the settlement standpipes and decant wells, and therefore more accurate monitoring of fill depths (Fitton, 2015b) (*Section 5 KKN Supporting Studies*).

The final level of 2s waste rock was completed in 2018. Surveys demonstrated that the level of 2s is below the 20 mRL, achieving the desired design parameters (Fitton, 2018b). The conservatism built into the design allows for additional tailings settlement induced by the weight of the final waste rock cover.

Following placement of the 2's, construction began on the surface layer in 2019. The surface layer was not constructed in thin lifts, like the underlying 2's layer, but two lifts, called the FL-2.5 m layer and final landform layer. The backfilling and contouring of the surface layer was completed in August 2020.

9.2.1.2 Current rehabilitation

Tailings consolidation and removal of pit tailings flux

Water from various sources contributes to the water balance of Pit 1 (Figure 9-4). Rainfall is collected both on the immediate surface of Pit 1, and indirectly via overland flow from nearby catchments that report to the pit. The bottom of the pit is filled with tailings that are nearly fully consolidated. The pore spaces between the tailings solids contain process water and, as the tailings have consolidated, that process water has been squeezed up as a consolidation flux (pit tailings flux). Above the tailings are several layers of waste rock backfill. Most layers of the waste rock backfill are porous and, as such, can accumulate water from the various sources. Groundwater from surrounding rock formations may enter this waste rock backfill.

Decant wells have been installed and extend from the surface of the waste rock backfill down to near the top of tailings. The towers consist of stacked concrete rings, with the bottom ring slotted to allow water to enter the decant.

As the tailings in Pit 1 approaches the completion of consolidation, the flow rate of expressed process water has declined to low levels. The decant towers have been retained as a contingency for managing any future tailings consolidation flux and mitigating seepage from the waste rock cap to the surrounding perimeter drain. The towers are currently operated on an 'as required' basis.

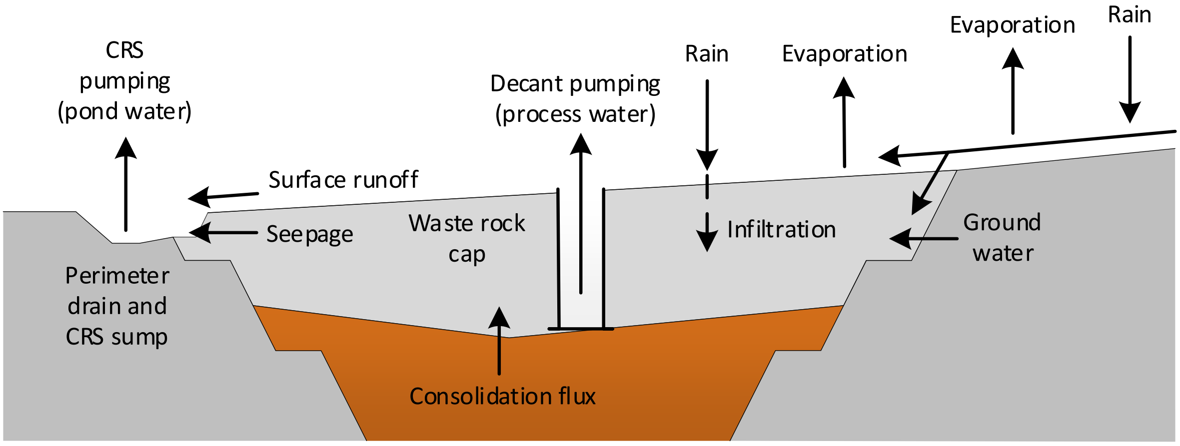


Figure 9-4: Pit 1 water balance schematic

Landform

In preparation for revegetation and further trials (Chapter 9.1.1.1), the surface of Pit 1 was lightly scarified in Q3 2020. This measure was implemented to reduce sediment movement and erosion during the 2020/2021 wet season (Figure 9-5).

Figure 9-5 Scarification as seen on 28 Oct 2020 (top), 6 Jan 2021 (middle), 17 Feb 2021 (bottom)

Pit 1 was walked and visually inspected for parameters such as accessibility and traversability by the representatives of the traditional owners (or themselves) once the surface preparation was completed. No additional surface preparation is currently planned to be applied to Pit 1.

To ensure that the final surface topography for the Landscape Evolution Model (LEM) was built to the design requirements, a high-resolution DEM of Pit 1 will be produced annually and provided to stakeholders. An annual topographic survey across the pit is also planned, as is a year-on-year DEM change detection to inform changes in surface topography.

Drone photography (high-resolution orthomosaic) was undertaken on a monthly basis to monitor the micro-erosion features on the Pit 1 surface. Comparison was made between drone captures, to enable a visual assessment of sediment movement across the Pit 1 landform and mapping of sediment transport zones. Identification of erosion from the aerial comparison will be complemented by field observations on a weekly basis throughout the wet season. The monthly stitched-orthomosaic proved to be a helpful monitoring tool to identify the leading indicators for landscape changes, which will inform the preparation works for next year's wet season (Figure 9-6).

Interim water management works were completed in 2020, and further upgraded in 2021, to mitigate the water and sediment risk from Pit 1. These included:

- The installation and improvement of a water collecting drain around the edge of Pit 1 to capture rainfall runoff (Figure 9-7). Hydraulics of the channel had been modified in 2021 by reinforcing the check dams near the inlet channel.
- The extension of the previous sump (CRS) to a sufficient capacity to collect this rainfall runoff.
- The installation and further capacity upgrade of the pumping and piping infrastructure (Figure 9-8).

These interim water management structures will remain in place until the final landform construction commences in the neighbouring Corridor Creek catchment, at which time the final erosion and sediment control features will be installed. The ongoing management, maintenance and monitoring of the interim water management structures will be described in the latest version of the Ranger Water Management Plan.

Figure 9-6 Time sequence of one channel forming on Pit 1. (2rog, 2021)

Figure 9-7: View of the perimeter drain along the southeast edge of Pit 1 (January 2021)

Figure 9-8 Completed CRS upgrade works with pumping infrastructure installed (January 2021)

Monitoring and maintenance activities

Pit 1 will be available two years before other sections of the FLF and, as such, it provides an opportunity to develop, and fine tune ERA's ecosystem re-establishment approach. The *Pit 1 Ecosystem Re-establishment Plan: Trials and monitoring program* developed the monitoring and research aspects that were key to to align with the *Pit 1 Progressive Rehabilitation Framework* and inform ongoing progressive rehabilitation across the Ranger Site (ERA, 2021c).

ERA intends for the monitoring proposed within the plan to be holistic as well as adaptive. Monitoring outcomes may change once more data is collected and the success of a method, including the suitability, is understood (ERA, 2021c). New monitoring techniques may also become available, and inform objectives. Key aspects described in the plan cover:

- Landform,
- Water,
- Ecosystem, and
- Radiation themes

Further details of the planned monitoring and maintenance aspects can be found in Section 10 *Monitoring and Maintenance,* and the *Pit 1 Ecosystem Re-establishment Plan: Trials and monitoring program* (ERA, 2021c)

Irrigation

A central pivot tower has been installed to operate as the main irrigation system for the whole Pit 1 area. A solid-state sprinkler system was temporarily used to irrigate revegetated areas from March – July until the pivot system was operating. The pivot was operational by the end of July, and was installed using a 310 m, 30 ha Upton Australian-made corrosion resistant system (ERA, 2021c). The location of the central pivot tower, including the wheel tracks, is shown in Figure 9-9.

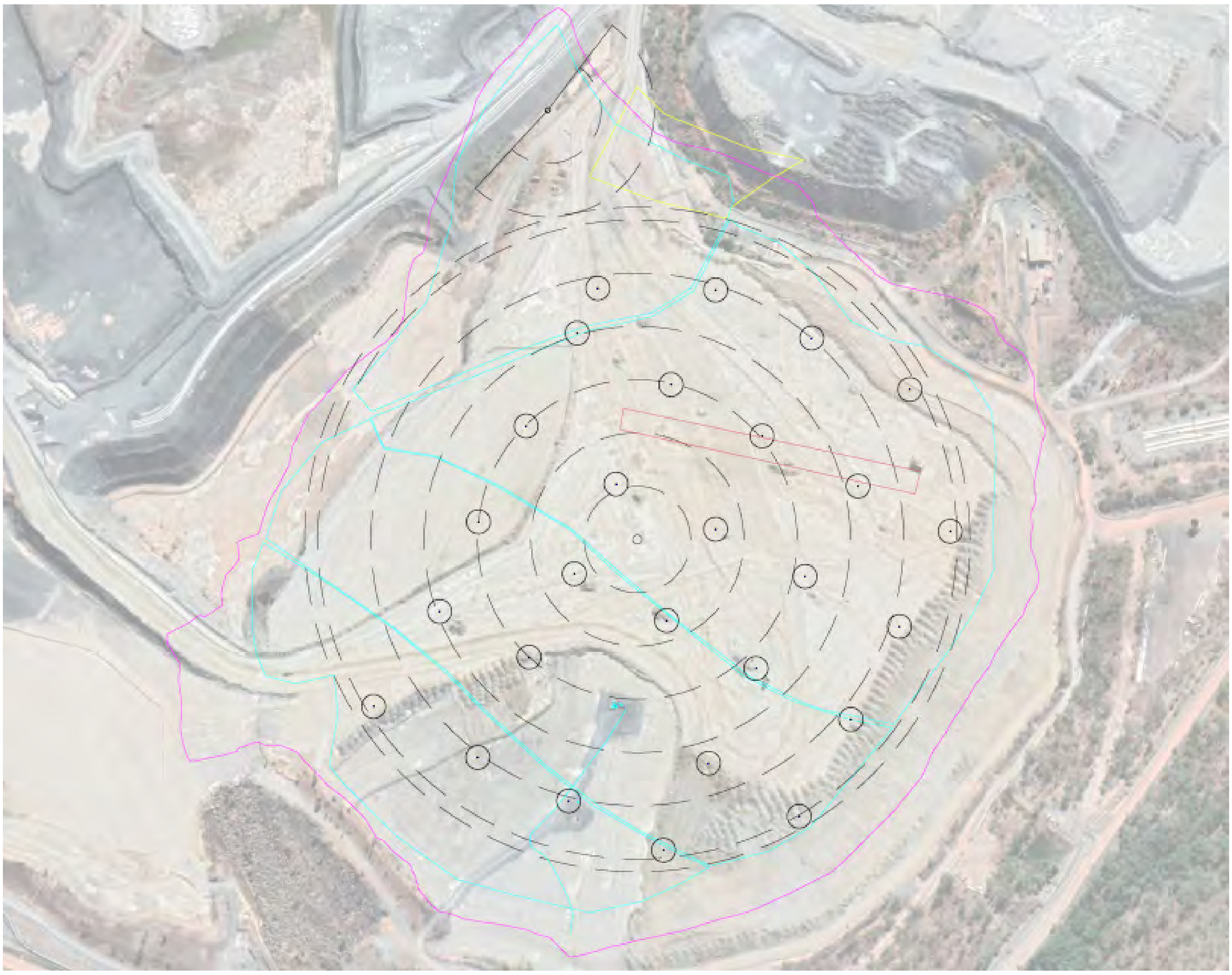


Figure 9-9 Location of the central pivot tower, including the wheel tracks. Total area of the pivot circle is approximately 29 hectares (ERA, 2021c)

Revegetation

Thirty-six hectares of revegetation was completed on Pit 1 over a ten month period in 2021 - 2022, including research trials and progressive revegetation (Table 9-5, Figure 9-10 & ERA, 2021c). Further details on the trial objective, methodology and preliminary results are discussed in *Section 5*, KKN ESR3. Further information on species planting lists, including conceptual reference ecosystem (CRE) work is discussed in *Section 5,* KKN ESR1.

Table 9-5 Summary of revegetation trials (ERA, 2021c)

	Research			Progressive Revegetation	
Timeline	March 2021 - April 2021	July 2021	October 2021	May -June 2021	November/ December 2021 and January 2022
Area (ha)	6.6	3.9	3.9	2.9	18.8
Vegetation	Trial species			CREv2 2020 version	CRE 2021 version

Irrigation	Solid state sprinklers until August	Pivot system	Solid state sprinklers until August	Pivot system

Figure 9-10 Pit 1 Revegetation Areas

Habitat creation

The revegetated final landform in its early years will have very little habitat areas and as such is unlikely to see the early return of fauna. To assist with the re-creation of the ecosystem, ERA has been working with traditional owners as part of the cultural reconnection committee (refer *Section 8*

Post Closure Land Use), to use rocks to create habitat areas (Brady *et al.,* 2021). These areas also provide the dual purpose of creating features on a relatively flat landform.

The rock habitat features have been placed on pre-determined lines that will link the surrounding ecosystem to the final landform (Figure 9-11). This will encourage the return of fauna from the surrounding areas.

The habitat features have been designed by local Bininj man, Peter Christophersen, who has decades of experience with mine rehabilitation. Peter has identified natural landscape features in the form of rocky outcrops that occur throughout Kakadu and in the area around the Ranger Project Area (Brady *et al.,* 2021). Several rocky habitat features were placed on Pit 1 during 2021 (Figure 9-12). The cultural reconnection committee is now being engaged to determine the selection of plant species for these rocky outcrops based on traditional ecological knowledge. The committee have begun discussing links between desired flora and fauna and their connection to each other and to places, people, story and cultural practice. Planting is expected to occur during 2022.

Figure 9-11 Preliminary plan for location of rocky outcrop habitat features on the final landform

Figure 9-12 Rocky outcrop habitat feature on installed on Pit 1

9.2.1.3 Planned rehabilitation

The only remaining rehabilitation in pit 1 is the removal of the interim water management drain and ponds, decant wells and infrastructure and revegetation of these disturbed areas.

9.2.1.4 Contingency planning

There is an ongoing monitoring program (*Section 10 Closure monitoring and maintenance*) that will consider the consolidation, erosion rates and revegetation success. Remedial action will be determined and implemented, where required, with appropriate consultation with the Minesite Technical Committee (MTC) stakeholders. This may include, for example, additional waste rock brought on to Pit 1 to remediate areas of excessive erosion.

9.2.2 Pit 3

Figure 9-13 Pit 3

9.2.2.1 Completed rehabilitation

Open-cut mining in Pit 3 commenced in July 1997 ending in November 2012, resulting in a base (floor) elevation of -265 mRL. The Pit 3 activity timeline is summarised in Table 9-6.

Table 9-6: Completed Pit 3 rehabilitation

Year	Works
1995	ERA submitted application to the MTC to mine Ranger Pit #3 orebody
1996	Approval received to mine the Ranger Pit #3 orebody
1997	Mining commences
2006	ERA submitted and application to deposit tailings to an average interim fill level of approximately -20 mRL which included preparatory works to construct a waste underfill and drainage bed
2007	Approval is received for the 2006 Application. ERA applied to extend the proposed pit outline “Shell 50” delaying tailings deposition until 2020.
2008	Approval received to commence additional mining works. Extension works commenced mining an additional 54.5 Mt of material containing 7,400 t of U3O8 of high-grade ore.
2012	Cessation of mining resulting in 94 million tonnes (Mt) of product to an elevation of -265 mRL in the east of the pit (INTERA 2014) altering the final tailings level to approximately -27 mRL, lower than previously identified.
2012 – 2014	Completion of the underfill, underdrain and dewatering systems. Waste stockpiles from the Ranger 3 Deeps exploratory decline are disposed of into Pit 3 (ERA, 2017a). Total material movement of 31.7 Mt into Pit 3 to an approximate elevation of -100m AHD (ERA, 2015).

Year	Works
2015	Five brine injection bores, piping and infrastructure are constructed within the underfill zone in Pit 3. Commencement of tailings deposition from mill processing. Predicted average consolidated tailings level is -30.2 mRL.
2016	Commencement of Brine injection. Commencement of tailings transfer from RWD into Pit 3.
2018	Commencement of alternating the discharge of dredged tailings from multiple discharge points on the Southern wall. Preparation for subaqueous dredged tailings deposition trial commences. Diffuser discharging dredged tailings from the RWD into Pit 3 trial commences.
2019	Installation and commissioning of second dredge. Final maximum level altered to -15 mRL at end of deposition. Subaqueous discharge of dredged tailings and subaerial discharge of mill tailings continues. Installation of multiple spigots along the eastern wall for mill tailings discharge (Figure 9-15).
2020	Final maximum tailings level altered to -10 mRL across the pit at end of deposition
2021	Cessation of mill operations and wind down of mill tailing deposition to Pit 3 on January 8 Cessation of dredging and bulk transfer of tailings from the tailings storage facility to Pit 3 on February 15 Successful wicking trials undertaken Construction of tailings dumping point on wall Approval to transfer remnant tailings from RWD to Pit 3 Remnant tailings transfer begins via truck and dozer Completion of remnant tailings transfer in December.
2022	CPT Campaign Rapid water drawdown to wicking level of RL -14.1 Reconstruction of Western Ramp Construction of Western Ramp Crane Pad & working platform for wicking Transfer and mobilization of workboats (Mudskipper & Ginga) into Pit 3 Reconstruction of Southern Ramp Construction of laydown areas for wicking (Stage 9 & Pit 3 South Laydown) Construction of dedicated access and egress to Pit 3 Western Ramp Installation of wash bays at controlled/supervised intersection points Installation of 2x time lapse cameras

Underfill and brine injection

Prior to tailings being deposited into the mined-out Pit 3, preparatory works were completed to enable the pit to receive tailings and brine, the conceptual design provided in Figure 9-14. The construction of the waste rock underfill and overlying underdrain raised the floor of the mined-out Pit 3 from -265 mRL to -100 mRL providing a broad, level surface area for tailings deposition. The construction of the underfill facilitated a low rate of tailings rise as well as optimising tailings consolidation rates. Early and rapid consolidation will support a stable waste rock capping design, improving the success of revegetation and rehabilitation programs.

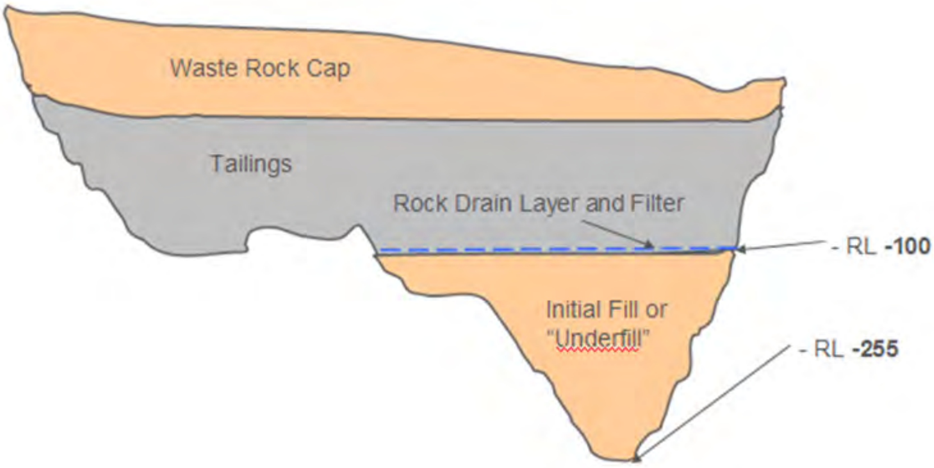
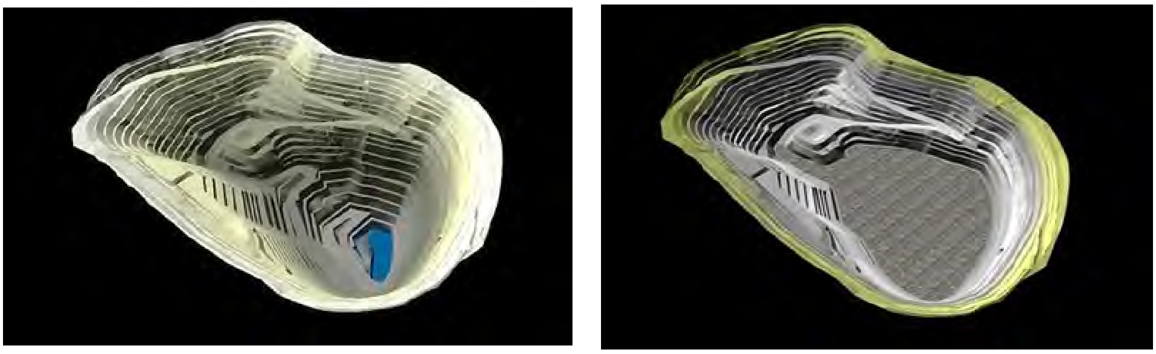


Figure 9-14: Pit 3 backfill conceptual design

The underfill material was sourced from low grade (2s) stockpiles. Deposition was in a fan pattern radiating outwards from a fixed point to maximise material segregation. This method ensured the larger size material filled the bottom of the pit, with fines content increasing as the underfill approached its maximum elevation (Figure 9-15 and Figure 9-16).



Empty pit shell: December 2012 | Pit base at end of underfill construction

Figure 9-15: Pit 3 before and after underfill construction

Figure 9-16 Pit 3 underfill during construction in 2014

The porous underfill is the final repository for the concentrated brine waste stream produced by the Brine Concentrator (MacKenzie 2018). Process water treatment by the Brine Concentrator is described further in Chapter 9.4.3.

The current water model forecasts approximately 1.8 GL of brine will be generated prior to final site closure. Available void volume, assuming a waste rock specific gravity of 2.65 and gravimetric moisture content of 2%, is 2.48 GL (Coghill 2016) determined from test work on the waste rock and final survey volumes. Overlaying the underfill is an engineered underdrain to remove process water expressed from the overlying tailings as they consolidate, and water displaced upwards from within the underfill from the brine injection process (Figure 9-17). The underdrain consists of a nominal 2 m thick waste rock drainage layer constructed at the interface of the underfill and tailings surface, graded slightly to the west to direct water towards an engineered sump located at a low point along the south-west wall of the pit.

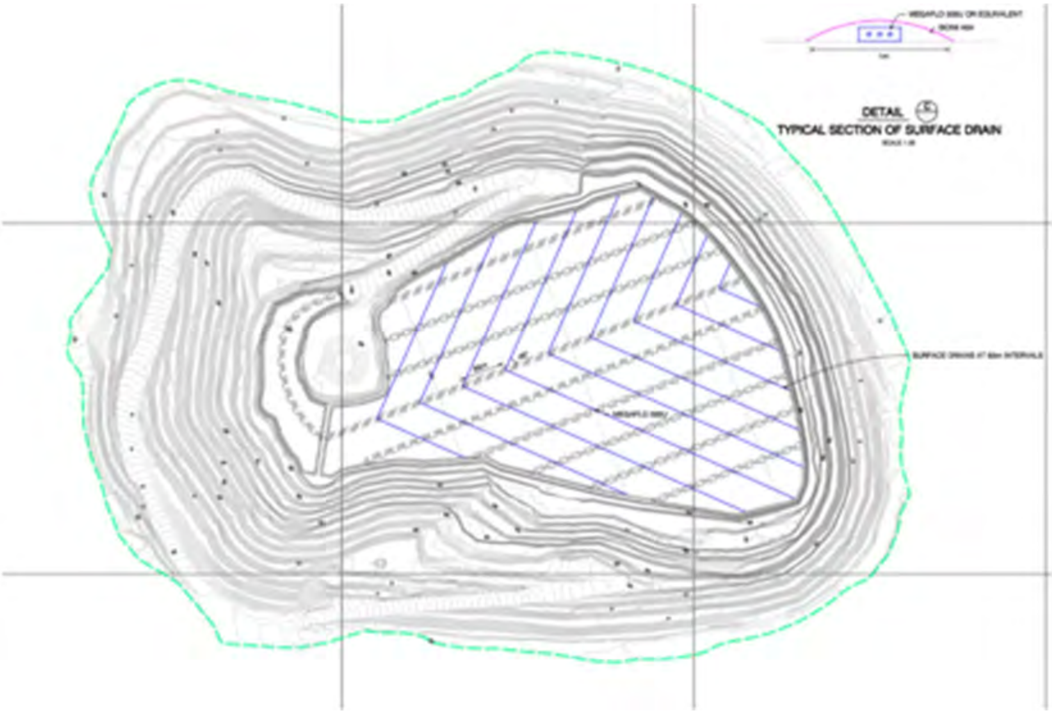


Figure 9-17 Pit 3 underdrain schematics

Collected water flows from the sump through a lateral borehole into a vertical borehole termed the Underdrain Bore. A pumping system consisting of a submersible pump and associated power and piping infrastructure transfers the collected water to the process water inventory via Process Water Return Tanks located on the southern margin of Pit 3. The flow and electrical conductivity of water collected by the Underdrain Bore is monitored.

The principal pathway for process water treatment over the closure period is through the Brine Concentrator, which generates a concentrated brine waste product requiring permanent disposal. Following construction of the underfill and underdrain in Pit 3, five brine injection bores were installed into the underfill, each with a dedicated pipeline connecting back to a valved manifold located on the western ramp of Pit 3.

A brine cooling and pumping system installed at the Brine Concentrator cools the otherwise hot brine to temperatures compatible with the feed pipelines, delivering the brine to the manifold. The hot concentrated brine uses indirect heat exchangers with process water as the cooling medium, which is then pumped to a storage (surge) tank. The brine is drawn from the surge tank and pumped to the brine injection system (Figure 9-18).

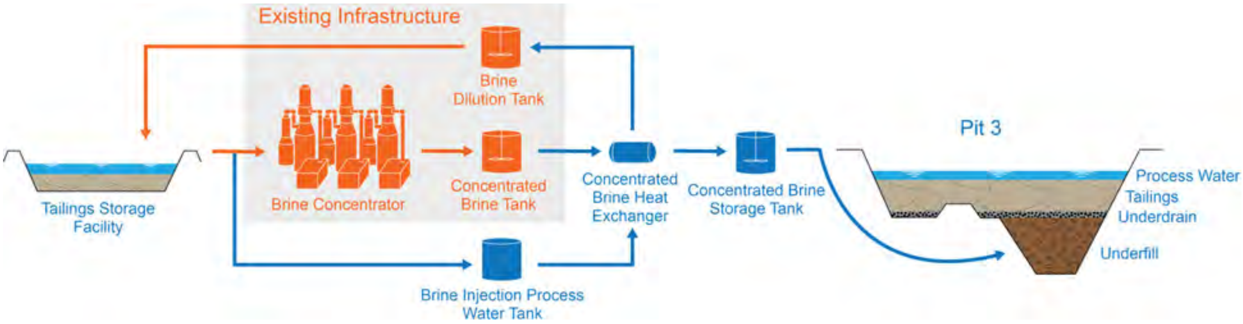


Figure 9-18: Flow Diagram of Brine Injection

Inherent scaling issues associated with concentrated brine requires all lines and equipment within the brine injection area to be regularly flushed with process water. In addition to this, a 'pigging' system removes any residual scale.

When the brine injection system is inoperable, Brine Concentrator brines are recirculated to the process water inventory causing the process water salt content to increase. The Brine Concentrator is specifically designed to treat high salt content water. At a total dissolved solids concentration over 120 g/L, however, the distillate production capacity is impacted. ERA regularly monitors the total dissolved solids concentration in process water and forecasts future concentrations through its operational water balance modelling software (refer *Section 2 Project Overview*).

Operational issues has required brines to be temporarily diverted back to the process water inventory. Remediation work completed in the second half of 2020 enabled Brine Injection to be resumed as the Brine Concentrator operations permitted in 2021. All of five original injection bores are now considered to have irrevocably failed, the in-pit components of that system decommissioned. Replacement bores are being installed described further in Chapter 9.2.2.3.

Tailings deposition

Tailings deposition into Pit 3 as defined by Environmental Regulation 11.2 requires all tailings are placed in the mined out pits. A schematic cross-section of Pit 3 prior to tailings deposition is presented in Figure 9-19.

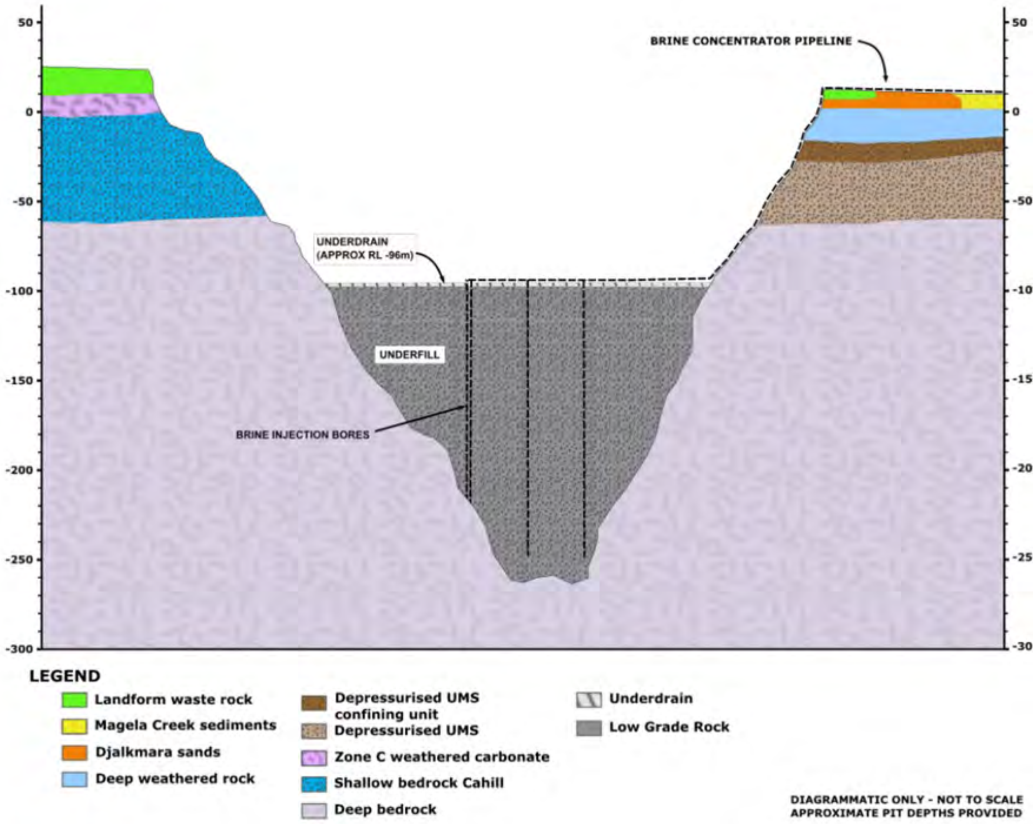


Figure 9-19 Schematic cross-section of Pit 3 before tailings deposition commenced

Tailings deposition into Pit 3 occurred by direct deposition of processing plant (mill) tailings commenced in 2015 and practically ceased on 8 January 2021, with the cessation of mill operations. Mill tailings were pumped as a neutralised slurry of approximately 50% solids by weight directly into Pit 3 via an overland high-density polyethylene (HDPE) pipeline.

Tailings were additionally transferred from the Ranger Water Dam (RWD) into Pit 3 via dredging operations from early 2016, with practical completion on 15 February 2021. Initial transfer was via a single diesel-powered cutter suction dredge. In 2019, a second dredge was installed and commissioned increasing dredging capacity. Dredged tailings transfer was via HDPE pipelines, the dredged slurry varied between 18 and 28% by weight solids, dependant on the type of tailings solid material (i.e. fine or coarse) and the dredge cutting head sweeping from side to side.

Both mill and dredged tailings slurry were originally deposited into Pit 3 subaerially via a number of spigots on the pit crest forming a sloping beach across the pit floor shown in Figure 9-20 and Figure 9-21. Coarse and fine tailings segregation was observed, the coarse tailings forming an elevated beach in the eastern end of the pit with the finer tailings migrating towards the western end and settling below the water surface.

Figure 9-20 Southeast wall of Pit 3 - subaerial discharge point for mill tailings (November 2019)

Figure 9-21: Pit 3 showing the original location of mill and dredge tailings deposition points

This segregation was a result of concentration of low discharge solids combined with fluctuating process water volumes, a consequence of dredging operations, creating a differential in tailings elevation from east to west of approximately 10 m, demonstrated in the surface contours from surface surveys conducted in April 2019 shown in Figure 9-22.

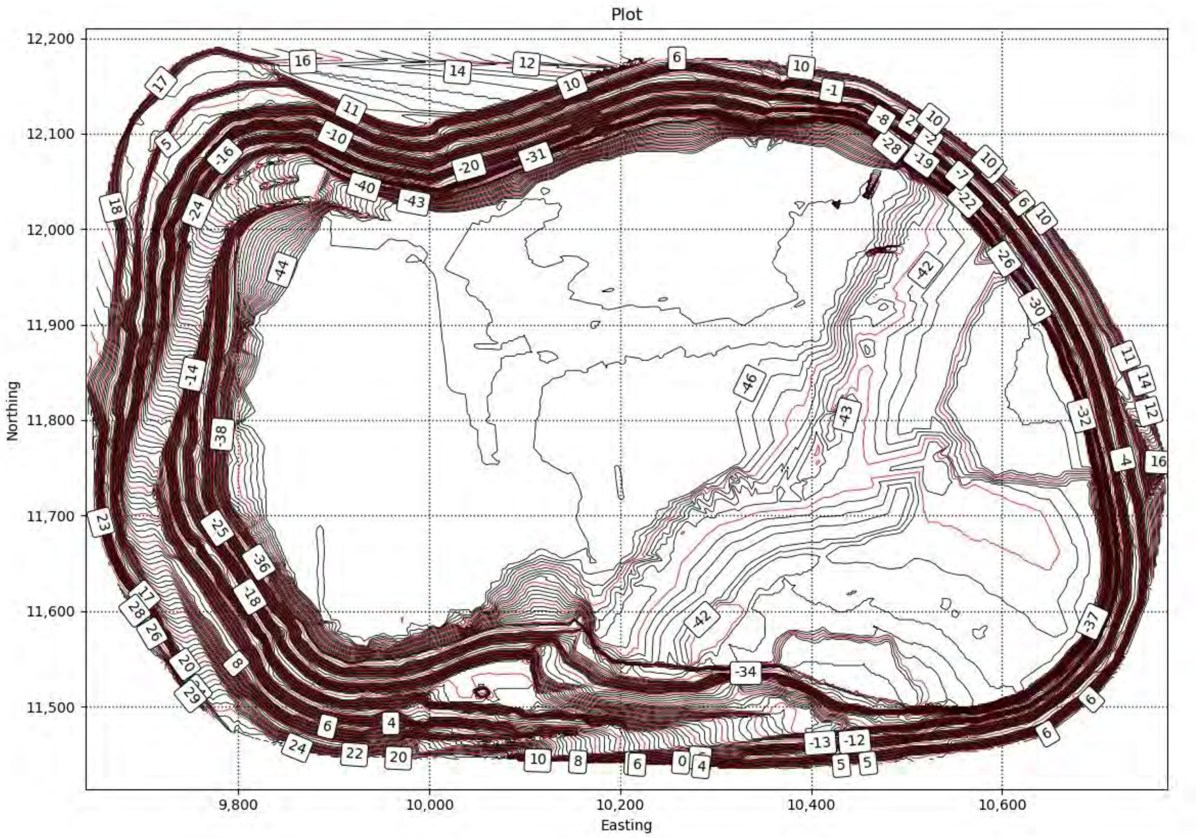


Figure 9-22: Tailings surface in April 2019 (Source: Fitton, 2019)

The segregation and subsequent differential in tailings elevation indicated the approved maximum tailings elevation of -20 mRL may be exceeded. Initial investigations how to attenuate the levels commenced in 2017, followed by studies into subaqueous deposition of dredged tailings in 2018. Subaqueous tailings deposition would potentially mitigate the risk of segregated coarse tailings exceeding -20 mRL. The identified benefits of subaqueous deposition in a fluctuating water level situation included:

- elimination of a coarse tailings beach deposited higher in the pit;
- elimination of a steep uneven tailings surface; and
- promotion of the homogenous deposition of tailings by systematically moving the deposition point.

On 15 and 16 January 2018, ERA hosted a stakeholder workshop discussing Pit 3 tailings deposition. Stakeholders agreed that subaqueous tailings deposition would be unlikely to increase the risk of long-term environmental impact to ground and surface water from solute egress. Subsequent approval to deposit tailings sub-aqueously was provided pending the completion of tailings characterisation studies (*Section 5 KKN Supporting Studies*, Chapter 5.4.1), groundwater modelling (*Section 5 KKN Supporting Studies*, Chapter 5.4.3), a subaqueous deposition trial and formal application to change the tailings deposition method. The studies validated that changing the tailings deposition method and consequent maximum tailings level would not result in any long-term environmental impacts to the surrounding Kakadu NP at the end of deposition nor have any material impacts on the Pit 3 closure schedule.

The tailings consolidation model was updated to provide understanding of the impact of tailings segregation and proposed subaqueous deposition of dredged tailings from a moving discharge pipe at the western end of the pit, estimating tailings surface during deposition and post deposition phases. Comparison between 2019 and 2018 results concluded the model accurately predicted distribution of the coarser/finer tailings split up to the commencement of the subaqueous deposition trial providing confidence in future consolidation modelling.

The subaqueous discharge trial of dredged tailings commenced in December 2018, concluding in March 2019, followed by an MTC application to modify deposition of dredged tailings from tailings beach (subaerial deposition) to inundation and deposition into water (subaqueous deposition). The application also requested a final average tailings level of -15 mRL (ERA, 2019b). Approval was received in August 2019 to increase maximum tailings level to -15 mRL, but this approval was specific to the fixed mill deposition spigots only. In August 2020 the level was increased to -10mRL across the pit based on low risk to the offsite environment during deposition provided process water levels in Pit 3 remained below 3.5 mRL.

The dredge tailings deposition system was modified (Figure 9-23) enabling the subaqueous deposition of dredged tailings (Figure 9-24), retaining existing subaerial discharge points for maintenance, pontoon movement operations and monthly bathymetric surveys.

Figure 9-23: Subaerial deposition of mill tailings from multiple spigot points

Figure 9-24: Subaqueous deposition of dredge tailings via floating pipelines and diffusers

Key elements for subaqueous deposition were:

- pumping of tailings by separate HDPE pipelines sized to match dredge flow;
- floating sections of pipeline enabling discharge over the entire pit area;
- each pipeline fitted with a novel diffuser to lower slurry velocity at the discharge point to reduce tailings segregation (Figure 9-25);
- diffusers supported by a single pontoon; and
- diffusers followed a deposition plan (Figure 9-28) and were moved using diesel-powered winches promoting even deposition across the pit.

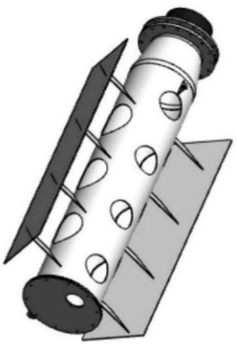


Figure 9-25: Novel subaqueous diffuser design

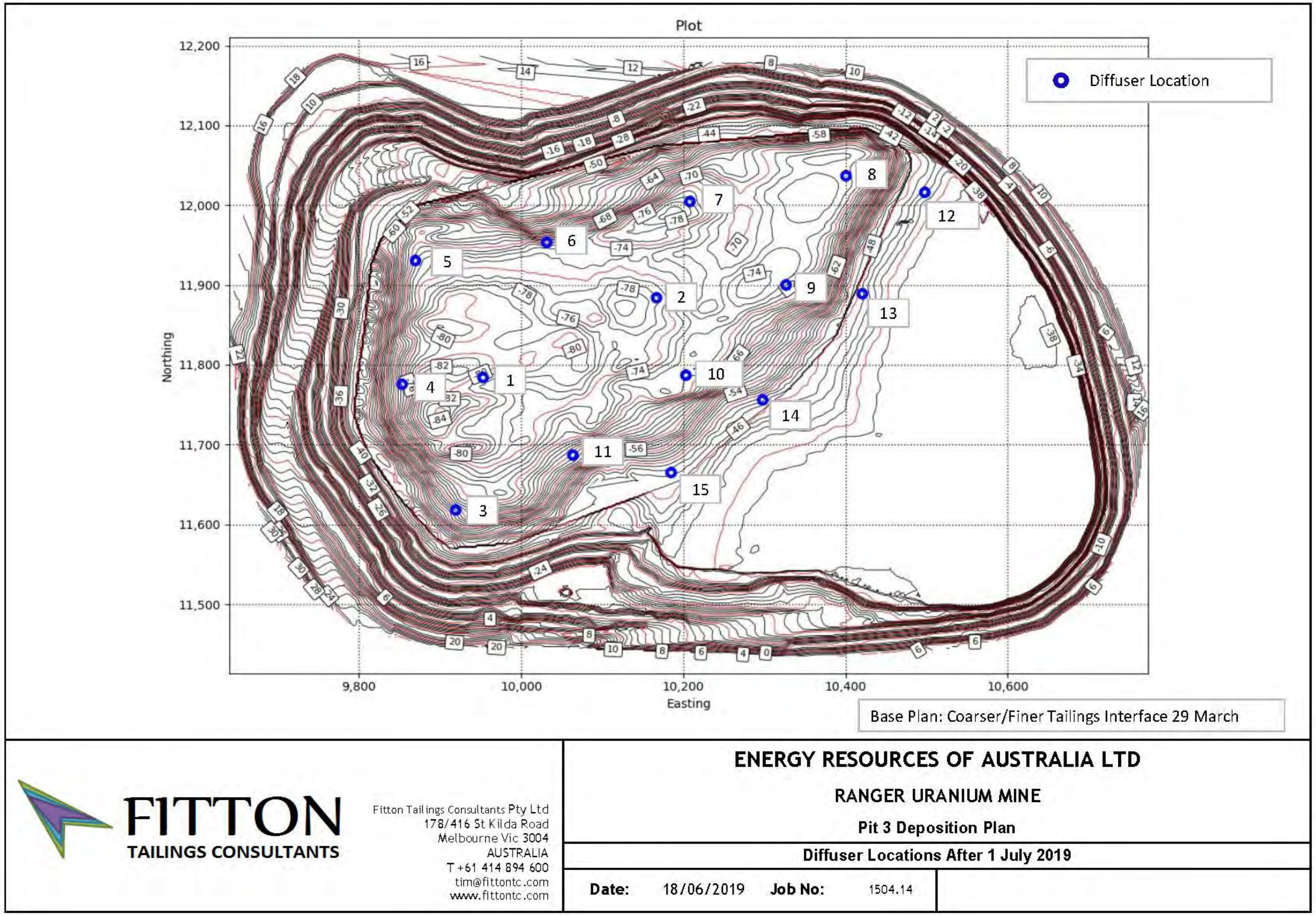


Figure 9-26: Pit 3 dredge tailings deposition plan

Remnant Tailings Transfer from Ranger Water Dam to Pit 3

Dredging of tailings from the RWD left a considerable volume of residual tailings. Regulatory approval was received to leave the RWD subfloor *in situ* in August 2020 enabling commencement of the RWD deconstruction planning and consideration of future remediation options (ERA, 2020d).

Following the cessation of dredging, a BPT assessment identified Option 3, pre-cap truck as the most appropriate approach to transfer remnant tailings material from the RWD to Pit 3 with a notification submitted to the MTC (ERA, 2021d).

Wall and floor cleaning activities are described in more detail in the *Tailings Storage Facility - Plan for Removal of Remnant Tailings* (ERA, 2021c).

Tailings material, from the floor, walls and borrow pits were dozed into stacks to dewater and dry loaded onto trucks for transfer to Pit 3 via the northeast ramp (Figure 9-27 and Figure 9-28).

Figure 9-27 Transfer of tailings works from the Ranger Water Dam to Pit 3 2021

Figure 9-28 Ranger Water Dam floor

Trucks approached the tip head, transferring tailings material onto an area next to the pit crest (Figure 9-29 and Figure 9-30).

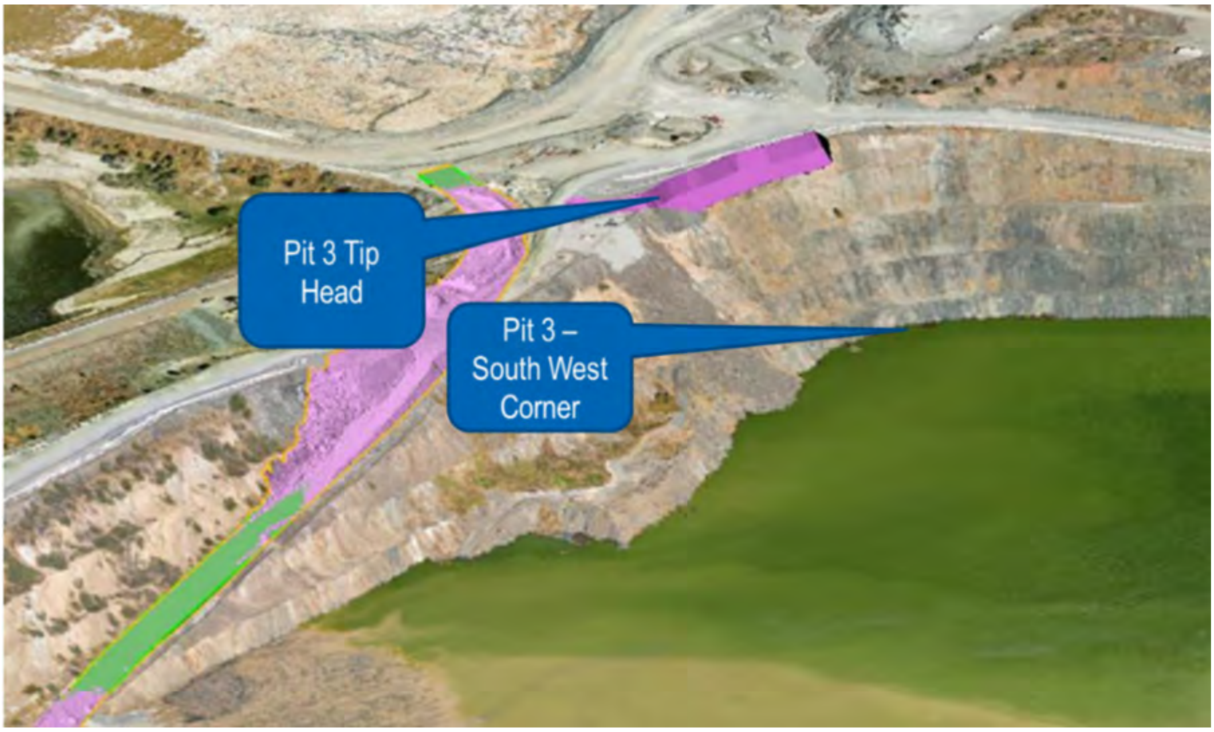


Figure 9-29 View of the Pit 3 wall for proposed tip head (south west view)

Figure 9-30 Construction of Pit 3 tip head

An excavator or dozer pushed tailings material down the pit wall (Figure 9-31). A water cannon aimed to clean material off the benches or push tailings material down the pit wall as it became hung up, resulting in some tailings remaining on the deposition point.

Figure 9-31 Transfer of tailings down tip head in Pit 3

Truck transfer commenced in July 2021 completed in December 2021 as summarised in Table 9-7. An estimated 1.77M m^3 of tailings material was transferred from the RWD to Pit 3 over the underdrain layer (ERA, 2021d), the estimate based on mill feed and lime consumption records, RWD to Pit 1 dredge tailings volume estimates, RWD to Pit 3 truck monitoring records, end of RWD dredging bathymetric surveys and cleaning floor surveys.

Table 9-7 Pit 3 tailings quantities

Description	Dry solids mass (Mt)
Tailings transferred from the RWD by dredge	24.2
Tailings deposited directly from the mill	15.4
Tailings transferred from the RWD by truck	2.0
RWD floor and wall material	0.5
TOTAL	42.2

A bathymetric survey of Pit 3 on 10 March 2022 shown in Figure 9-32 confirmed the total volume of deposited material above the underfill layer as 32.1M m^3.

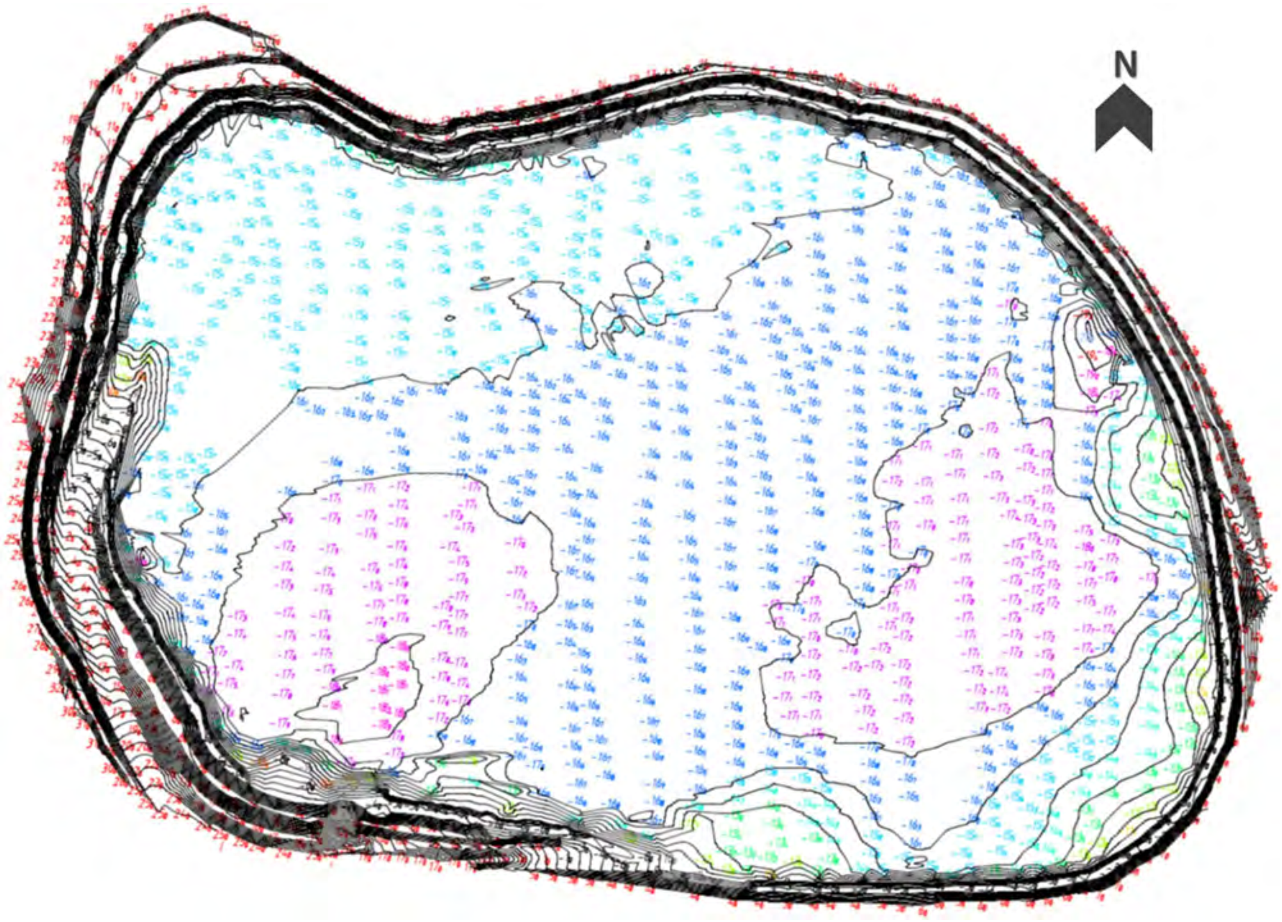


Figure 9-32 Pit 3 bathymetric survey, 10 March 2022

9.2.2.2 Current rehabilitation

The Pit 3 capping, waste disposal and bulk backfill closure activities are described in a standalone application for approval from both the MTC and Ministers detailing the closure of Pit 3 components and associated supporting studies. The final 6 m of the landform will be considered in a separate 'Final Landform' application.

To inform the Pit 3 capping design, geotechnical investigations determined the strength of the tailings and assessed the geotechnical risk of construction prior to commencement of capping activity. Investigations from September to November 2020 included cone penetration tests with pore pressure measurement, vane shear tests, recovery of tailings samples and laboratory testing. Tailings strength will inform the selection of geosynthetic material to ensure adequate bearing capacity and the size and weight of the construction equipment to be utilised in the secondary capping layer and bulk fill activities. The thickness of each capping layer is consequently influenced by equipment size.

9.2.2.3 Planned rehabilitation

A series of activities to facilitate tailings consolidation and waste rock backfill of Pit 3 have commenced. It is noted the standalone Pit 3 capping, backfill and waste disposal application has been lodged and is not yet approved, where the following summarised activities may change based on future discussions with stakeholders.

Brine injection

The bores of the original brine injection system are considered to have completely failed. ERA is in the process of installing three replacement injection bores. The concept design for well locations and piping layout is shown in Figure 9-33. Replacement bores will be directionally drilled from outside the perimeter of Pit 3, down towards the underfill shown in Figure 9-34. The system design includes:

- Tie in of the delivery pipework into the Brine Concentrator at the same location as the existing injection wells – downstream of the brine cooling heat exchangers;
- The ability to 'pig' and flush the delivery piping system, to remove accumulated scale and settled solids;
- Containment bunds and shields around the well heads, pipe-in-pipe protection of connecting pipelines, and leak detection systems to protect against egress of brine or flushing water to the environment around the Pit 3 rim; and
- Features to accommodate expected changes in Pit 3 and surrounding landforms, with progression of capping, backfill and revegetation, such as return pipework to enable delivery of flushing water back to the process water inventory that does not rely on an open pit void.

Unlike the existing system, where the well heads are buried under a substantial thickness of tailings, the surface accessible well heads allow for remedial works, such as re-drilling or descaling, on the injection wells proper. The design enables a choice of well casing material and use of a portable positive displacement pump that permits brine or process water injection into the Pit 3 underfill under pressure, reducing the impact of scaling on well lifetime. Installation of the new wells commenced in August 2022.

Figure 9-33 : Concept design for additional injection wells

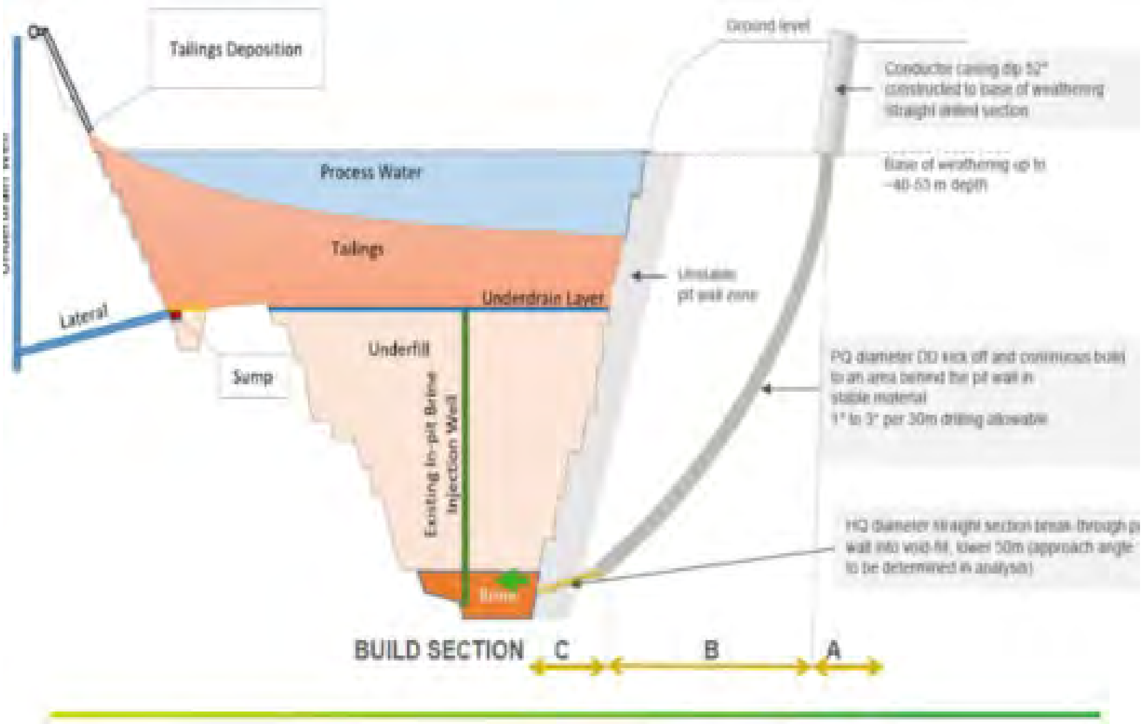


Figure 9-34: Concept section for additional injection wells

Wick drains

Wick drains or prefabricated vertical drains (PVD), increase the rate of tailings consolidation, reducing the time for the closure final landform to reach its final profile. Wick drains were successfully installed to consolidate tailings deposited in Pit 1 (Chapter 9.3.1.1). Faster consolidation increases both the rate of tailings strength with time and rate of removal of consolidation flux (water trapped within the tailings) as process water.

The wicks are a polypropylene drainage core wrapped in a geotextile filter with extruding channels to promote vertical drainage; the filter prevents soil particles from clogging the drain. Wicks significantly shorten the tailings drainage path length, increasing the removal rate of trapped liquid, dissipating pore pressure build-up and reducing the risk of sudden failure during the capping and bulk fill activities. Wicks installation will aid dissipation of pore water pressure in the upper tailings profile to a depth that the wicks can reasonably be deployed. Wicks are of greatest benefit where the fine tailings are deepest, the relative rate of rise of the tailings is greatest and the degree of consolidation at the end of deposition is least (highest excess pore pressures).

Tailings strength is improved through consolidation, the rate influenced by flow path length of the water expressed both vertically upwards and downwards. Wicks decrease this flow path improving the shear strength of the tailings, fundamental to progressing capping works by enabling safe access for heavy equipment. Installation of wicks in soft tailings will:

- Achieve dissipation of pore pressure increasing undrained shear strength to facilitate capping;

- Achieve early expression of pore water for decant and treatment (minimising remnant consolidation volume); and
- Be an ongoing mechanism for acceleration of pore pressure dissipation during capping works.

Wicking trials between March and April 2021 informed installation methodology, anchor system, resistance to deformation and position stability of the wicking plan. The wicking trial layout is presented in Figure 9-35 with an example anchor provided in Figure 9-38.

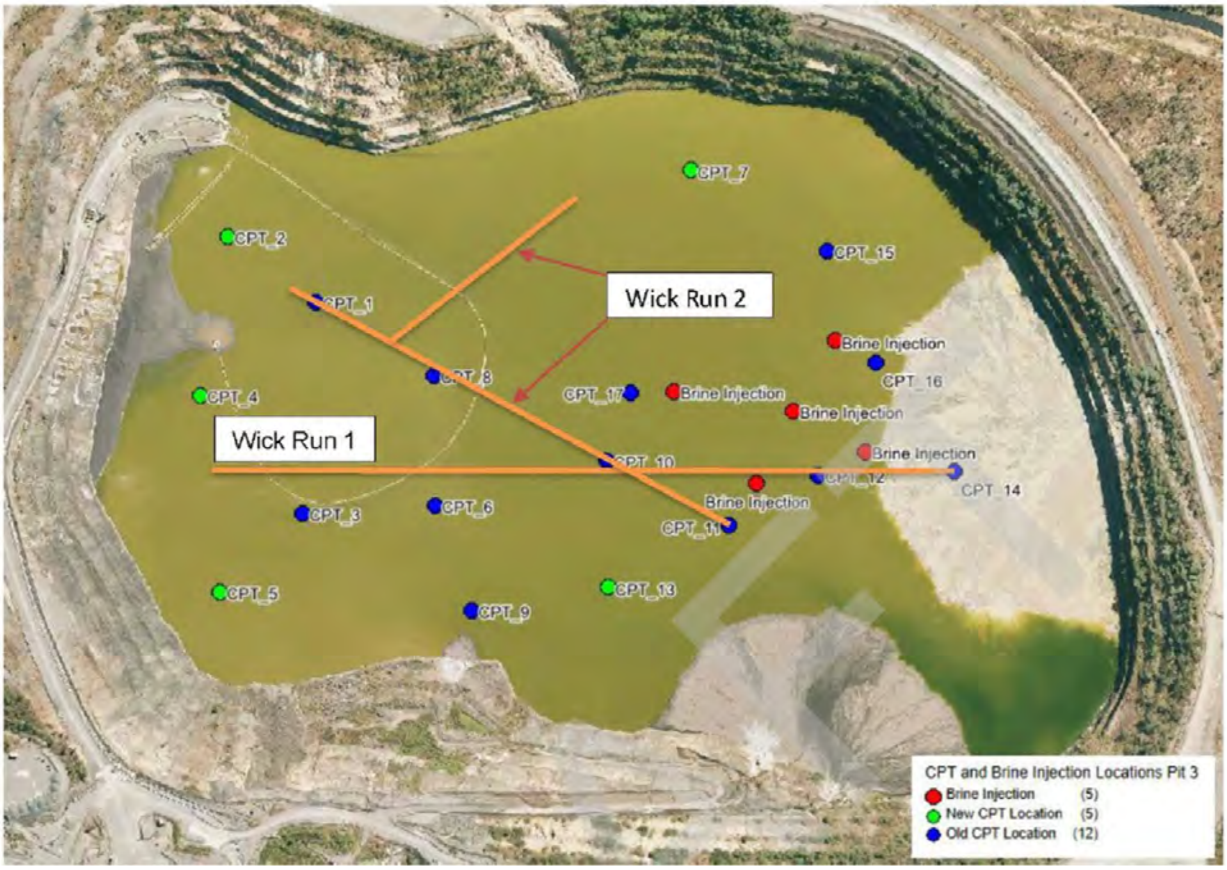


Figure 9-35 Wicking Trial Layout

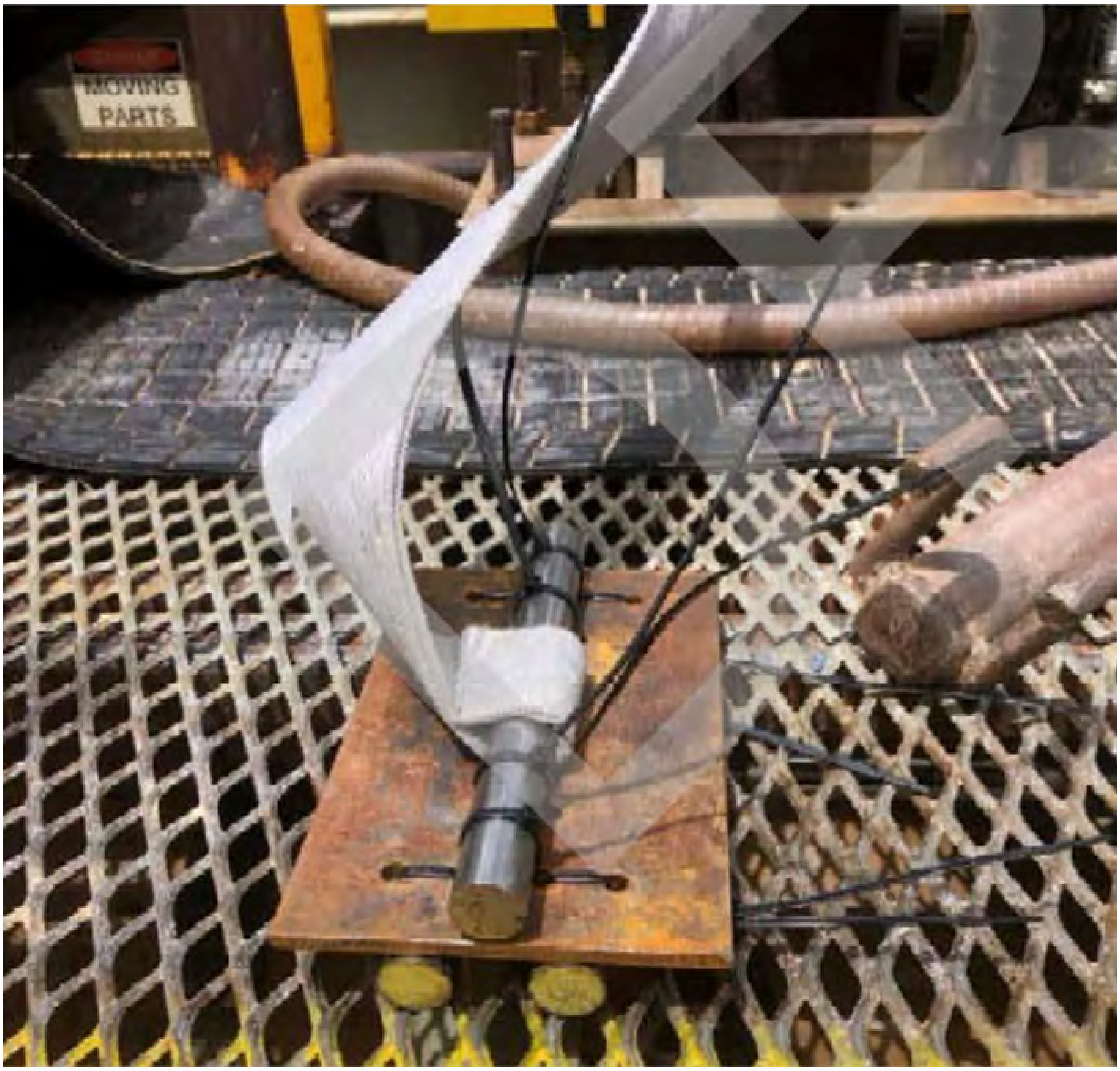


Figure 9-36 Typical anchor as used in the trial

The final wicking plan shown in Figure 9-37 was developed from the most recent tailings properties data, consolidation model and wicking trial outcomes. Wicking zones will focus on the finer tailings in the west of Pit 3 that contains the most under-consolidated tailings and highest excess pore pressures. Wick quantities are described in Table 9-8.

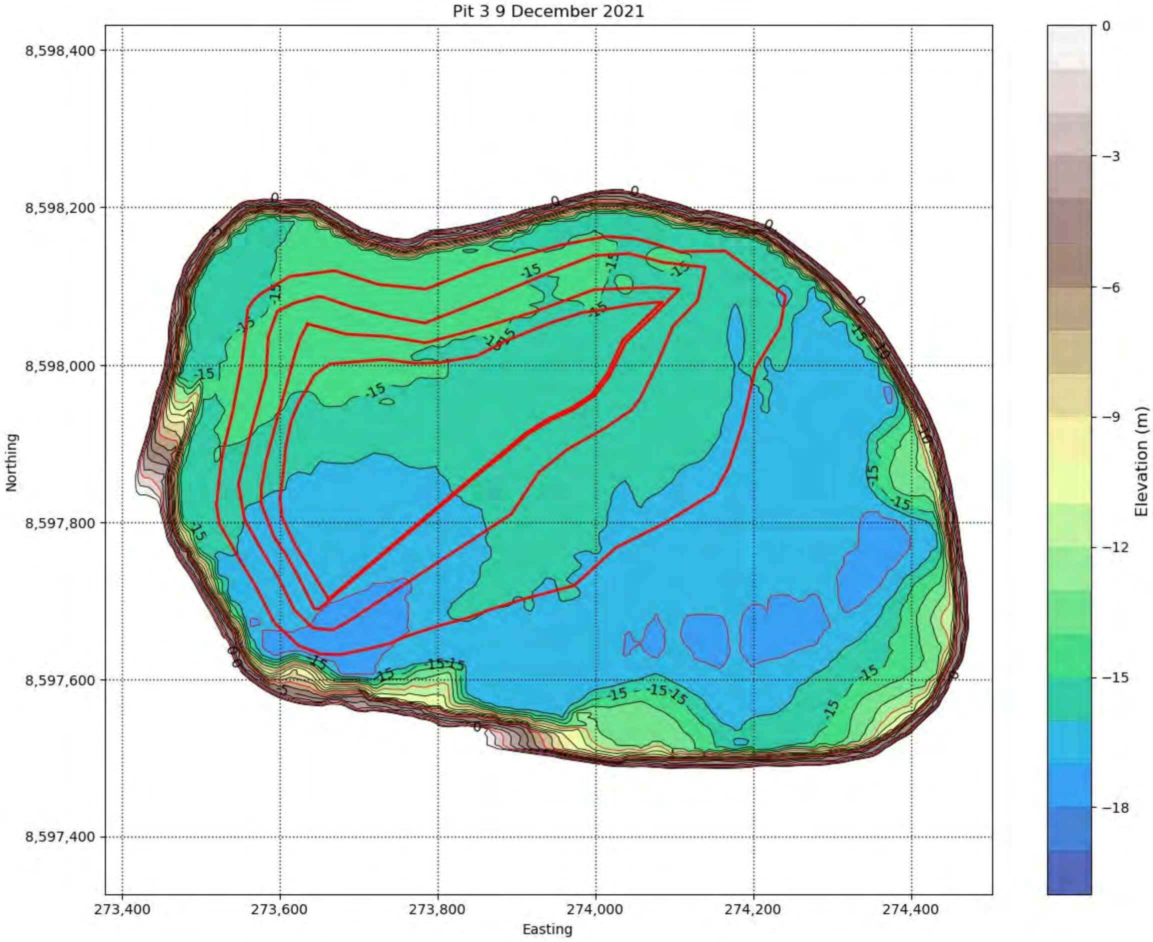


Figure 9-37 Pit 3 tailings bathymetry (horizon) as at 9 Dec 2021 with North up the page. The red lines show the wicking zones, Zone 1 the inner most to Zone 4 the outer most area.

Table 9-8 Current wicking plan per zone

Zone	Depth (m)	Spacing (m)	Area (m^2)	Wick quantity (count)	Linear metres of wick / zone
1	40	2.5 x 2.5	76,861	12,298	491,910
2	40	2.5 x 2.5	22,238	3,558	142,323
3	40	2.5 x 2.5	59,151	9,464	378,566
4	20	2.5 x 2.5	113,696	18,191	363,827
Total				43,511	1,376,627

To access to the low strength tailings, wicks will be installed from a floating barge, a preliminary design shown in Figure 9-38. The wicking barge and rigs will require management of water levels in Pit 3. Wick spacing will dissipate surface pore pressure, accelerate consolidation and increase surface strength of the tailings. Following wicking activity, limited activities will be undertaken in this zone to ensure interference with wick tails is minimal.

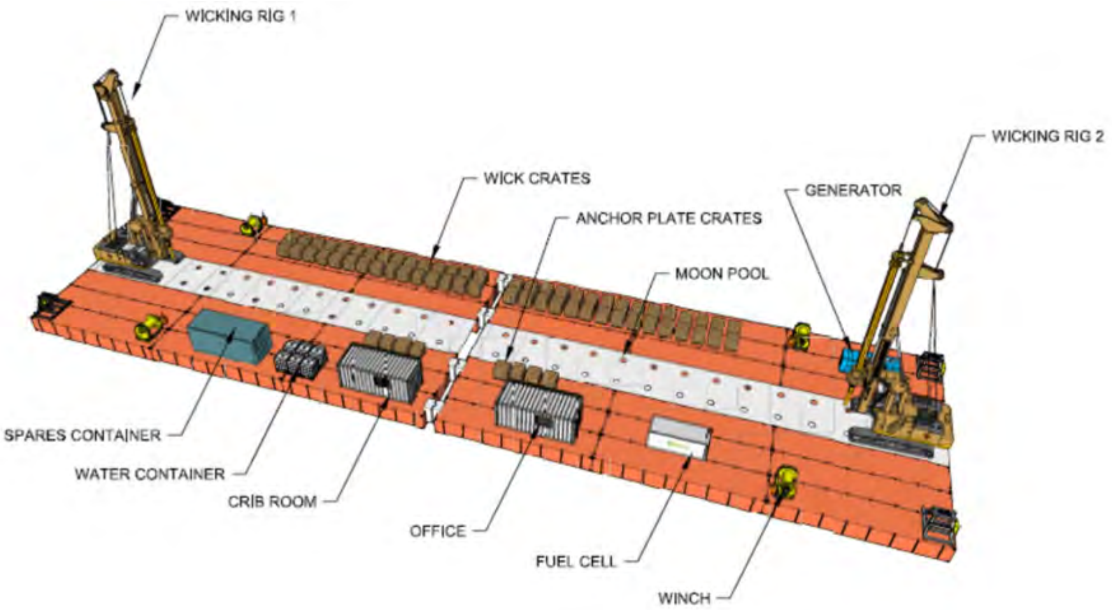


Figure 9-38 Diagram of wicking barge

The completion of tailings transfer from the former Tailings Storage Facility to Pit 3 the Tailings Storage Facility was re-commissioned to a Ranger Water Dam. Most of the process water from Pit 3 was transferred into the RWD water storage facility, with the remaining water levels held at approximately -14 mRL during construction of the wicking barge and the installation of the wicks.

Pit 3 dewatering and drainage

Following completion of wicking, Pit 3 will be dewatered to facilitate desiccation of the tailings surface and facilitate capping works. Suitable pumping infrastructure similar to Figure 9-39 will be installed to keep the pit tailings surface as dry as possible as well as manage expected and usual flows.

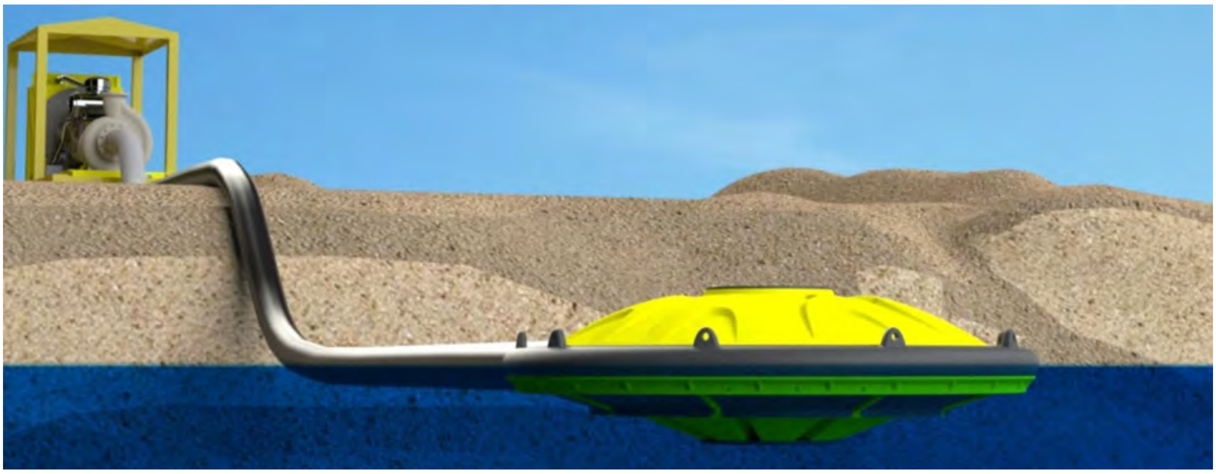


Figure 9-39 Shallow water turret suction intake

Amphibious or barge mounted equipment may be utilised to construct drainage channels or alter the tailings profile to promote surface drainage in the non-wicked zone. The water management plan is summarised in Table 9-10.

Table 9-9 Pit 3 Water management during capping works

Stage	Mechanism to get water to storage or treatment infrastructure
Wicking	Water level managed by pumping system
Tailings	Amphibious equipment for maintenance of drainage paths
Post initial capping	Transition from pumping system to decant wells during initial capping activity.
Secondary capping Bulk backfill	Decant wells Capping works profile and pit water storage to manage surface inflow and groundwater Water pumped out of pit as required

Accelerating tailings desiccation

The Pit 3 capping schedule is less than for Pit 1. Accelerating the desiccation of tailings in un-wicked areas of Pit 3 by mechanical means will create a higher strength in the tailings surface crust to facilitate overlaying of geotextile and capping material on a stronger base.

Mechanisms to accelerate tailings desiccation include:

- drainage channels and surface drainage creating water flow away from the tailings;
- machine weight to aid in expression of tailings water; and
- disturbance of crust layer and tailings shown in Figure 9-42 to promote solar drying.

Figure 9-40 Mud Master at Yarwun Alumina Refinery Red Mud Dam

Where a crust cannot be constructed and low surface strength is observed, low strength capping techniques may be utilised. Alternatively, activities may be excluded if tailings conditions are better than predicted.

Tailings strength surveys, tests and investigations

Surveys and tests will be undertaken throughout capping operations.

Terrestrial, aerial and bathymetric surveys of tailings surface and sub-surface horizons at the end of tailings deposition, prior to installation of wick drains and ongoing as required to monitor tailings behaviour and consolidation.

Wall surveys will be conducted to monitor pit slope stability through automated stations and pit mounted prisms. Barge, equipment, or hand shear vane tests will determine tailings surface strengths confirming tailings condition limits to support safe capping works.

Tailings strength gain will be identified from vibrating wire piezometers within the tailings to measure pore pressure dissipation during placement of initial capping.

Monthly bathymetric data from sonar (echo sounder) will be used to survey the upper surface layers of the tailings body informing consolidation rates and levels across the pit. The data will provide trends in consolidation and tailings behaviour.

Prior to wick installation, cone penetration testing (CPTu) investigations will be undertaken to:

- provide an understanding of the strength gain in the upper portion of the tailings;
- provide progress of excess pore pressure dissipation at depth from consolidation under tailings self-weight;
- inform construction of the eastern platform, perimeter access road and similar works;
- predict and validate behaviour of the tailings, and inform consolidation model updates; and
- to monitor progress of excess pore pressure dissipation at depth and strength gain in tailings following installation of wick drains.

Figure 9-41 presents the CPTu locations and tests to monitor the behaviour of tailings over time. CPTu tests will be undertaken from a barge shown in Figure 9-42.

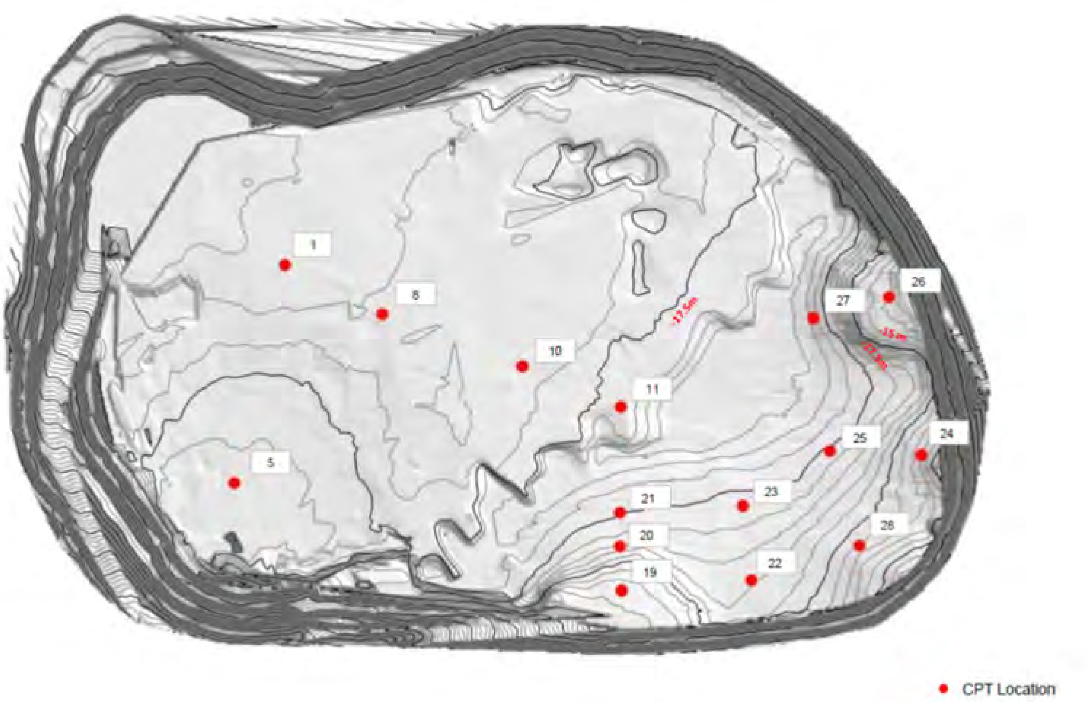


Figure 9-41 CPTu locations within Pit 3

Figure 9-42 Placing CPTu barge in Pit 3 with CPTu rig mounted

Construction of staging and wharf facilities

Material and equipment laydown areas may be constructed at the bottom of the western and eastern ramps, improving access for surveys and test, wicking, personnel and barge activity. A crane pad may also be constructed.

Initial Capping Works

The initial capping design consists of a layer of geotextile and one or more metres of select waste rock to provide a working platform for subsequent capping and backfill layers. Surveys prior to execution works will determine tailings properties and inform capping design and geotextile requirements.

Geotextile

A geotextile layer between the capping layers and the tailings will:

- improve the bearing capacity, stability and constructability of the capping layer on very soft tailings;
- provide tensile strength to the underside of the capping layer;
- reduce capping layer thicknesses; and
- support bulk backfill with heavy mine fleet activity.

Geotextile placement will be developed by the contractor in consultation with ERA. If required, larger geotextile blankets will be constructed and pulled across and capping material.

Trial platform

Trial platform construction on the coarse tailings will optimise capping methods, enable study of tailings consolidation behaviour and verify tailings segregation assumptions through assessment of tailings segregation at various locations. Bearing capacity and CPTu tests of the platform over time will provide understanding of tailings strength.

Capping methodology

A dry capping methodology similar to Pit 1 shown in Figure 9-43 was identified as the current best practicable technology, with planned reviews and updates as new data becomes available. The capping execution plan for Pit 3 will be sequentially constructed, each area employing specific capping techniques. Each area for Pit 3 capping works are delineated in Figure 9-44.

Aspects of capping works quality and control include:

- regular surveys of tailings at the work front;
- review by qualified engineer to inform capping design;
- construction of the cap with onsite geotechnical and earthwork expertise;
- inspection and quality systems; and
- final inspection and signoff by design engineer (Rio Tinto D5 standard).

Figure 9-43 Pit 1 Capping construction method showing material ‘fingers’ pushed across the geotextile.

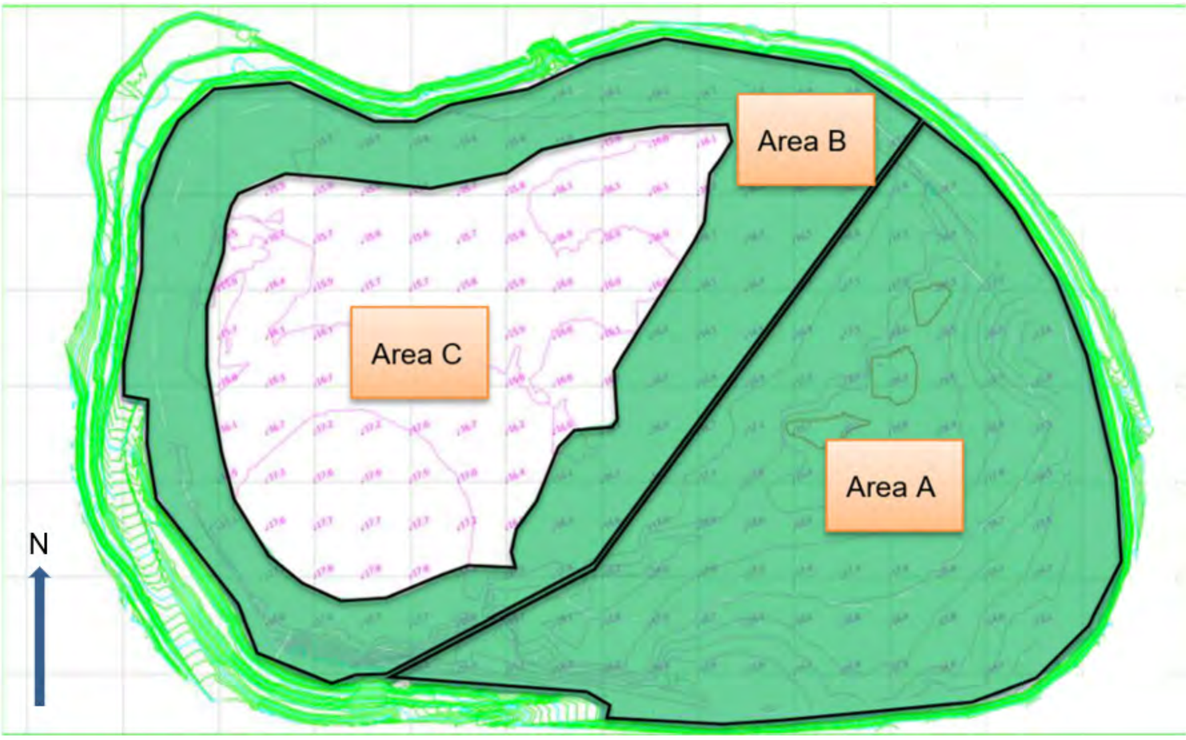


Figure 9-44 Pit 3 capping locations delineating based on expected tailings surface conditions

Contours are tailings surface.
Lime green identifies pit walls and features.
Dark green defines non-wick areas.
White area identifies the proposed wicked zone

Water draw-down and dewatering of Pit 3 will initiate solar desiccation. Progressive construction of an access road from the southern access ramp will extend to the most northerly tailings deposition point to facilitate capping works. The access road can be strengthened by initial capping material and geogrid spreading the load, minimising liquefaction and equipment movement impact.

Area A - eastern platform - Capping works in Area A will be constructed over a coarse tailings beach with underlying fine tailings similar to the northern section of Pit 1. Construction of the capping layer will be via material pushing and 'finger' or groyne infill techniques as shown in Figure 9-45 to Figure 9-48.

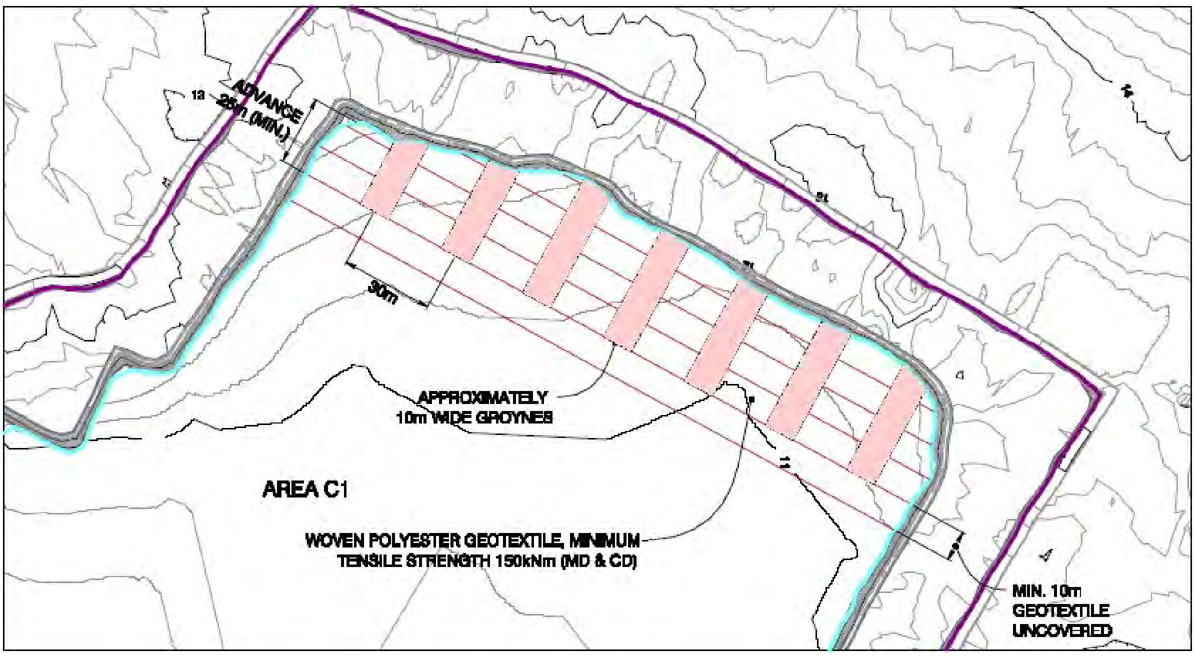


Figure 9-45 Typical geotextile placement (plan view)

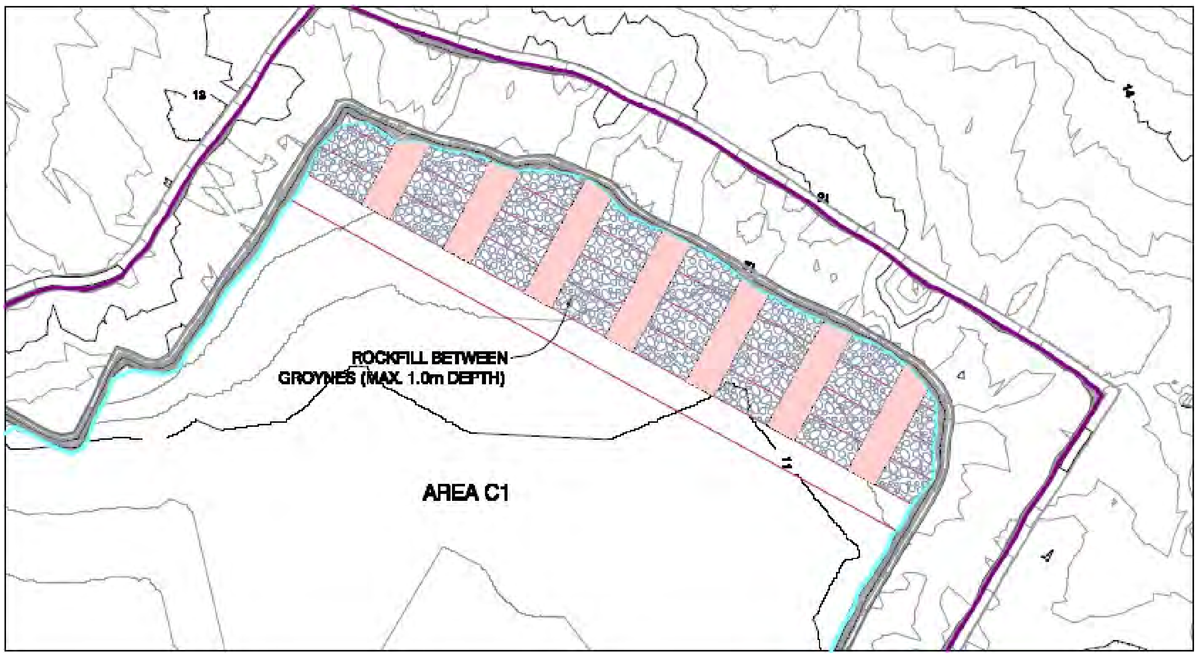


Figure 9-46 Typical initial capping layer placement, post geotextile, finger or groyne method, infill (plan view)

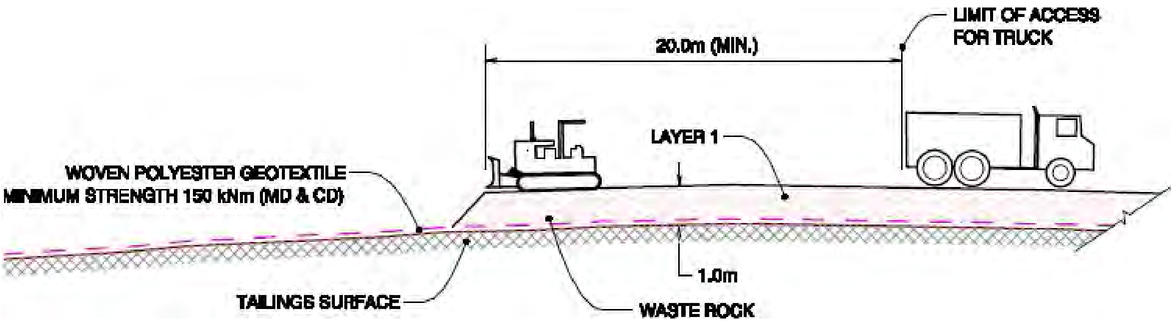


Figure 9-47 Initial capping placement typical detail – section view

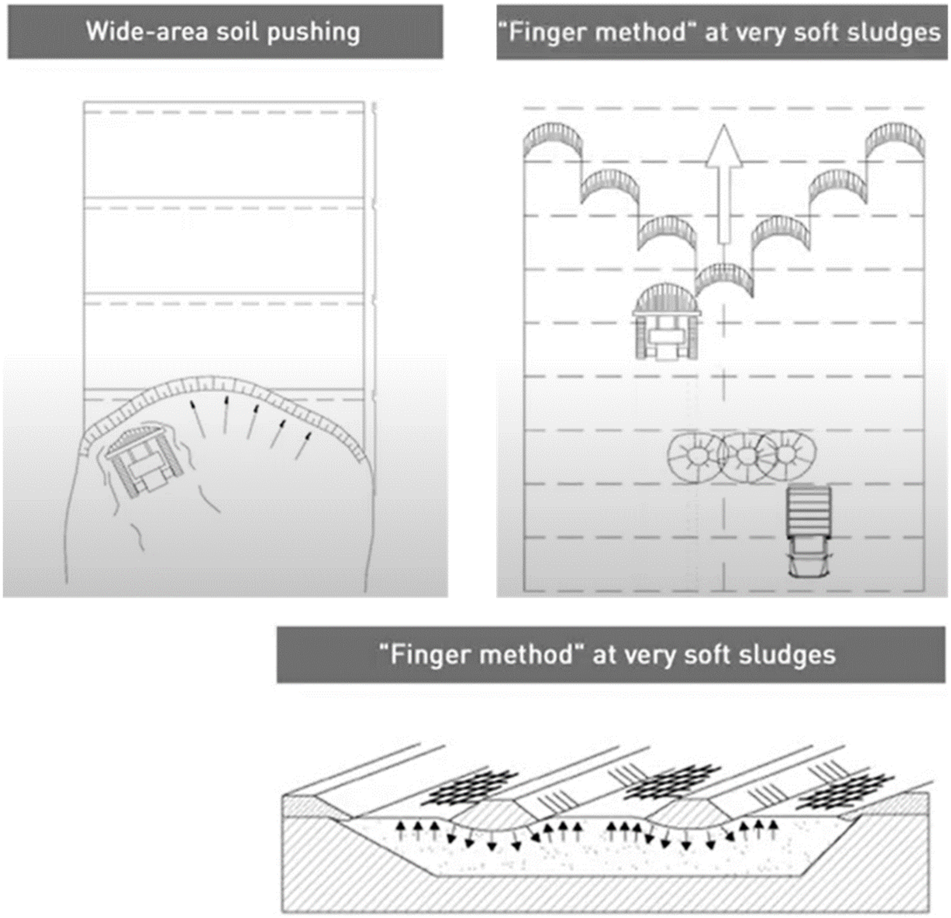


Figure 9-48 Options for initial capping progression

Area B - perimeter access- Area B will have less tailings strength than Area A. Capping works will progress around the perimeter using the underlying pit wall berms and benches creating a perimeter access 30 to 50m wide to progress capping work fronts and facilitate construction of a solid anchor point for the geotextile (Figure 9-49). Capping construction will be similar to Area A.

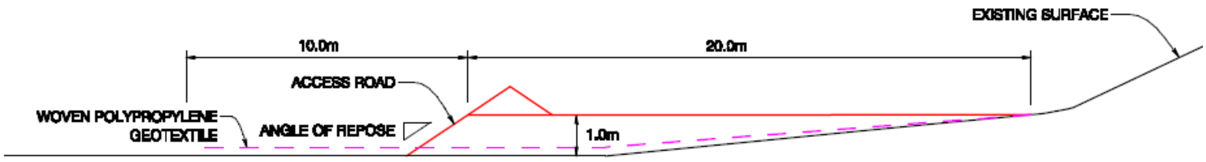


Figure 9-49 Typical perimeter access road – section view

Area C - wicked area capping- Wicking works will improve the low tailings strength of Area C. The fine tailings are predicted to slowly form a crust to installation of the geotextile and initial capping layer. Construction of the geotextile anchor berm will commence near the perimeter access to enable anchoring of the geotextile towards the lowest point shown in Figure 9-50. The geotextile will be securely anchored along its length during capping activity.

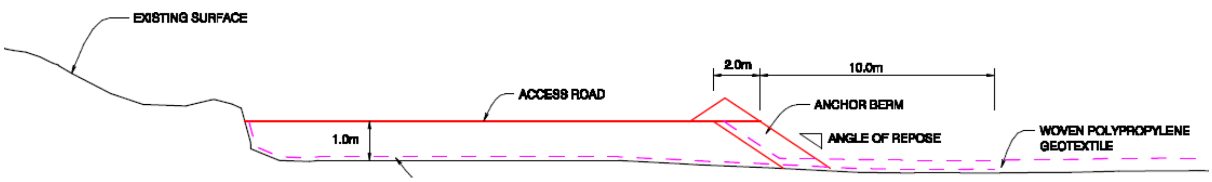


Figure 9-50 Typical geotextile anchor berm detail – section view

Following completion of initial works, the edge of the capping layer can be stabilised to support further capping works. Low strength tailings capping techniques may be employed where rock material is placed with low ground pressure equipment and long reach excavators. If the tailings strength is observed to be sufficient, capping works may be undertaken similar to those in Areas A and B.

Decant Towers and Settlement Monitoring Towers

Expressed tailings pore water due to tailings consolidation will be collected by Decant Towers and supporting infrastructure, the primary risk control for solutes transported from the tailings pore water into the environment. Three decant towers will be constructed at low points around Pit 3 on top of the consolidating tailings surface following initial capping works. Pore water expressed from the tailings, mixed with groundwater and infiltrating rainwater, will migrate through the lower waste rock capping layer and collected in the decant towers and transferred to the process water inventory by submersible pump.

The stacked tower sections will be supported by a concrete slab located as close as practical to the top of tailings surface. The bottom sections will be perforated to enable water migration into the tower. Additional rings and supporting backfill will be progressively constructed in stages. Each tower will remain for the entire duration of the capping and backfill activity.

The nominal location for the three towers was developed through tailings consolidation modelling shown in Figure 9-51. Decant Tower location will be reviewed based on tailings surface surveys prior to installation and consolidation model updates. Two submersible diesel-powered pumps will transfer process water to the return tanks by overland pipe. These pumps can be relocated between towers dependant on capping and bulk backfill activity requirements. Water removed by the decant towers will be measured by flowmeter.

At least 20 Tailings Settlement Towers will be installed across the pit shown in Figure 9-51 to monitor tailings settlement. The towers will be constructed as close as practical to the top of tailings surface shown in Figure 9-52 with some towers used to monitor water quality, level and Electrical Conductivity (EC). Remaining towers will be configured for water extraction with their lower segments perforated to enable migration of water into the tower. Pumps can be fitted to aid water extraction which will prevent concurrent use for water quality profiling. When not being actively pumped, decant towers and tailings settlement towers will measure the standing level of water in the capping layer across Pit 3 on a monthly basis.

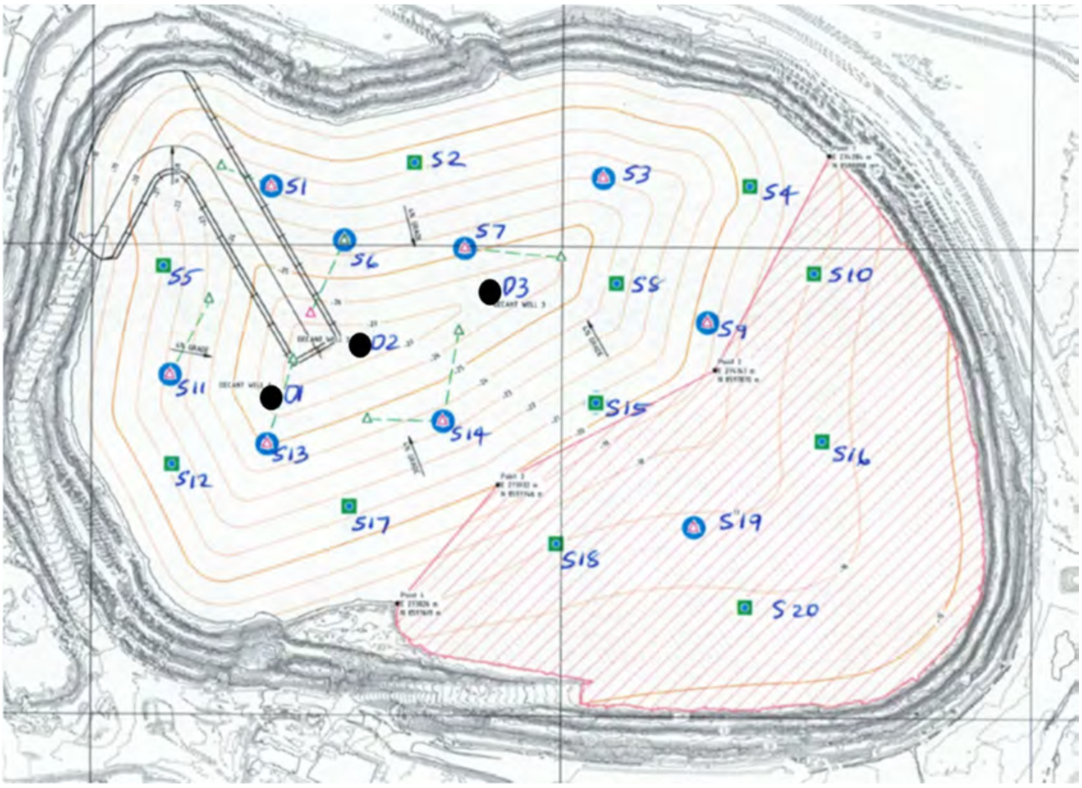


Figure 9-51 Locations of Decant and Settlement towers

+Green squares represent towers to monitor water quality. Blue circles indicate towers for water extraction. Black circles represent the decant towers.

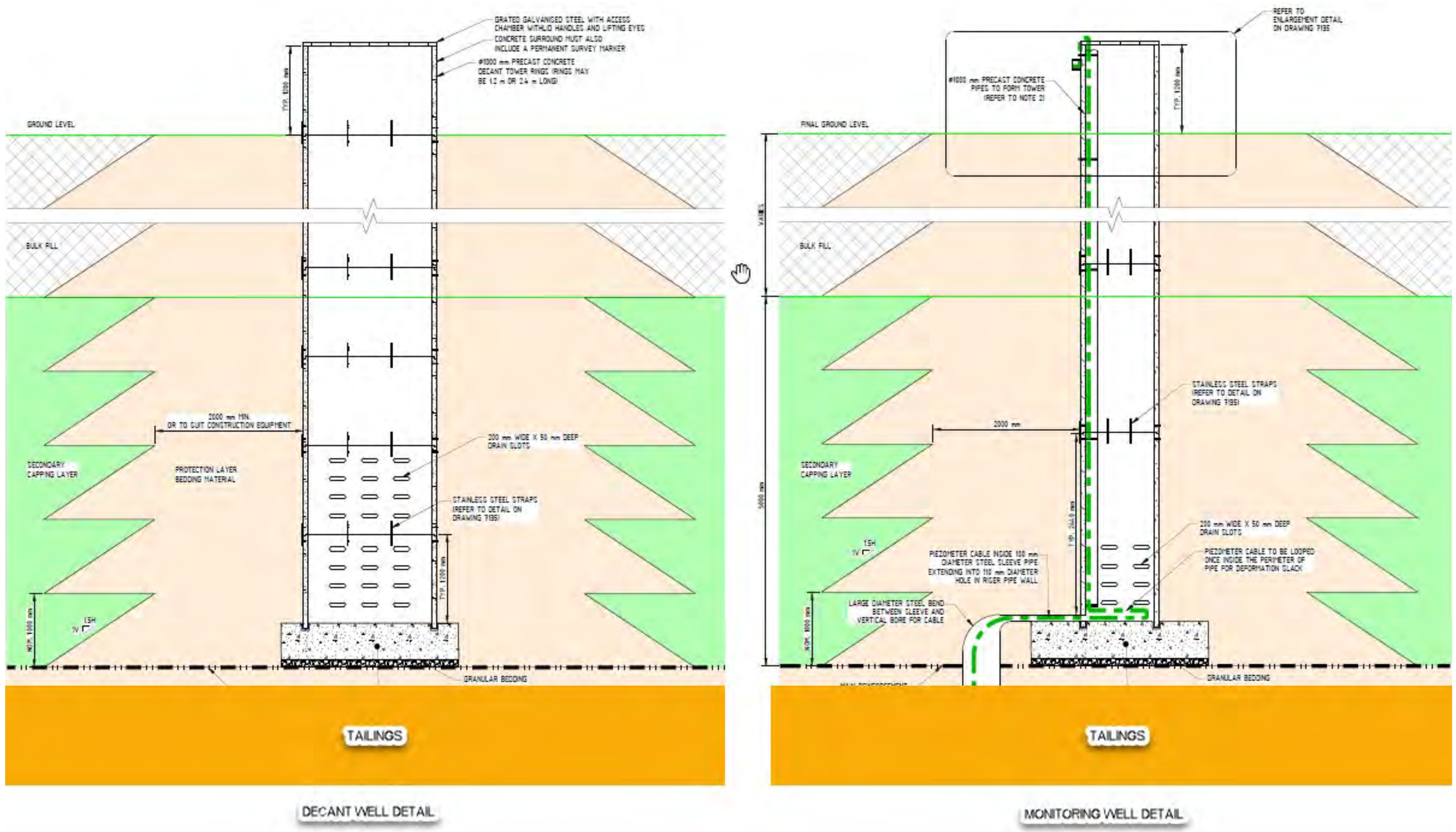


Figure 9-52 Decant well (left) and monitoring well (right)

Secondary capping works

Following the assessment of the initial capping layer and tailings strength, secondary capping layer works can commence. The carefully controlled works will place approximately five to ten metres of waste rock material on top of the initial capping layer via dozers and dump trucks shown in Figure 9-53, creating a working surface to enable larger mining fleet equipment for bulk backfill activity.

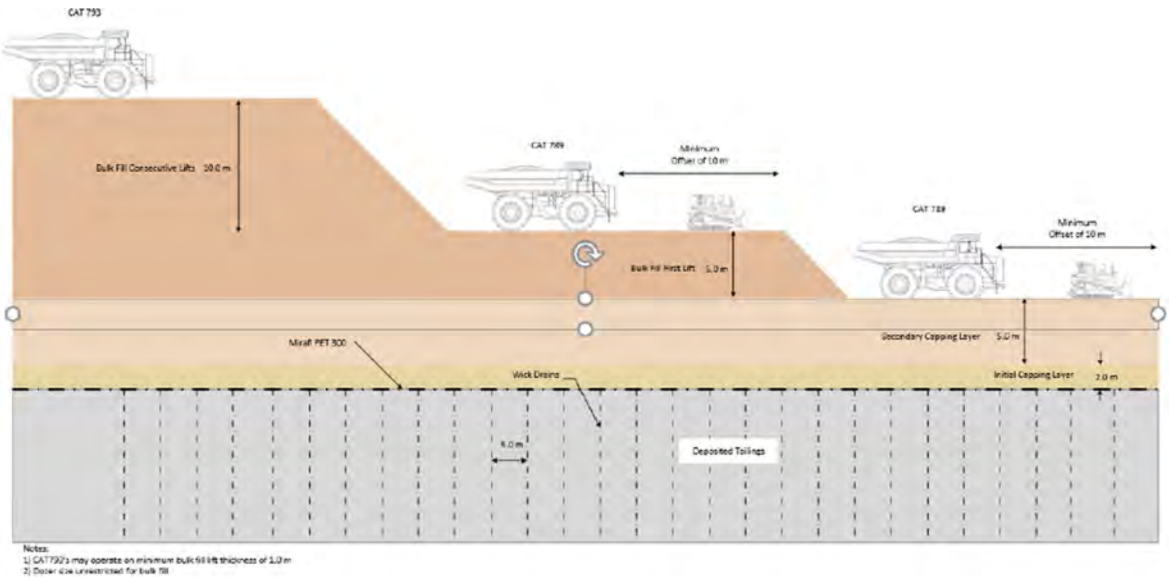


Figure 9-53 Backfill layer construction method. Note thickness, offset and machines are typical and subject to final tailings testing and capping designs

Bulk backfill

The estimated waste rock to be placed into the Pit 3 void is approximately 60 Mt. Bulk material movement to backfill Pit 3 will be dependent on tailings strength and associated geotechnical constraints.

Bulk backfill works can sequentially commence in parallel with the capping activities as shown in Figure 9-53 with the first 5 m lift layer tipped directly on top of the secondary capping layer, followed by successive layers tipped with progressively less constraints. Some geotechnical constraints to capping and bulk fill are summarised in Table 9-10.

Table 9-10 Pit 3 Backfill Geotechnical Design Criteria

Backfill Layer	Layer Thickness (m)	Lift Height (m)	Maximum Grade (%)	Minimum Bench Offset (m)
Initial Capping	2	2	-	10
Secondary Capping	5	1 - 5	10	10
Bulk Fill – 1st Layer	5	5	-	-
Bulk Fill – Successive Layers	Variable	Variable	-	-

Pit access is via two ramps on the western and southern side the locations shown in Figure 9-54. Vehicle movement and traffic control will form a critical part of the works.

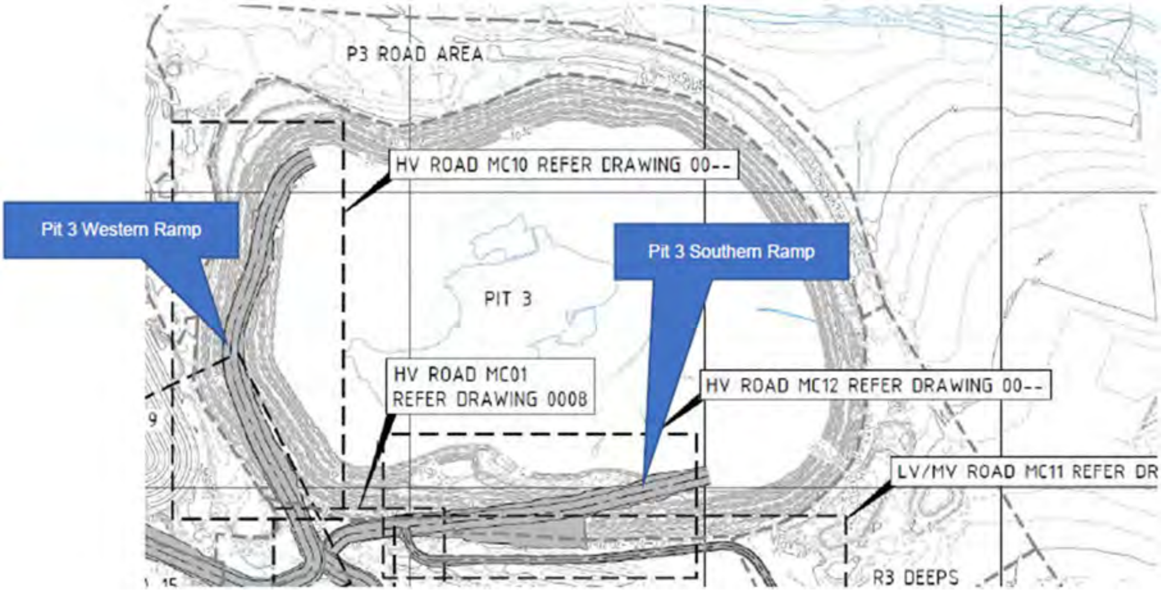


Figure 9-54 Pit 3 access ramps

The bulk backfill requirements for Pit 3 are included in Table 9-11.

Table 9-11 Bulk Material Movement to Pit 3

Stage	Material movement (m^3)	Haul distance (m)
Stage 9	3,188,633	1,000
ROM/crusher stockpile	996,641	2,000
Stage 6	3,015,822	2,100
Stage 8	3,162,177	2,050
Stage 10	37,932	1,800
Stage 11	6,254,874	2,100
Stage 14	2,909,829	1,500
Stage 15	4,242,621	1,500
Stage 12	913,582	2,700
Stage 16	44,481	1,500
Stage 16 (non-mineralised)	7,082,833	1,500
TOTAL	***31,849,425***	

Solute transport source term modelling identified a better environmental outcome if all mineralised material is placed below the 2s cap called the vadose zone located between 8 to 14 mRL across the Pit 3 surface. Approximately 50 M tonnes of material must be placed below the surface of the 2s cap in Pit 3. A void may remain open for late placement of demolition and/or contaminated material, subject to the completion of the detailed demolition execution plan and schedule.

Disposal of Demolition waste into Pit 3

The process plant, administrative offices, workshops and warehouses, mobile operational equipment and other waste materials will be decommissioned, demolished and transferred by truck to Pit 3 for disposal. Multiple demolition phases may occur, the final demolition plan will be included in future Mine Closure Plans. Demolition phases will be timed to fit in with Pit 3 backfill activities. Demolished material for disposal will be held either near it’s point of origin or on an interim pad prior to Pit 3 availability.

Key assumptions for disposal of demolition waste includes:

- most demolition material will be disposed of in Pit 3;
- hazardous materials (except bulk contaminated hydrocarbons and returnable items) will be disposed of in Pit 3;
- disposal activities in Pit 3 will be concurrent with bulk backfill activities;
- disposed items in Pit 3 will be buried 6 m below final landform; and
- demolition materials will be prepared, placed and backfilled to minimise voidage and settlement issues.

An environmental assessment in 2018 determined the minimum depth for burial of non-mineral waste beneath the final waste rock landform is 6 m based on:

- plant (vegetation) available water and vegetation requirements;
- Northern Territory asbestos disposal requirements;
- predicted denudation over 10,000 years;
- diffusion length for 222Radon;
- Northern Territory general landfill requirements; and
- The Ranger Conceptual Model.

The outcome of the assessment determined revegetation is the most restrictive aspect for minimum depth of waste rock, associated with plant available water and rooting depth in waste rock. An estimate of the current waste material that requires disposal in Pit 3 (or RP2) is summarised in Table 9-12.

Table 9-12 Waste materials for management and/or disposal at closure

Waste Material	Amount
Demolished material	
Demolished structural & non-structural steel, concrete, asphalt, piping	130,000 m^3 (235 kt)
Listed wastes	
Asbestos	400 t
Rubber and other hazardous wastes	8,000 t
General waste	
General rubbish	17,000 t
Heavy Mining Equipment	21,000 m^3
Special Items	
Calciner to Pit 3	1 unit
Geological ore samples (mixed uranium content) to Pit 3	1,400 t
Rags and Pads 77 x 44Gal drums (hydrocarbon/uranium)	100 t

Asbestos

Asbestos is a 'listed waste' under the Northern Territory Waste Management and Pollution Control Act (*WMPC Act*). The *WMPC Act* does not apply to mining; therefore no approval under this act is required. However, ERA is committed to achieving the best environmental outcome for Ranger rehabilitation and will ensure that all disposal of asbestos in Pit 3 is in accordance with the *WMPC Act* guideline *Asbestos disposal in the Northern Territory*.

9.2.2.4 Contingency planning

Brine injection

The deviated drilling of wells to facilitate brine injection into the underfill is currently underway. Included in the well design is the ability to access the well head, enabling clean-out of redrilling of the well, casing material selection and well head infrastructure design to permit injection of brine or flushing fluids into the well under significant pressure. Either of these design features may enable otherwise blocked wells to be recovered. If these remedial activities fail, then additional injection wells can be constructed.

Should injecting brine into the Pit 3 underfill cease to be a viable option and/or the allowed void space is insufficient for the brine volume, additional contingency options will be required. Currently ERA is developing contingency options for two scenarios:

- the brine injection system fails to operate early in the closure project; and
- the brine injection system fails and/or void spaces are exhausted late in the closure project.

During 2021, ERA engaged consultants to assess a range of potential disposal locations and methods against those two scenarios, and develop a short list for more detailed evaluation, including best practical technology assessment. The preferred options selected for the two scenarios will be included in future updates of the MCP.

Tailings consolidation

The volume and rate of water expressed during consolidation of tailings is dependent upon the properties of the tailings and the mass of rock placed as part of the overall capping works. Both of these are well understood by ERA, refer to *Section 5 KKN Supporting Studies*, Chapter 5.4.2 for the tailings properties data. The consolidation model will inform the safe design of the capping layer and provide an estimate of the timing for expressed water. ERA has a number of contingency options should either the consolidation target be shown, through solute transport modelling, to be insufficient to protect the environment, or the consolidation model update determines that the consolidation will take longer. These options relate to the timing of achievement of the closure project and will not impact on the environmental outcome.

For the case where no design options remain to increase the speed of consolidation or where it is identified during execution that consolidation is taking longer than expected, the contingency would be to operate the decant structures and treat the expressed water until the consolidation target was achieved.

Learnings from Pit 1 wet season indicate that large rainfall events that flood the tailings, will not impact tailings settlement or damage completed capping works because water can be pumped out and works resumed following appropriate safety inspections.

The 20 tailings settlement towers are a contingency for expressed pore water extraction in the event that the lowest point of the consolidated tailings surface is not located in the vicinity of the 3 decant towers.

Geotextile

Varying tailings conditions may exhibit liquefaction resulting in capping ‘boil’ failures. Geogrid in high traffic areas will aim to spread load. Any repairs required will be by careful placement of material or covered by extra geotextile and re-capped. The weight of the initial capping layer expresses pore water from the tailings facilitating consolidation and increasing strength. The capping layer will be surveyed to confirm strength and enable access for the bulk backfill fleet (larger HME) for construction of the secondary capping layers.

9.2.3 Ranger Water Dam

Figure 9-55: Ranger Water Dam (September 2021)

The Ranger Water Dam (RWD) is the former Tailings Dam or Tailings Storage Facility (TSF). Bulk dredging and transfer of tailings from the RWD to Pit 3 was completed in February 2021. Transfer of remnant tailings from the RWD floor and walls to Pit 3 was completed in December 2021. Process water is currently stored in the RWD. Deconstruction of the RWD will commence once it is no longer required to store water.

9.2.3.1 Completed rehabilitation

Mill tailings deposition into the RWD ceased in 2016, following the conversion of Pit 3 into a tailings storage facility. Progressive rehabilitation of the RWD commenced with dredging and transfer of tailings to Pit 3. A summary of completed rehabilitation works in the RWD is provided in Table 9-13.

Table 9-13: Completed RWD rehabilitation

Year	RWD closure activity
1996	Tailings deposition from the RWD into Pit 1 commenced in August
2015	The tailings dredge ‘Jabiru’ was launched and commissioned in the RWD
2016	In January, commencement of transfer of approximately 27 Mt of dredged tailings from the RWD to Pit 3
2019	Remnant tailings cleaning from the walls of the RWD commenced
2019	A second tailings dredge ‘Brolga I’ was fully commissioned
2019	Tailings transfer upgraded to new flow rates to meet the requirements of the two dredges
2020	ERA received MTC approval to leave the RWD subfloor material in-situ
2021	Completion of bulk dredging 15 February 2021 Initiation of floor and wall cleaning activities (Figure 9-57) Transfer of remnant tailings from the RWD to Pit 3 via heavy vehicle commenced in June and was completed in December
2022	Water transferred from the RWD to Pit 3 to complete floor and wall cleaning Transfer of process water from Pit 3 to RWD to commence wicking in Pit 3

Tailings transfer

The bulk tailings reclamation system recovered tailings material from the RWD by means of two dredges, the ‘Jabiru’ and the ‘Brolga I’ and their supporting maintenance crafts ‘Mudskipper’ and ‘Ginga’ respectively. The Jabiru shown in Figure 9-56 a stainless steel dredge, weighing approximately 170 t used a five-wire, three-anchor, system to manoeuvre whilst dredging.

Figure 9-56: The Jabiru dredge

The Brolga I (Figure 9-57) was a Damen CSD500S cutter suction dredge, using two spuds and two side wire anchors.

Figure 9-57: The Brolga 1 dredge

Maintenance craft (or workboats) set the anchors and assisted the dredge moves under tow, mobilised crew and equipment and supported the servicing of the vessels. The Mudskipper

(Figure 9-58) is a 13 m maintenance craft that serviced the Jabiru. The Ginga serviced the Brolga I.

Figure 9-58: The Mudskipper

A dredge plan was developed by ERA based on HYPACK DredgePack dredging software to control dredging practices, with accurate positioning and monitoring of progress. Run lines allowed for a 40 m swing cut for the Jabiru and 50 m wide run lines for the Brolga I.

Each dredge operated in its own working area so as not to impede each other's operation. The south side was dredged by the Jabiru and the remainder dredged by the Brolga I. The result was a 60 /40 volume split between the Brolga I and Jabiru. The north side of the RWD was allocated to the Brolga I due to the deeper floor providing for more consistency in the water level over the course of the project. The maximum dredging depths for the Jabiru and Brolga were 10 m and 14 m, respectively.

The upstream clay core of the RWD embankment was protected from contact with the dredge cutter head by the inclusion of a 0.5 m standoff zone programmed into the dredge computer.

The dredged tailings were transferred to Pit 3 via a dedicated single overland pipeline for each dredge until the completion of bulk dredging on 15 February 2021. The pipelines connect directly to the discharge of the floating pipeline from the dredge on the eastern notch. Tailings were discharged into Pit 3 via subaqueous and subaerial deposition.

Process water return Pit 3 to RWD

The process water stored within the tailings in Pit 3 is continuously expressed as sedimentation/consolidation occurs. The water that flowed upwards (decant), while the dredges were operational, was pumped back to RWD to keep up with the dredge operation, the process shown in the block diagram in Figure 9-59.

RWD wall notches

The progressive reduction in water level associated with the dredging operations necessitated the creation of notches within the RWD walls to facilitate safe access to floating infrastructure and improve return water pumping efficiency. Figure 9-60 shows the location of RWD wall notches. The East wall notch was installed to improve the pump efficiency for process water and tailings pipelines. Stages one and two of the North wall notch, were built to allow safe access to floating infrastructure in the RWD as the tailings was progressively removed. Finally, two shallow notches, in the western wall and south-western corner, were constructed to allow access into the RWD for wall and floor cleaning activities in 2020.

Prior to the construction of each notch engineering designs and stability assessments were completed. The design and assessment were reviewed by an independent specialist to meet the requirements of the Rio Tinto Group Standard D5 – Management of tailings and water storage. Regulatory approvals were also obtained prior to the execution of notch works where the notches result in a change to the certified clay core crest height and associated decrease to the maximum operating level (MOL) of the RWD.

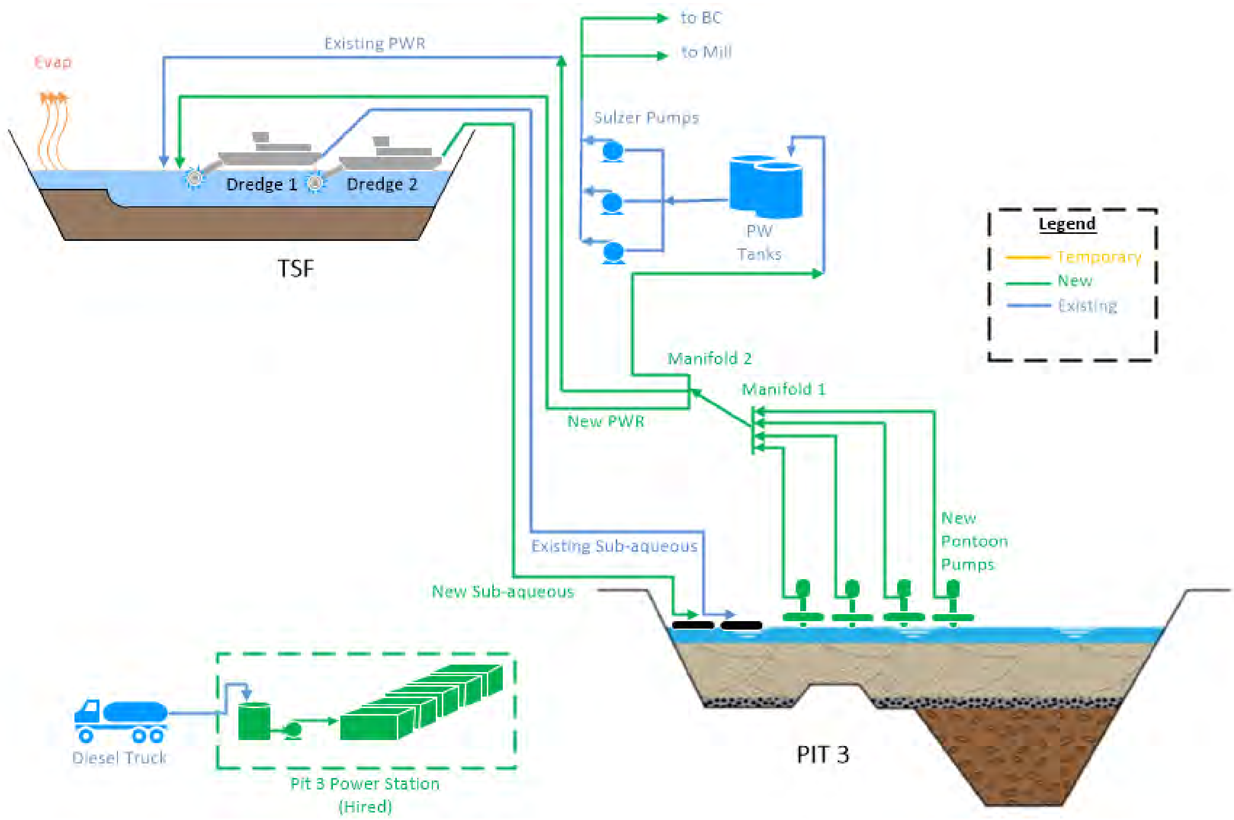


Figure 9-59: Process water return from Pit 3 to the RWD

Figure 9-60: Location of notches within the RWD walls

RWD wall cleaning

Condition 11.2 of the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (the ERs), requires that all tailings must be placed in the mined out pits. In order to comply with this condition ERA completed a wall and floor cleaning program to remove the remnant tailings within the facility. ERA continues to collaborate with stakeholders to determine the final criteria to confirm compliance with condition 11.2.

The upstream clay core of the RWD embankment was protected from contact with the dredge cutter head by the inclusion of a 0.5 m standoff zone resulting in tailings 'hang-up' on the RWD walls (Figure 9-61). ERA used excavators to scrape remnant tailings from the internal RWD walls, progressively transferring the tailings down the walls onto the RWD floor. The excavators manually sorted larger rocks or rubbish material within the tailings. An amphibious excavator was used to access to wet areas not accessible by conventional excavators. The cleaning methodology steps were:

Step 1: Bulk Tailings Removal

An excavator removed hung up tailings material down the wall, stacking the tailings on the RWD floor while maintaining the wall integrity.

Step 2: Scrape

With a flat bladed bucket, excavators scraped tailings from the wall surface, able to occur concurrently with Step 1, removing all visible tailings from the wall surface shown in Figure 9-62.

Figure 9-61 Typical wall cleaning operation above 45 mRL

Figure 9-62 –RWD wall post step 1 & 2, with tailings patches indicated (dark grey/khaki colour)

Step 3: Inspect and Correct

The work crew undertaking the wall cleaning inspected the work and took corrective action if required. This is recorded in an Inspection and Test Plan (or verification plan) and included further, targeted removal of tailings material with an excavator where required. It is noted that rainfall also assisted in wall cleaning by washing tailings down the slope.

Current visual inspections show that one wet season has cleaned a significant amount of fine tailings from the walls. This is apparent in the before and after pictures taken of one section of wall shown in Figure 9-63 and Figure 9-64.

Figure 9-63 Section of the West wall showing a scraped clean wall section prior to wet season 2020/21. Some fine tailings may potentially sit in between wall armouring

Figure 9-64 Same section of the West wall of Figure 9-63 showing cleaned surface following rain

RWD floor cleaning

The dredges removed most of the tailings material from the RWD. However, due to the presence of buried waste material, large displaced rock armour and ‘spill’ from the dredges, some remnant tailings remained on the RWD floor following the completion of the dredging program.

Cleaning of the RWD floor commenced early 2021. Low Ground Pressure (LGP) ‘swamp’ dozers and all terrain excavators (ALTEX) created initial drainage paths, allowing the RWD floor to gradually drain, creating a more trafficable surface. Excavators and LGP ‘swamp’ dozers then pushed tailings into stacks and rows, further dewatering the tailings.

ERA undertook a BPT assessment on 24 February 2021 to determine the most appropriate approach for the disposal of the remnant tailings within the RWD. Trucking the tailings to a tip head in Pit 3 had the best performing approach with the highest, or equal highest, ranking for every criterion.

In June 2021, ERA commenced the remnant tailings transfer from the RWD to Pit 3, utilising trucks, which access and depart the RWD floor via the northeast ramp. The most stable and competent tailings were moved first, in small volumes, to verify contamination and material management controls.

The remnant tailings transfer followed a designated haul route, through the mine area, between the RWD and Pit 3 with restricted access classified as a controlled area.

Foreign material removal

Magnetometer surveys of the RWD completed in 2012 and 2019 located potential buried iron objects (Fugro 2012 & Surrich Hydrographics, 2019). The 2012 survey reported ‘a very strong anomaly on the south-eastern side of the RWD, believed to be the sunken remains of the old survey barge / pontoon’. Data acquired through the 2019 magnetometer surveys (Surrich Hydrographics, 2019) with a towed magnetometer compared to the 2012 is shown in Figure 9-65.

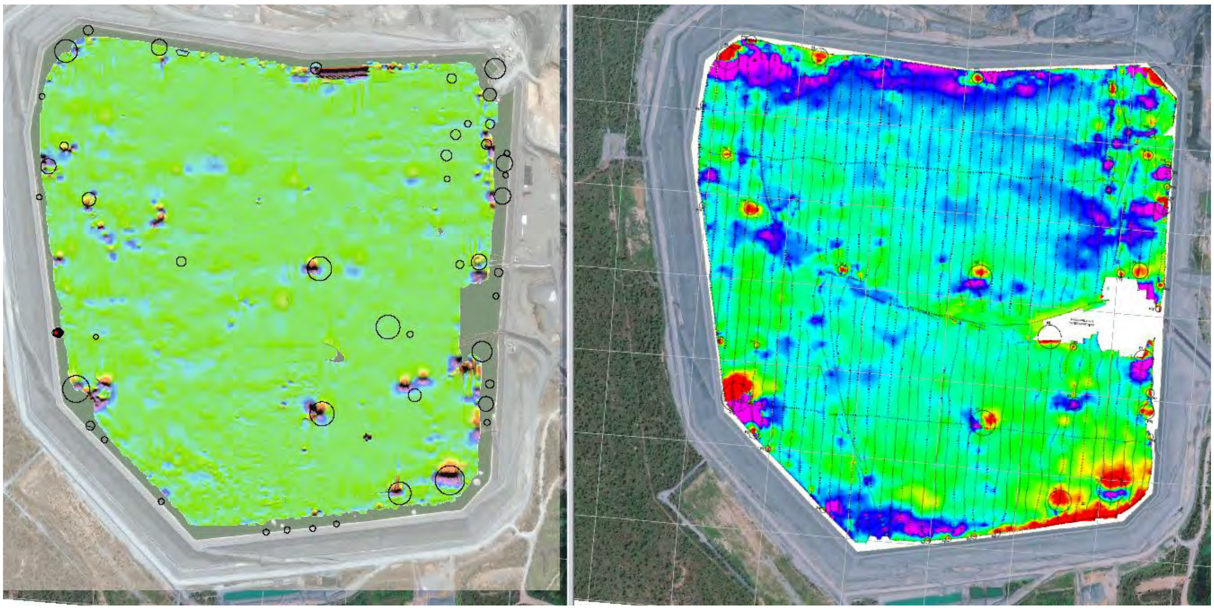


Figure 9-65: April 2019 Magnetic Anomaly Map (left frame) comparison with the 2012 Magnetic Anomaly Map (right frame)

Objects were identified close to the RWD embankment, whilst the central area was relatively free of anomalies. The magnetometer detected a very strong anomaly on the south-eastern side of the RWD, again, believed to be the sunken remains of the old survey barge/pontoon. No other features of similar magnitude were found. Many anomalies, either localised or diffuse, were likely caused by magnetic material in the tailings, accentuated by variations in the water depth that changes the range between source and detector. Small, localised anomalies, particularly around the RWD perimeter, probably represent iron debris.

Throughout the dredging operations, foreign materials were encountered and they were either removed from the RWD, cleaned and stored, or placed temporarily on the walls as they were encountered. All waste materials found in the RWD will either be buried in-situ, transferred to Pit 3 or transferred to RP2 for final burial.

9.2.3.2 Current rehabilitation

The RWD is currently storing process water returned from Pit 3. No current rehabilitation activities are occurring.

9.2.3.3 Planned rehabilitation

RWD subfloor material management

The management of contaminated sites is a critical step for rehabilitating Ranger mine and meeting closure criteria. The RWD subfloor was identified as an area requiring further investigation to assess the levels of contamination and solute egress risk based on a final disposal location. In June 2020, ERA submitted an application to the MTC to remove the option of transferring RWD subfloor material to Pit 3 as part of the closure strategy. An assessment was undertaken to identify a management option that would achieve the best environmental outcome in terms of minimising contaminant loading to the environment. The supporting studies (including solute egress modelling discussed below) and a BPT assessment indicated that the most viable management option involved leaving the subfloor material *in situ*. This decision was important for informing the list of source terms for the closure of Pit 3, and to allow commencement of RWD decommissioning planning with consideration of future remediation options.

The solute egress modelling undertaken by INTERA indicated that all options involving the transfer the RWD subfloor material to Pit 3 would increase the direct Magnesium (Mg) peak loadings to Magela Creek by a significant margin in contrast to leaving the material *in situ*. In addition, the physical removal of the RWD subfloor, and backfilling with waste rock, would further alter the hydraulic characteristics within the RWD footprint, causing changes to the surrounding drainage dynamics and increasing the peak Mg loading to drainage areas within the Ranger Project Area (RPA). It was also found that Mg loadings to the Coonjimba catchment (the nearest sensitive receptor to the RWD) will not differ significantly if the RWD subfloor material remains *in situ* or is removed, when considering the contribution from the broader RWD groundwater plume. The modelling work is discussed detail with *Section 5 KKN Supporting Studies*, Chapter 5.5.2.

The RWD subfloor risk assessment concluded that the risks associated with leaving the RWD subfloor material *in situ* can be adequately managed. Any potential consequences resulting from this management option are likely to be confined to RWD footprint and surrounding drainage areas and represent consequences that are as low as reasonably achievable (ALARA) within the boundary of the RPA. In implementing this management option, ERA recognised the opportunity to undertake *in situ* remediation to further minimise levels of contamination. This will be investigated through further assessment.

Regulatory approval to leave the RWD subfloor *in situ* was received in August 2020. The RWD deconstruction application will include a BPT assessment of potential remediation options and an updated risk assessment to demonstrate how risk ratings can be improved.

Dredge disposal

One of the two RWD dredges (the Brolga 1), has been removed from the RWD, cleaned, decontaminated, radiation cleared and sold. Ideally, this same process would occur for the second dredge (the Jabiru) and the two supporting vessels (the Mudskipper and the Ginga, which are currently being used in Pit 3 to support wicking activities). If this does not happen, this equipment will be made safe and disposed on-site. Options for disposal are:

- burial in the RWD;
- burial in Pit 3 (or RP2).

An environmental assessment, completed in 2018, determined the depth for burial of non-mineral waste as 6 m below final landform. ERA has identified a suitable location in the south-east corner of the RWD; where the surface area and cover depths in relation to the final landform and minimum burial requirements allow for burial without the need for further excavation. This option allows for the burial of the dredging equipment and any other miscellaneous waste material remaining in the RWD at the time of deconstruction.

Removal of HV power supply and telemetry

As activities at the RWD are reducing, so too is the power demand. High Voltage (HV) power distribution lines (mostly aerial but some buried) will start to be decommissioned and removed. This will occur progressively, with HV power in the area of the processing plant being retained for some time for the BC, Brine Squeezer and water treatment plants. The removal of the HV line to the RWD including the HV spur line to the Brockman Bore will also necessitate the conversion of the Brockman borefield power supply to a diesel-powered generator or similar.

Process water storage

At the commencement of Pit 3 capping activities, water in Pit 3 will be pumped back to the RWD for storage pending treatment. Once the process water volume in the RWD falls below 1 GL, the process water will be transferred out of the RWD into RP6. This allows the deconstruction of the RWD to occur before the completion of process water treatment.

Once the RWD is empty of process water, decommissioning, including any contaminated material management activities, will commence. During the deconstruction work, the RWD will be converted to a pond water catchment. Any water captured in the RWD area after this time will be collected and transferred to Retention Pond 2 (RP2). Upon completion of the final landform in this area, the RWD catchment will be converted to a release water catchment.

RWD decommissioning

The decommissioning of the RWD involves both the management of the contaminated material remaining in the RWD sub-floor and the deconstruction of the facility. The options for management of contaminated material remain under assessment and will be provided in future updates to this MCP and a standalone approval application.

RWD deconstruction will involve reducing the walls to final landform level. Wall material will be used to fill in the RWD. The majority of the material used in the construction of the RWD walls will fit into the RWD to achieve the final landform. A small volume of the wall material may need to be transported to a nearby stockpile area. The material in the wall will be mined using standard material movement practices with dozers, trucks and excavators. The RWD deconstruction material quantities are shown in Table 9-14 with sequencing shown in Figure 9-66.

Table 9-14: RWD deconstruction material quantities

RWD Segment	Material Movement	Brief Description
RWD EAST	Excavation and distribution to final landform levels: 835,121 m^3 Final landform surface area: 24.99 ha	Deconstruction of the eastern RWD walls. Utilise material to shape final landform surface in the eastern area.

RWD Segment	Material Movement	Brief Description
		Excess material taken to other site fill areas.
RWD WEST	Excavation and distribution to final landform levels: 2,440,743 m^3 Final landform surface area: 43.07 ha	Deconstruction of the western RWD walls. Utilise material to shape final landform surface in the western area. Excess material taken to other site fill areas.
RWD SOUTH	Excavation and distribution to final landform levels: 2,881,980 m^3 Final landform surface area: 98.15 ha	Deconstruction of the southern RWD walls. Utilise material to shape final landform surface in the southern area. Excess material taken to other site fill areas.
RWD NORTH	Excavation and distribution to final landform levels: 1,463,850 m^3 Excavation and distribution to Pit 3: 1,086,537 m^3 Final landform surface area: 31.19 ha	Deconstruction of the northern RWD walls. Utilise material to shape final landform surface in the northern area. Excess material taken to site fill areas.

RWD plume

Gradual seepage from the RWD, since the time of its construction, has resulted in the formation of a groundwater contamination plume. The extent and behaviours of the plume have been investigated over time (Weaver, 2010). Test work and studies were completed during 2020 to further define the plume and model the groundwater transport (*Section 5 KKN supporting studies*, Chapter 5.5.2.5). A BPT assessment of potential remediation options for this plume is planned to be completed in conjunction with the other RWD contaminated material, as discussed above. These assessments and any remediation plans required will be included in the RWD deconstruction application and subsequent updates of this MCP.

Landform and erosion control

The final surface of the RWD will be shaped to form the final landform. The RWD topography forms a drainage flow path running south to north along the historic Coonjimba Creek. Landform and erosion controls for the RWD will be included in the RWD deconstruction application and subsequent updates of this MCP.

Revegetation

ERA is currently assessing the potential impacts on vegetation from any contaminated materials buried under the final landform. The outcomes of this work and any risk mitigation measures required will be included in the RWD deconstruction application and included in the relevant update of the MCP.

9.2.3.4 Contingency planning

RWD deconstruction methods are currently being finalised by ERA in preparation for the RWD deconstruction application. This involves a best practical technology assessment of the options. The options not selected for progression, that have not been show stopped for environmental or cultural reasons, will then form the basis of ERA's contingency planning.

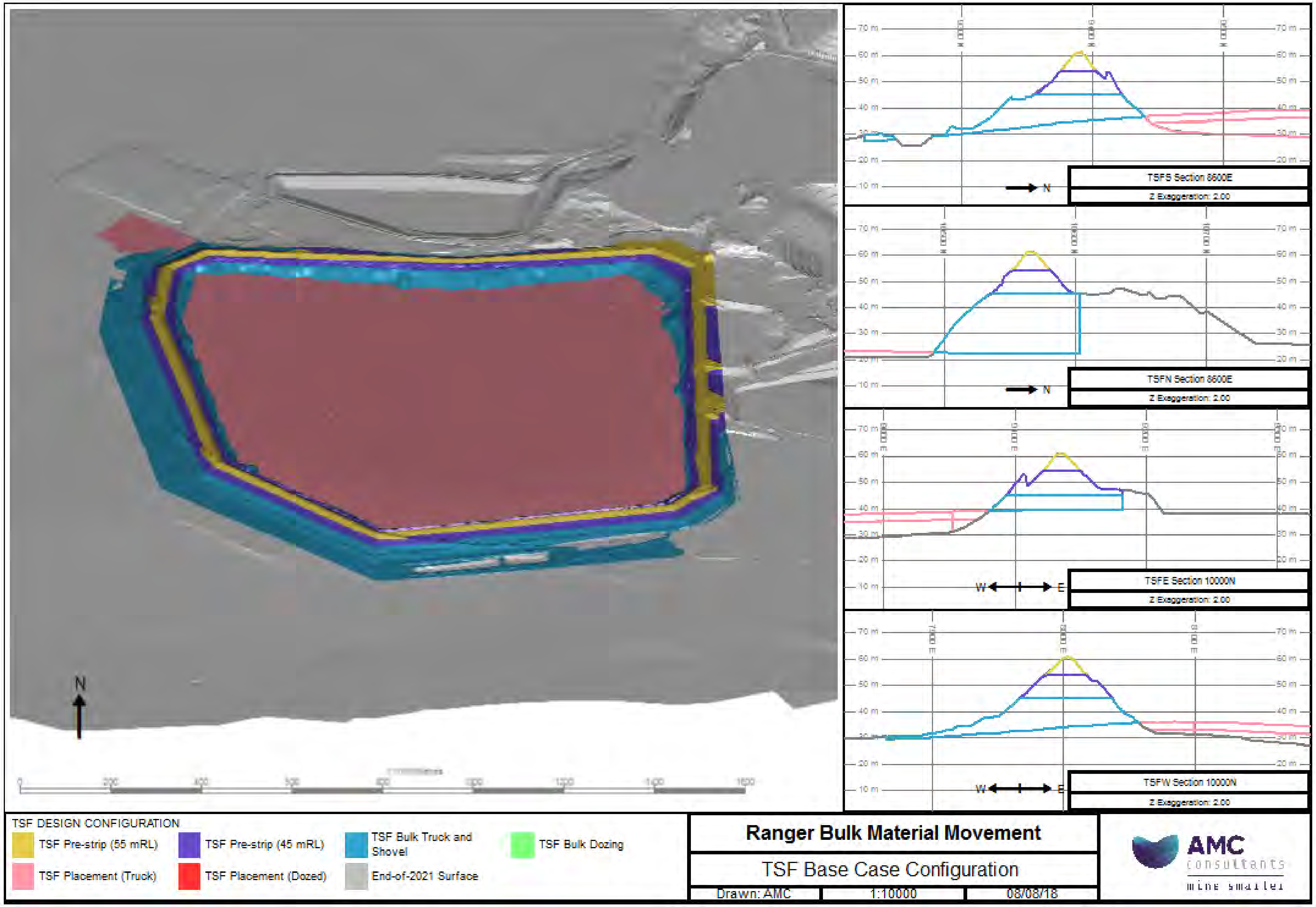


Figure 9-66 RWD wall deconstruction sequence

9.2.4 Land Application Areas

Figure 9-67 Djalkmarra and Djalkmarra Extension Land Application Areas (May 2019)

Land application areas (LAAs) allow for the disposal of water through spray or flood irrigation (Figure 9-69). The quality of water disposed on the LAAs has varied over time, however LAAs are now used purely for the disposal of release quality water, Water Treatment Plant permeate and Brine Concentration distillate water. The LAAs are designed to retain uranium in near-surface soils. Ranger mine has eight LAAs in total, with a combined size of 328 hectares.

LAAs will be required throughout closure to allow for the ongoing disposal of release water, generated through rainfall runoff and water treatment. As catchment areas transition to direct release and water treatment requirements reduce, these areas will gradually become available for decommissioning. Decommissioning of these areas will involve:

- removal of any infrastructure (i.e. pipes, irrigation spray heads). Figure 9-68 and Figure 9-69 provide examples of infrastructure at each LAA;
- completion of any remediation works, as determined from contaminated sites and best practical technology assessments;
- scarifying of tracks, as required; and
- completion of any infill revegetation, as required.

Figure 9-68: Infrastructure for removal at Corridor Creek LAA

A preliminary assessment of the total percentage of each LAA requiring revegetation has been made (Addison, 2011). The size of these areas is dependent on the quantity and quality of the native vegetation and the density of weeds, present after years of irrigation.

Table 9-15: Area of the LAAs

#	LAA		AREA (ha)
A	Corridor Creek LAA	Total area:	131
		Planned revegetation (10%):	13.1
B	Magela A LAA	Total area:	33
		Planned revegetation (100%):	33
B	Magela B LAA	Total area:	20
		Planned revegetation (70%):	14
C, D	Djalkmarra East (DLAA) & Djalkmarra West (DLAA ext) LAA	Total area:	38
		Planned revegetation (50%):	19
E	Retention Pond 1 LAA	Total area:	46
		Planned revegetation (80%):	36.8
F	Retention Pond 1 LAA ext.	Total area:	8

#	LAA		AREA (ha)
		Planned revegetation (10%):	0.8
G	Jabiru East LAA	Total area:	52
		Planned revegetation (80%):	41.6
LAA – TOTAL HA			328
TO BE REHABILITATED – TOTAL HA			158

Figure 9-69: Infrastructure for removal at Corridor Creek LAA

9.2.4.1 Completed rehabilitation

There has been no progressive rehabilitation undertaken of the LAA sites to date as these areas remain in use.

9.2.4.2 Current rehabilitation

Assessments to characterise the LAA substrates have been completed. ERA will be deriving site specific Environmental Investigation Levels (EIL) for Uranium in order to assess the required rehabilitation. All LAA rehabilitation assessments will be informed by a BPT assessment and an ALARA assessment.

Previous assessment of the Land Application Areas (LAAs) was conducted in 2009 by Jane Addison Consulting, and more recently in October 2021 by the Supervising Scientist Branch (SSB). EcOz Consultants were engaged to provide an update of the current condition of the

LAAs, with the collected information used to inform future rehabilitation and management objectives and strategies (EcOz, 2022). The objective of the study was to provide an up-to-date, detailed assessment of each LAA, with a focus on vegetation composition and structure, weeds and disturbance, and fire history (EcOz, 2022). The surveys undertaken follow the methods described in Addison (2011) with the study following a similar structure to enable data comparisons where possible (EcOz, 2022).

A total of 34 sites were assessed across the seven LAAs shown in Figure 9-70 and described in Table 9-16. Sites were selected from Addison (2011) and resampled to update the dataset as well as for comparison to previous data and existing reference sites (EcOz, 2022). Sites were initially selected by overlaying a grid containing 150 m^2 cells within the LAAs and placing one 20 x 20 m quadrat in the centre of 34 chosen cells (Addison 2011). Each site was assessed for vegetation composition and cover, presence of weeds, fire history, and disturbance. The methods mostly replicated those described in Addison (2011), with some minor changes. Data were obtained from within each 20 x 20 m quadrat. A single photograph was taken facing due south from the centre of each quadrat with a team member holding a measuring tape to 2 m height for reference, standing approximately 5 m away from the camera.

A comprehensive report on the 2022 ground surveys was drafted in September 2022 (EcOz, 2022), and key findings will be used to develop individual rehabilitation strategies for the different areas. The LAA rehabilitation strategies will also consider the findings from the Dendra aerial monitoring trial (Section 10.6) and the contaminated site surveys. More details will be provided in the 2023 MCP. Several changes were observed in the LAAs compared to their last survey in 2009, including an increase of weeds and a marked decreased in fire activity.

Table 9-16 Land application areas surveyed within the Ranger Project Area

LAA	Approximate Area (ha)	Number of sites surveyed	Sites within LAA
Jabiru East	5305	5	S01 – S05
RP1	45.1	3	S11 – S12
RP1 Extension	8.6	2	RP1 a, b, c
Djalkmarra	23.5	4	S06 – S09
Djalkmarra Extension	11.0	1	S10
Magela (incl. Extension)	48.7	5	S13 – S17
Corridor Creek	146.1	14	S18 – S31

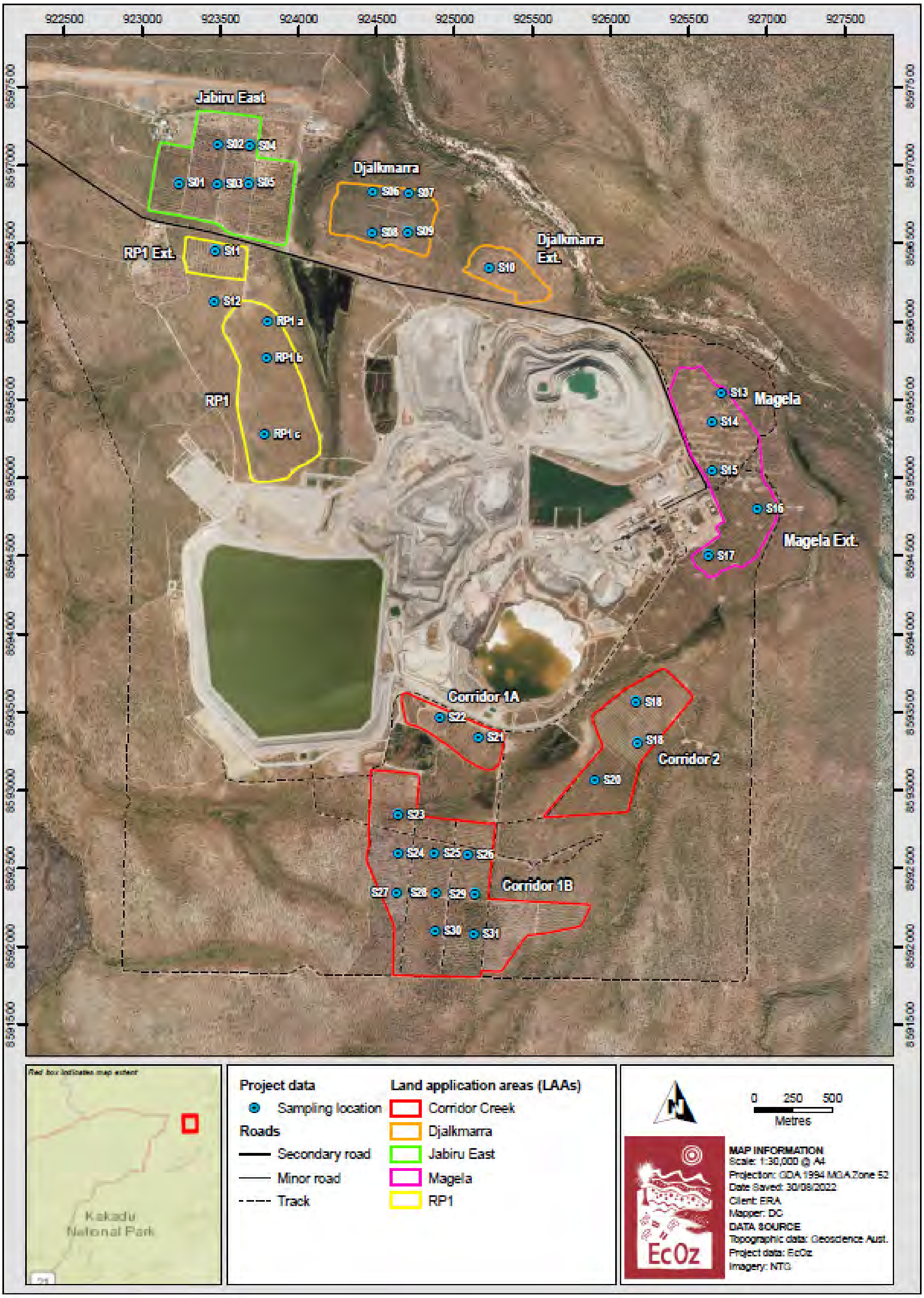


Figure 9-70 Map of Land Application Areas and survey locations within the Ranger Project Area

9.2.4.3 Planned rehabilitation

As described above and shown in , it has been determined that only 158 ha within the total area of LAAs will require active revegetation (i.e. planting in addition to self-regeneration). It is noted that the basis of this work was completed in 2011 and will be updated with the new information from the 2022 survey described above This will be included in future updates of the MCP.

9.2.4.4 Contingency planning

No contingency planning is required for the LAAs:

- Land application areas will not be rehabilitated until the areas are no longer required for water disposal.
- Historical soil sampling has been undertaken across all the LAAs. The analysis of these soil assessments will be used to undertake a BPT assessment to determine, if required, the best strategy for remediation of the LAAs.
- Monitoring will determine whether the selected revegetation strategy has been successful and if any further additional works are required.

9.2.5 Process plant, water treatment plants and other infrastructure

Figure 9-71 Process plant, mill and water treatment plants (May 2019)

This domain, as shown in Figure 9-71, includes all infrastructure from the processing plant, administration block, heavy vehicle area, power station, gatehouse and water treatment plants.

A discussion on the activity of water treatment is provided in Chapter 9.3.3, whilst this Chapter describes the removal of the water treatment infrastructure.

External services (Telstra) has been excluded from the Ranger Mine closure demolition scope as discussions are currently underway on the transfer of the facilities to the Northern Territory or Commonwealth government.

9.2.5.1 Completed rehabilitation

Prior to commencement of the decommissioning and demolition of the Ranger processing plant, ERA obtained a 'Permit to Decommission Facility' from the Australian Safeguards and Non-Proliferation Office (ASNO). The application for a permit outlined timeframes and estimated start and completion dates for the decommissioning of infrastructure associated with the leaching and solvent extraction circuits and areas of calcination, drying and product packing. This permit was received on 8 January 2021 at the completion of milling activities and allowed decommissioning works to proceed.

Decommissioning

Work on decommissioning and decontamination of all infrastructure within the processing plant has now been completed. The main goals of the decommissioning and decontamination implementation strategy are:

- controlled shutdown of all assets within a demolition area;
- decontamination of all infrastructure to the extent required to ensure safe and efficient demolition and disposal;
- de-energisation and isolation of each demolition area, scheduled in conjunction with the continuity of services works;
- interim management of the demolition area until handover to the demolition contractor; and
- walk-down, punch-listing (checklist) and handover to the demolition contractor once contract has been awarded.

The main stages of the decommissioning works are represented in Figure 9-72.

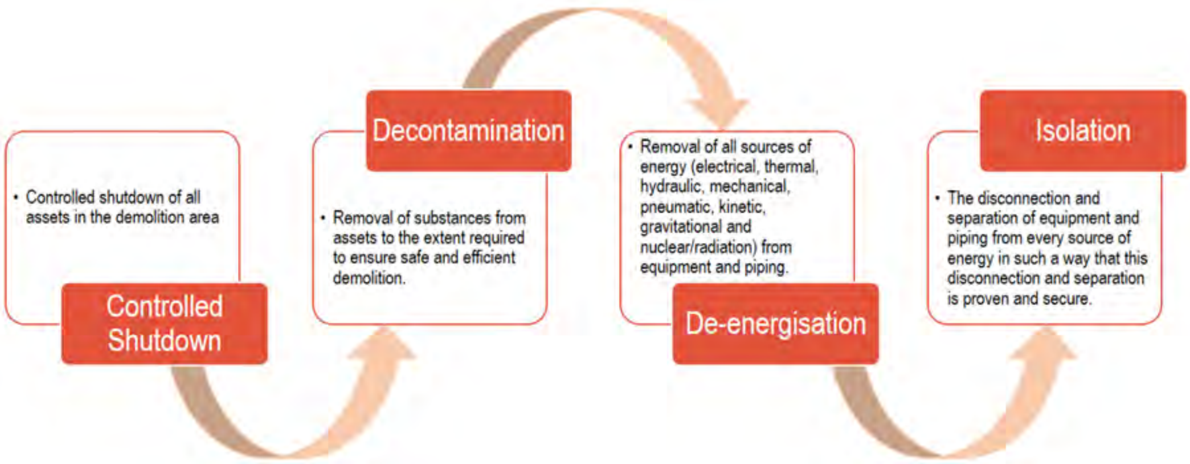


Figure 9-72 Decommissioning stages

All de-energisation and isolation activities of the demolition area were divided into electrical and control, piping, structural and miscellaneous and all activities completed according to ERA standards.

Works to ensure the continuity of services have also commenced. This involves moving service corridors, such as power and water lines, outside of the future zone of demolition. This process is required to be completed before the commencement of phase 1 demolition.

9.2.5.2 Current rehabilitation

With the completion of decommissioning of the processing plant, current rehabilitation involves only care and maintenance work to ensure the area remains safe prior to completion of demolition work. This, and the management of the demolition area (prior to handover to the demolition contractor), will involve the following activities:

- management of rainwater in the process area bunds via existing sump pumps while power remains live in decommissioned area;
- once the existing system of sump pumps are shutdown the following installation will be reviewed:
    - sampling and testing of rainwater in 'decontaminated' sumps to confirm that it is still sufficiently contaminated that it cannot be released
    - installation of a system of portable diesel pumps and lay flat hosing to pump contaminated rainwater to the retention ponds
    - documentation of the system to enable handover of management to the demolition contractor.
- demarcation of the demolition area boundary with tape, spray paint or similar;
- where required, installation of a temporary generator to connect to the light and power board to provide power for lighting in de-energised buildings during inspection activities. This generator is to be removed after inspection activities are completed;
- completion of the decommissioning work pack and handover check sheet (by the responsible party as the work is completed), including:
    - initialled and dated sign-off of all work by the responsible party
    - identification of any residual hazards on registers and drawings
    - results of radiation survey, and underground services surveys appended to the work pack (gas clearance surveys will be completed by demolition contractor prior to demolition activities commencing)
- walk-down of the demolition area to confirm completion of all activities in the decommissioning work pack and punch-listing (checklist) of incomplete items for handover to Continuity of Services team. Sign-off of the completion of activities is to be performed by the following accountable parties:

  - Area Superintendent – to confirm that all shutdown and decontamination work is complete
  - Radiation Safety Officer – to confirm all radiation surveys have been completed correctly and radiation levels are acceptable
  - Safety Officer – to confirm that all gas clearances have been completed correctly and explosion risks have been removed
  - Closure Project Engineering – to confirm that all continuity of services and de-energisation and isolation work is complete
- gas clearance and radiation surveys will be re-performed immediately prior to handover to demolition, to confirm areas are still safe after any extended period between decommissioning and demolition;
- second walk-down and punch-listing (check list) will be undertaken with the demolition contractor (to be conducted with demolition contractor prior to mobilisation of demolition equipment and crew to site and with sufficient schedule float for rectification works).

9.2.5.3 Planned rehabilitation

Continuity of services

Some services are required to be kept online or re-routed to allow continued operation of some aspects of the mine beyond cessation of milling operations.

Key aspects of the continuity of services plan are:

- essential services are assumed to remain operational, as per the current operating system, until commencement of Phase 1 demolition (Table 9-18);
- services within the Phase 1 demolition zone which are required after Phase 1 demolition are subject to continuity of services;
- equipment will be reused where possible;
- purchase of new equipment will be minimised; and
- Pipe and cable routes will avoid the Phase 1 demolition zone, where possible.

Continuity of services requires multiple piping tie-ins for various services. These services are split into the following:

- acids and reagents;
- potable water;
- plant air;
- diesel;
- fire water;
- pond water;

- instrument air;
- process water; and
- sewage.

Demolition and disposal

A demolition sequence has been determined for the areas of the plant based on the interaction of the plant with other activities in the overall closure project. Each plant area is colour coded according to the phases of demolition and are shown in Figure 9-73 and described in Table 9-17.

Demolition is defined as the tearing down of buildings and other structures (including the underground infrastructure) within the boundaries of the RPA. It includes:

- fixed or demountable process plant, buildings, mechanical or electrical infrastructure;
- tanks, both above and below ground;
- all pavements (bitumen and/or concrete) and associated infrastructure such as kerbs, gutters and gully pits;
- concrete slab and foundations to a depth of 1.5 m below existing ground level;
- all piping to a depth of 1.5 m below existing ground level;
- all cabling to a depth of 1.5 m below existing ground level;
- bitumen surfaces from roads;
- asbestos;
- loose solid materials across the sites;
- processing of demolished materials to approximately 1.5 m x 1.5 m lengths to ensure maximum density can be achieved at the disposal location; and
- removal and final disposal of the materials and hazardous waste.

Demolished items must be buried on site at 6 m level deep below final landform in Pit 3, RP2 or other purpose excavated locations on site (Figure 9-74).

There is one deep underground structure where some equipment will be left *in-situ*. Using the same burial depth of 6 m applied to other demolition material, anything at or below that depth within the Primary Crusher area shall be left *in-situ*. Fill material will be added in and around the equipment within the Primary Crusher shaft up to final landform.

The environmental impact from burial in these locations has been assessed as part of ERA solute transport model. Some hazardous wastes will be returned to suppliers following strict removal guidelines and requirements.

Demolition of infrastructure within a certain area is deemed to be complete when the area is available for rehabilitation activities (bulk material movement and final landform works) and, subsequently, revegetation activities.

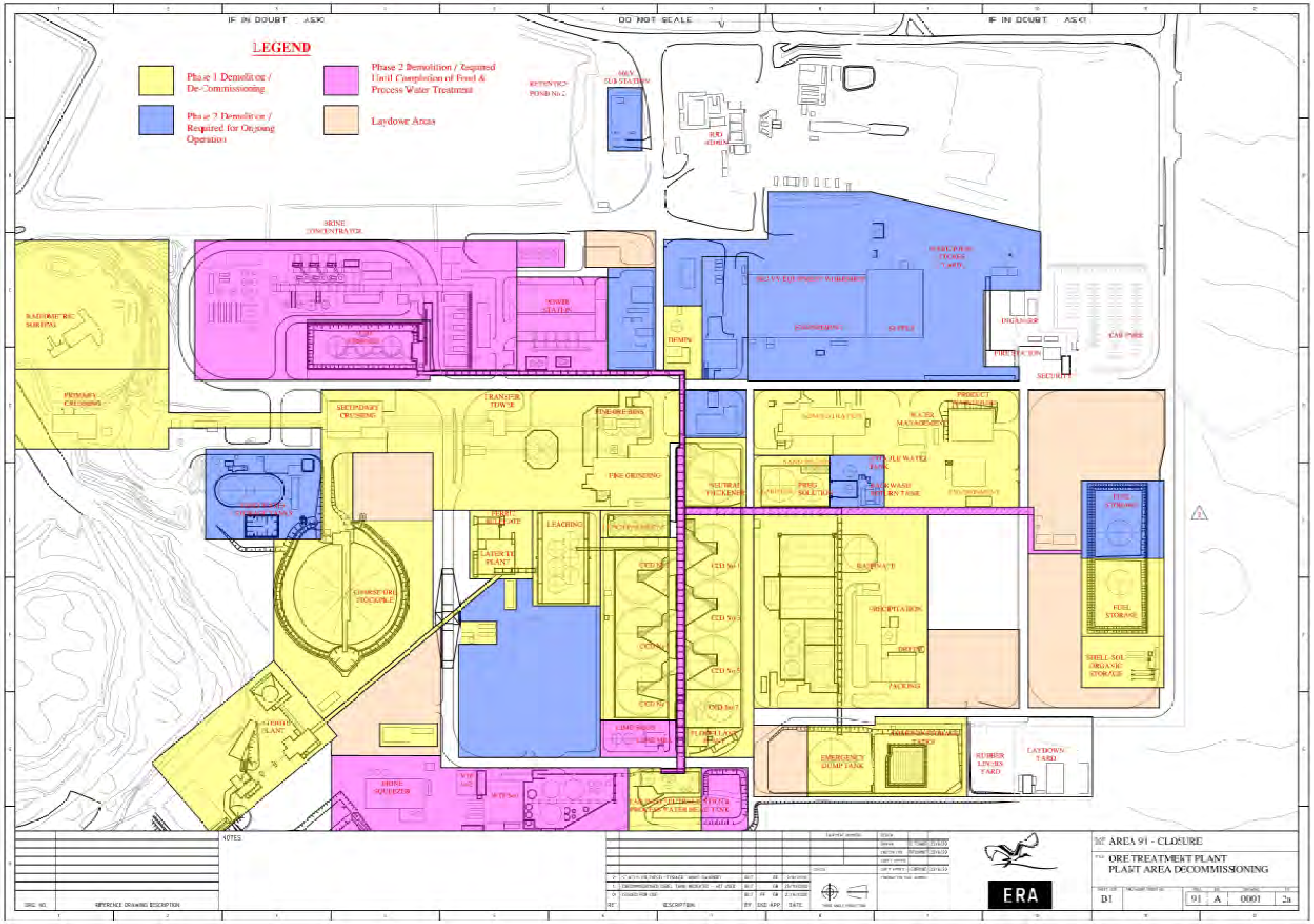


Figure 9-73 Plant demolition sequence

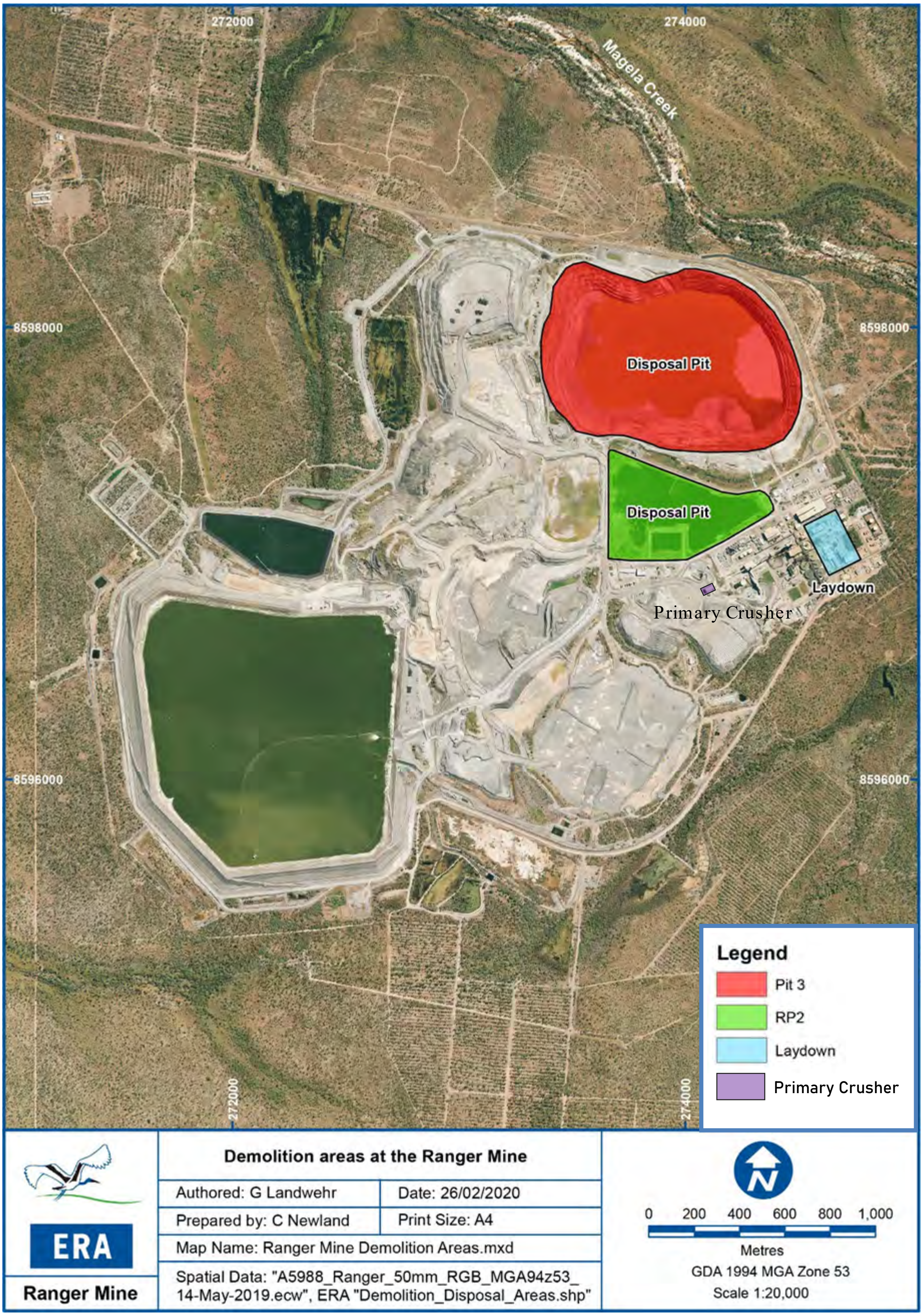


Figure 9-74 Areas for disposal of demolition material

Table 9-17: Demolition phases

Phase	Associated infrastructure
1	Mill, processing plant and tailings transfer infrastructure
2	Process water treatment / transfer, mine and closure activities infrastructure
3	Post-closure management infrastructure

The following demolition methods may be used to demolish the facilities on the RPA:

- manual demolition;
- mechanical demolition;
- cut and pull;
- induced collapse; and
- explosive demolition.

Wherever possible, large-scale demolition activities will be performed using machinery as it is the quickest, safest and cheapest method. Where explosive demolition is required, the demolition contractor will provide a detailed explosives Work Method Statement prior to mobilisation.

The key infrastructure and services for Phase 1 works, including demolition and transportation of the waste (including hazardous materials) to Pit 3, are listed in Table 9-18. The key infrastructure and services for Phase 2 works are listed in Table 9-19.

Asbestos was identified in the processing plant, power station and associated administration buildings through an initial audit of the Ranger Mine by Environmental Health Services in February 2003, and a subsequent audit by SLR Consulting in 2016. The quantities of asbestos across the site are relatively small and are located in clearly defined areas. Asbestos shall be removed by an appropriately qualified contractor and buried in Pit 3.

Detailed material take-offs (a list of materials with quantities and types) have been completed to provide a more accurate estimate for major process buildings. These include the fine crushing building, grinding building, solvent extraction plant, Calciner and product packing, engineering supply workshop and power station. Quantities were approximated based on similar metrics for remaining areas.

Phase 1 demolished materials will be disposed of in Pit 3, whilst it is open and accessible, concurrently with bulk material movement works. Demolished items will be processed at the designated laydown area and transferred to Pit 3.

The following items have been identified as materials that should not be processed but placed in Pit 3 whole due to the expected level of contamination post decommissioning:

- Calciner;
- sand filter in SX building; and
- asbestos drums.

The key assumptions for Phase 1 are:

- all Phase 1 demolition material to be disposed of in Pit 3, with the exception of equipment left in Primary Crusher shaft;
- all Phase 1 demolition hazardous materials (except for contaminated hydrocarbons and items returnable to vendor, such as density gauges, acid and ammonia) to be disposed of in Pit 3;
- disposal activities in Pit 3 will be concurrent with bulk backfill activities; and
- disposed items in Pit 3 to be buried at least 6 m below final landform.

Table 9-18: Phase 1 demolition areas

Area	Infrastructure/service demolished
Radiometric sorting	All infrastructure and services
Primary crushing	All infrastructure and services
Fine crushing	All infrastructure and services
Demin plant	All infrastructure and services
Grinding	All infrastructure and services
Leaching, counter-current decantation (CCD) and clarification	All infrastructure and services
Neutralisation	All infrastructure and services
Solvent extraction	All infrastructure and services
Laterite treatment plant	All infrastructure and services
Product warehouse	All infrastructure and services
Precipitation, drying and packing	All infrastructure and services
Ammonia handling	All infrastructure and services
Pond water	Pond water tanks demolished, pond and fire water system and pumps relocated to R3D
Acid storage	Acid storage tanks A and B, and distribution pumps
Bulk fuel storage	Bulk fuel storage tank B and shellsol tanks
Administration	All

Phase 2 demolished materials will be disposed of in RP2 concurrently with rehabilitation works. Key assumptions for the Phase 2 demolition are:

- Phase 2 materials can be disposed of in RP2 if pond water storage requirements permit;
- ERA mobile fleet, consisting of 18 heavy vehicles (21,000 m^3), and light vehicles will be disposed of in RP2. Forklifts and service trucks will be taken offsite; and
- Items disposed in RP2 are to be buried 6m below final landform.

Table 9-19: Phase 2 demolition areas

Area	Infrastructure/service demolished
Sewage treatment	All infrastructure and services
Bulk fuel storage	All remaining infrastructure and services
R3D	All infrastructure and services
Brine Concentrator	All infrastructure and services
Mine centre	All infrastructure and services
Water treatment plant 3 (WTP3)	All infrastructure and services
Power station	All infrastructure and services
Security, gatehouse and emergency services	All infrastructure and services
Acid storage	All infrastructure and services
Orica yard	All infrastructure and services
Tailings Storage Facility (RWD)	All infrastructure and services
Retention ponds	All infrastructure and services
WTP1 and WTP2	All infrastructure and services
Brockman bore field	Remain post-closure for potable water supply
Plant services	All infrastructure and services
Engineering and supply	All infrastructure and services

Relocation of gatehouse and office spaces

To maximise Phase 1 demolition efficiency, the following is planned:

- the gatehouse and security check-point will be relocated to near the Gagudju yard area on the main Access Road; and
- some of, or all of, the site offices, facilities, amenities and carpark may be relocated or replaced at the previous Ranger Mine Village footprint (adjacent to the Gagudju yard).

Power stations

The mine site has two main power stations:

- Ranger Power Station (RPS), with five 5.1 MW diesel alternators (shared with BCPS); and
- Brine Concentrator Power Station (BCPS), with four 2.1 MW diesel alternators.

As various parts of the mine progress through decommissioning, demolition and closure, the demand for power reduces. With this reduced demand comes an opportunity to reduce the current generation capacity on-site and progressively decommission/demolish the RPS. Planning for this reduction in generation capacity is occurring and several options are being investigated, including the installation of a temporary modular or containerised diesel power generator/s. At some point ERA will decommission the RPS and move to temporary Independent Power Plant (IPP).

9.2.5.4 Contingency planning

If the demolition of specific infrastructure planned to be deposited into Pit 3 is delayed, then RP2 has the capacity to take extra material than currently planned.

9.2.6 Stockpiles

Figure 9-75: Stockpile area (May 2019)

Bulk material movement from the stockpiles (Figure 9-75) is covered in the activities Chapter 9.3.4.

9.2.6.1 Completed rehabilitation

Stage 13.1 (Areas A-C) is a 4 ha section of final landform that became available for revegetation at the beginning of 2020 (Figure 9-76, Figure 9-77). A waste rock stockpile was cut down to the designed final landform surface level and used to backfill Pit 1, leaving an average 3.1 m thickness of waste rock overlying natural ground.

In February 2020 the entire surface of Stage 13.1 was ripped at 3 m intervals to a depth of 50 cm to provide surface roughness and alleviate any compaction. A relatively saturated substrate and an abundance of large rocks brought to the surface resulted in a generally undesirable planting surface with significant bogginess in some places. The ripping outcome was different to the Trial Landform (TLF), likely due to a higher portion of fine material in the waste rock substrate (assessed visually). The majority of the surface was re-graded to flat in November 2020, however a small area (approximately 0.75 ha) was considered suitable for planting, and was used for Area A and some of Area B trials.

Area A (0.6 ha) was planted out in April 2020 with 1,207 tubestock of 22 species and Area B (1 ha) was planted out in October 2020 with 1,012 tubestock of 50 species. Both areas are part of opportunistic, small-scale pilot trials that have informed large-scale Pit 1 activities. These trials are further discussed in *Section 5 KKN Supporting Studies*, KKN ESR3.

Area C (2.4 ha) was planted out in August 2021 with 2,370 stems of 50 different species. This area is progressive revegetation consisting of species typical of a *Eucalyptus tetrodonta / miniata* savanna woodland ecosystem, with a slight increase in the density of contingency species that are well suited to finer substrate and potentially water logging conditions.

Figure 9-76: Monitoring of native seedlings planted on Stage 13

Figure 9-77: Planting areas A, B and C of Stage 13.1

9.2.6.2 Current rehabilitation

Refer to bulk material movement Chapter 9.3.4.

9.2.6.3 Planned rehabilitation

Central services corridor

A services corridor, which accommodates several waste streams pipelines and an access road, is currently located in the stockpile domain to the north of Pit 1. The pipelines supply feed process water to the Brine Concentrator and allow movement of water between Pit 3 and the Ranger Water Dam. The corridor is located primarily on non-mineralized material (termed 1s), but some mineralized material (termed 2s) may be encountered in the stockpiles north of Pit 1 (red shaded zone in Figure 9-78). The mineralized material is to be excavated and placed into Pit 3, requiring a relocation of the services corridor.

Figure 9-78: Existing pipeline corridors (blue lines) and proposed central services corridor (green line)

Another existing pipeline corridor, allowing transfer of process water between the various water treatment plants and the Ranger Water Dam, runs along Corridor Creek Road. Both pipeline corridors are proposed to be replaced by a single central service corridor, to be constructed across surfaces that are already predominantly at final landform level to the west and north west of Pit 1.

New-build parts of the corridor will be designed to provide secondary containment for the process water lines planned to run in the corridor, in a similar manner to the current Corridor Creek pipeline corridor. The surface of the corridor will be compacted to reduce infiltration, and the corridor will be isolated from the surrounding landform by windrows. Sumps at low points along the corridor will direct collected water to the pond water inventory. Water collected in these sumps will be monitored for electrical conductivity to detect process water leaks.

Some bulk earthworks will be required to get the corridor to be as close as final landform as possible. For any surface run segments in the vicinity of the run-of-mine stockpiles, these bulk earthworks will include over-digging and backfill with waste to remove mineralized material from the surface of the corridor. The connection between the central services corridor and Pit 3 will run as per the current Ranger Water Dam to Pit 3 corridor. Existing pipe-in-pipe pipework in this section will continue to be used, rather than constructing a new corridor. The corridor is expected to be available for services in the first half of 2023. Relocation of services to the corridor will be staged to maximise re-use of existing pipework on site. While the intent is to minimise the need for further pipeline relocations, future minor modifications to the pipeline corridor route, particularly through the run-of-mine area, may be required as bulk material movement activities progress.

The corridor will be decommissioned in its entirety once process water storage in the Ranger Water Dam or RP6 is no longer required. Pipeline materials removed from the corridor will be disposed of with the demolition materials arising from removal of the process water treatment plants. Contaminated surface material within the corridor will be scraped and disposed of in RP2.

Landform and erosion controls

Earthworks for final landform construction, including erosion control structures, will be implemented after the bulk material movement from the stockpiles is complete (Chapter 9.3.5).

Revegetation

Revegetation of stockpile areas will be undertaken following standard methods that are outlined in Chapter 9.3.6.

9.2.6.4 Contingency planning

There are no contingencies specific to the stockpile domain as:

- all mineralised material will be moved to Pit 3 through bulk material movement scheduling; and
- contingencies for unsuccessful revegetation or erosion control are covered later in this Chapter.

9.2.7 Water management areas

Figure 9-79: Retention Pond 1 (RP1) and RP1 Wetland Filter (May 2019)

The effective management of water at the Ranger Mine is critical for successful closure implementation and to ensure the surrounding Kakadu NP remains protected. There is an ongoing need to actively manage water throughout the closure phase. At the completion of rehabilitation works, all water management areas will have been rehabilitated. These water management areas include:

- pond water storages (RP2 and RP6);
- release water storages (RP1 (Figure 9-80), GCMBL and Sleepy Cod);
- wetland filters (Corridor Creek wetland filter and RP1 wetland filter);
- various water management sumps; and
- onsite billabongs that have received release discharge water.

Further details of each water management area, the different classes of water at Ranger Mine, and their use during operations is provided in Chapter 9.3.3.

9.2.7.1 Completed rehabilitation

No progressive rehabilitation has been possible to date as all water management areas are in use.

9.2.7.2 Current rehabilitation

There is no current rehabilitation underway as no water management areas are available.

9.2.7.3 Planned rehabilitation

The exact timing and methods for the rehabilitation of the various water management areas depend upon a number of factors, primarily rainfall and the requirements of other closure activities. Currently, within the closure schedule, each water management area is assumed to undergo rehabilitation as late as possible.

Catchment management

As described in detail in the Ranger Water Management plan, surface runoff and seepage from disturbed areas of the site is typically collected and diverted to pond water storages, while runoff from undisturbed areas may be collected and diverted to release storages. To complete closure, ultimately all catchments across the site will need to be able to passively shed water into the surrounding environment, without any collection and diversion infrastructure. The process the enables the decommissioning the collection and diversion infrastructure for a catchment is known as catchment conversion.

The water management infrastructure for the current collection and diversion of surface water from site catchments has developed over time to suit the operational configuration of the site. As closure activities, such as capping of Pit 3 and the construction of the final landform progress, this infrastructure will need to be modified and augmented to suit the changing nature of the site.

The principles that will inform the design of this modified infrastructure include:

- Runoff from active mining areas, for example where stockpiles are being removed, landform is being built up or the haul road network, will be collected and potentially managed for sediment and solute quality.
- Surface water from active mining areas will be collected and directed using infrastructure such as channels, drains, levees, collection sumps, and pumping and piping systems.
- Water collected from freshly completed landform will also be monitored for sediment and solute quality.
- Collected water that is of a quality that can be released off site without further treatment will be directed to releases storages. Water with unacceptable sediment or solute loads will be directed to infrastructure such as active sedimentation basins (where solids settling characteristics enhanced by the use of coagulants and flocculants), passive sedimentation basins, wetland filters or the existing pond water storages.
- Collection infrastructure around a catchment will be removed once active mining is no longer occurring in an area, and runoff is consistently of release quality. Local infrastructure, such as collection sumps and sediment basins, will be recontoured to match the final landform design, and revegetated.

To reduce sediments loads from freshly constructed landform, temporary surface treatments such as scarification, spray polymers, erosion socks, sediment fences and grassing may be applied. These will complement more permanent features, such as rock mulch, leaky weirs, and sporadic rip lines.

The conceptual design of the surface water management infrastructure, the details of the temporary and permanent erosion management treatments and features, and the criteria for runoff to be directed to release will be discussed in the Final Landform Application, and reflected in future updates to the Ranger Water Management Plan.

Pond water storages

Pond water collected on the RPA is transferred to RP2 (the main pond water storage) or RP6. The inventory within the pond water storages is maintained to a minimum level to ensure the supply of pond water for dust control and other onsite service requirements. The total inventory of pond water is balanced between RP2 and RP6 to reduce the likelihood of overflow of RP2 into Pit 3.

Retention Pond 6

To allow earlier deconstruction of the RWD, as the process water inventory nears exhaustion the process water in the RWD may be transferred out of the RWD into RP6. This transfer can be initiated once:

- catchment conversion activities have progressed to the extent that RP6 is no longer required for pond water storage,
- the process water volume in the RWD falls approaches the design storage capacity of RP6 for process water (approximately 800 ML), and
- any existing pond water in RP6 has been transferred to RP2.

When water transfer starts, all infrastructure associated with process water must be relocated from the RWD to RP6. This includes infrastructure associated with:

- WTP brine discharge;
- Brine Squeezer brine discharge;
- Brine Squeezer process water feed;
- BC diluted brine discharge; and
- BC process water feed.

Whilst RP6 is currently a pond water storage, it was originally designed with the ability to store process water, being fitted with two layers of plastic liner and a liner leak detection/recovery system. Ahead of the use of RP6 as a process water storage, the integrity of the liners and associated leak detection/recovery system will be assessed and remediated if required.

If RP6 is used as a process water storage, then it will remain a process water store and catchment until process water treatment exhausts the free process water inventory, and then be decommissioned and demolished.

If RP6 is not used as a process water storage, then it will be decommissioned and demolished once it is no longer required to augment RP2 for pond water storage.

Decommissioning and demolition of RP6 will involve the removal of the liners and their burial in RP2, followed by the re-contouring of the site to form the final landform. Retention Pond 2

Retention Pond 2

RP2 is the hub of the pond water collection and distribution system on site and is expected to be required for pond water storage until late in the closure sequence. It is also an identified site for the disposal of waste generated during phase 2 demolition. Consequently, RP2 is expected to be one of the last areas on site to be decommissioned and rehabilitated.

An environmental assessment, completed in 2018, determined the minimum depth for burial of non-mineral waste beneath the final waste rock landform as 6 m. Following the completion of any waste disposal, the pond will be backfilled to final landform with waste rock.

Release water storages

Release waters are stored within RP1 and GCMBL. As detailed in the land application areas Chapter 9.2.4, these ponds will be required until almost to the end of closure. Once no longer required, these areas will have any infrastructure removed, be re-contoured and revegetated. Refer to Chapter 9.3.1 for details of further assessments to determine if any additional remediation works are required.

Wetland filters

ERA has installed wetland filters at Ranger Mine to passively treat water prior to release. Historically, raw pond water was sent to these wetland filters. More recently, however, the filters provide final polishing of water of better quality.

Wetland filters will be required throughout the majority of closure for ongoing water management. Once no longer required, the areas will be rehabilitated by the removal of any infrastructure, and by re-contouring and revegetation. The use of these areas for passive water treatment over the years may have resulted in some level of contamination. These areas will be assessed to determine the extent of any contamination and if any additional remediation work is required.

Onsite billabongs

There are two billabongs on site that have received release quality water throughout operations. These billabongs, Georgetown and Coonjimba, will continue to receive release water from the final landform during and after closure.

Studies are currently underway to assess the rehabilitation strategy for these billabongs (Appendix 5.4). This information will be provided in future versions of the MCP.

Revegetation

Revegetation will be undertaken in accordance with the Ranger Mine revegetation strategy (Appendix 5.4). A detailed revegetation plan for the water management areas will be provided in future updates of the MCP.

9.2.7.4 Contingency planning

As the final rehabilitation plan for many water management areas is not complete, contingency plans have not yet been developed. If RP2 is later determined to be unsuitable as a waste disposal site, an alternative landfill will be constructed on site following an appropriate approvals process.

Studies assessing the current level of contamination of various water management areas are currently underway and have been detailed in *Section 5 KKN Supporting studies*, Chapter 5.5.2. Once complete, these studies will be used to determine if remediation of any area is required and inform the final closure strategy for each. This closure strategy will be provided in future updates of the MCP.

9.2.8 Linear infrastructure

Linear infrastructure around the site includes the various road, tracks, fences and other minor miscellaneous infrastructure and/or corridors that have been installed during operations. These areas are outside of the final landform footprint. Rehabilitation will include removal of infrastructure and scarifying the natural soil, as required. This has been a successful rehabilitation protocol for areas disturbed during exploration on the RPA and requires neither direct seeding nor planting to achieve acceptable outcomes.

The planned rehabilitation of the ERA groundwater bore network is divided into three stages. Stage 1 was completed in late 2020 and involved the collation of all the information on the ERA groundwater monitoring network into AcQuire, a geoscientific data management software package. This will be used to track the progressive rehabilitation of groundwater bores located across the RPA. Stage 2 will involve the ground-truthing of sites recorded in AcQuire. Stage 3 involves the active decommissioning of redundant infrastructure.

The timing for the rehabilitation of linear infrastructure will be based on the utilisation requirements for closure implementation work. Some linear infrastructure, for example the boundary fence and various access roads, may be required following the completion of rehabilitation work, as part of the ongoing monitoring, maintenance and security of the site. Discussions with Traditional Owners are underway to determine preferred pathways for cultural use in the future.

9.2.8.1 Completed rehabilitation

There has been minimal opportunity for progressive rehabilitation of the linear infrastructure. Two redundant tracks have been rehabilitated, totally an area of 3.65ha.

There have also been six drill pads rehabilitated, representing 0.8ha of previous disturbance.

9.2.8.2 Current rehabilitation

No current rehabilitation underway.

9.2.8.3 Planned rehabilitation

Planned works will be completed once the infrastructure is no longer required.

9.2.8.4 Contingency planning

There are no contingencies required for this domain.

9.2.9 Ranger 3 Deeps exploration decline

Figure 9-80: R3 Deeps portal and offices

The Ranger 3 Deeps (R3D) exploration decline (the decline) is a 2,710 m long exploration decline, constructed between May 2012 and October 2014. The decline allowed for exploration and delineation of the Deeps resource associated with the proposed R3D underground mine, east of Pit 3 (Figure 9-81, Figure 9-82, Figure 9-83).

The proposed R3D underground mine project was not progressed and the decline was placed in care and maintenance in June 2015. Closure planning has considered the major R3D infrastructure including the:

- decline (which is 5.5 m wide by 6.0 m high, and descends at a gradient of 1 in 6 to approximately -430 mRL);
- ventilation shaft (approximately 3 m wide, extending to 280 m below the ground);

- portal (a steel lined tunnel that extends 185 m from the ground surface, through the weathered rock zone to approximately -8 mRL); and
- major infrastructure including pumps, fans, compressors, generators and refuge chambers.

ERA submitted an application to commence rehabilitation and closure of R3D in September 2018 and received approval from both the Commonwealth and Northern Territory Ministers in April 2019. An update to the plan was submitted to stakeholders in January 2021, incorporating changes to water level management and outlining the decommissioning progress that was completed by that time.

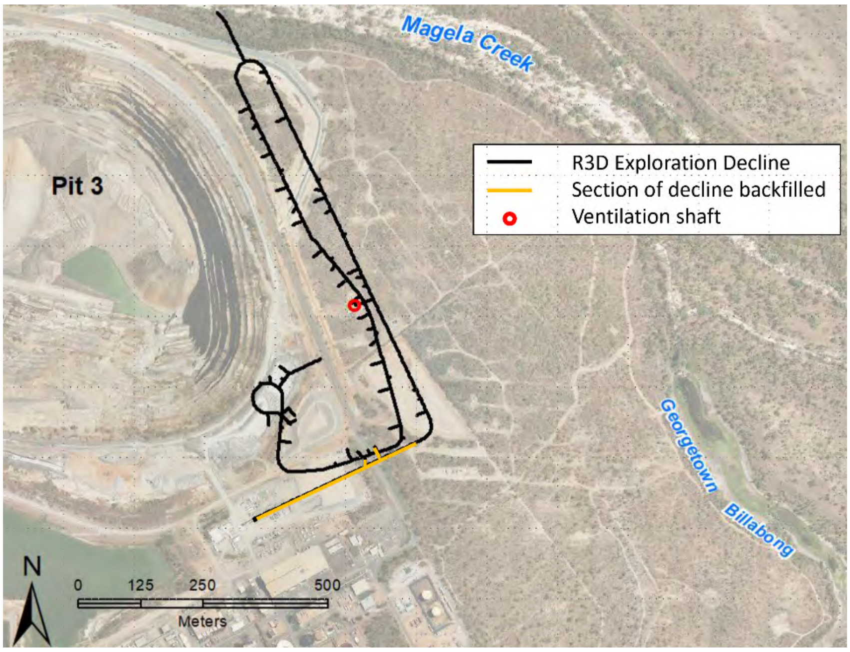


Figure 9-81: Plan view of the decline

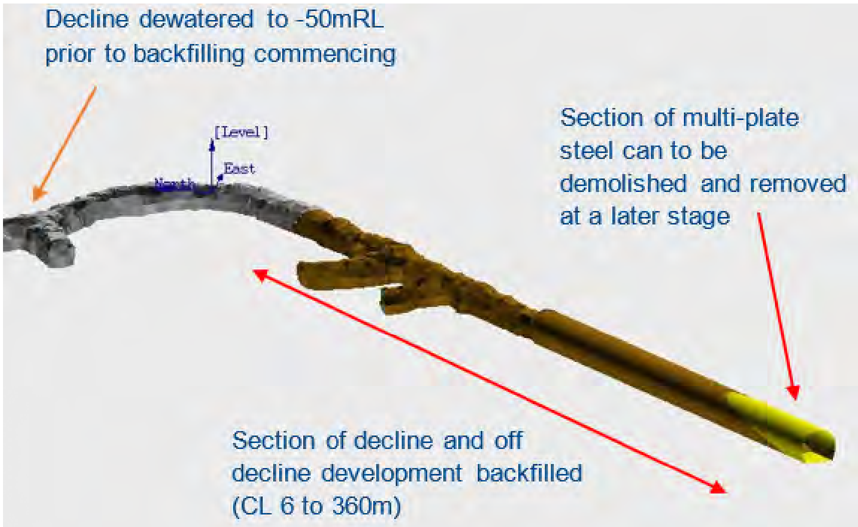


Figure 9-82: Oblique view of R3D decline and main closure elements

Geotechnical considerations

The geological conditions (strength and weathering of schist) varied along the depth of the portal and decline. Considerations for closure of the decline and portal relating to these conditions are described in Table 9-20.

Table 9-20: Geological conditions, decline reinforcement methodology

Depth (m)	Substrate	Methodology
0 - 185	Low strength, weathered schist	Cut and cover tunnel (see below).
185 - 213	Low strength, highly weathered to moderately weathered schist	Category 5 support and consisted of lattice girders, spiling bars and 290 mm thick fibrecrete.
213 - 290	Low, then medium strength; moderately weathered to fresh	Category 3 support. This support comprises 2.4 m galvanised fully encapsulated chemset bolts and 100 mm thick fibrecrete.
290 - 675	Medium strength fresh schist	Category 2 support. This support comprises 2.4 m galvanised fully encapsulated chemset bolts and 50 mm thick fibrecrete.

Due to the poor ground conditions in the vicinity of the portal, the first 185 m of the decline down to a depth of 35 m was developed as a cut and cover tunnel. A 35 m deep box-cut was excavated; then a steel arched tunnel was constructed from the bottom of the box-cut back to ground level (Figure 9-83). The box-cut was progressively backfilled with sized waste rock and box-cut material. When the box-cut was excavated groundwater was intersected 6 m below surface at 17 mRL.

Figure 9-83: Boxcut and portal, completed in December 2012

The schist is foliated and jointed, giving rise to a blocky structure. These blocks were supported by the ground support that was installed at the time of development (pattern bolted with 2.4 m long, galvanised rock bolts at 1.5 m centres, plus 50 mm thickness of plastic fibre reinforced, pneumatically sprayed concrete). The ventilation shaft was developed in low strength to medium strength hanging wall schist. On completion, the shaft walls were sprayed with a layer of shotcrete. The top 21 m has a steel liner.

Hydrological conditions

INTERA conducted an assessment of the expected hydrological conditions at the decline once dewatering pumps are turned off, and the decline and ventilation shaft flooded. INTERA also assessed the requirements for grouting of the four standpipe holes and construction of bulkheads (INTERA 2018).

9.2.9.1 Completed rehabilitation

Works commenced immediately after approval of the closure plan in April 2019. During early 2019, many of the demountable accommodation units at Ranger 3 Deeps were sold and transported off site.

2019 works program

The 2019 works program incorporated the removal of infrastructure, including pumping and electrical equipment, within the vicinity of the base of the ventilation shaft and subsequent backfilling of the vent shaft access. These works were completed between mid-April 2019 and end of June 2019 and included:

- installation of water level monitoring equipment in the vicinity of the base of ventilation shaft and monitor water level;
- removal of existing pumps to allow the decline to flood;
- backfilling of the -263 mRL ventilation shaft access with 700 m^3 of fresh rock;
- removal of refuge chambers;
- removal of the underground 11kVA substation;
- removal and demobilisation of the two twin 90 kW fans;
- installation of a 25 kW submersible pump in the ventilation shaft to maintain the water level below -20 mRL;
- cleaning and radiation clearance of the removed infrastructure;
- blocking of access to the decline through the portal; and
- demobilisation.

The ventilation shaft access at -263 mRL was backfilled with waste rock to form a plug to mitigate the possibility of the backfill material flowing out into the decline. The decline was then allowed to naturally flood to -20 mRL.

Care and maintenance program

Following the 2019 works program the decline was put into reduced care and maintenance until the remainder of the rehabilitation works could be completed. These activities include:

- keeping the decline dewatered to -20 mRL via the submersible pump in the ventilation shaft;
- monitoring the submersible pump on a weekly basis;
- prevention of access to the decline unless under special permit; and
- monitoring of the water level rise in decline by the decline monitor installed near the base of the shaft at -263 mRL and from existing surface monitoring bores.

2021 works program

In May 2021 ERA notified stakeholders of their intent to commence the final closure and backfill component of the R3D exploration decline decommissioning plan. The key components of the program were the closure of the ventilation shaft, and the waste rock backfill of the decline. The Ranger 3 Deeps Radiation Management Plan was revised and updated. This update incorporates information relating to the closure and backfill program, including radiation controls for backfilling works (ERA 2021d).

Sufficient waste rock was moved to the decline stockpile pad, 200 m north of the decline portal, and the decline dewatered to -50 mRL in preparation for the commencement of closure works (ERA 2022). Prior to re-entry the decline was inspected and a ventilation system was installed (Figure 9-84).

Figure 9-84 Photo taken on 3 June, during decline inspection, from the end of the steel multiplate tunnel (ERA 2022)

Backfilling of the decline commenced on 22 June 2021 and was completed on 7 August 2021 (ERA 2022). The original 300 m backfill commitment in the R3D closure plan, was extended to a minimum 350 m backfill, following consultation with stakeholders, as a mitigation against the risk of a decline collapse propagating through the weathered zone to the surface.

Backfilling commenced at a centreline (CL) distance from the portal of 361 m and finished at CL 6 m, completing a 355 m backfill (Figure 9-85). All the backfilling was done with CAT 740 ejector trucks with a total volume 14,525 m3 to be filled (ERA 2022). Backfilling in the decline was completed as tight as practicable. 13,970 m3 of waste rock was placed with a bulk density of 2.077 m3/t (Figure 9-86, Figure 9-87 & ERA 2022).

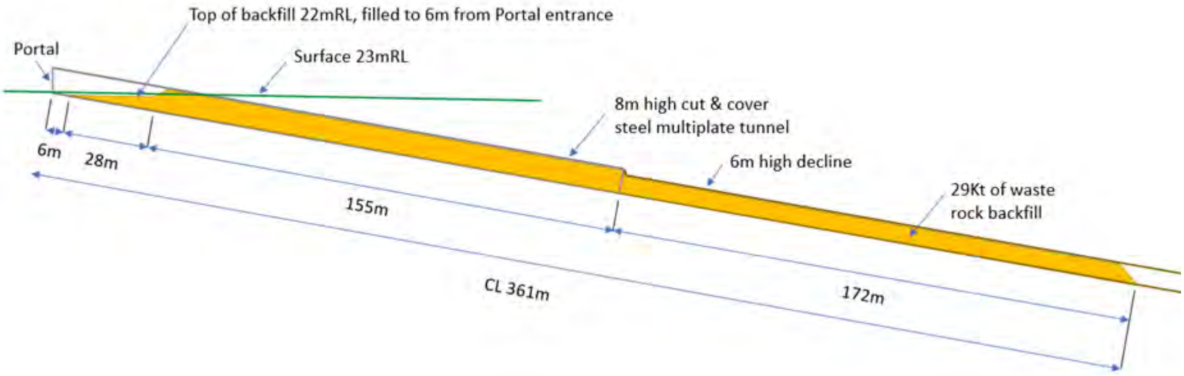


Figure 9-85: Decline long section looking North. Backfilling commenced at a CL distance from the portal of 361 m and finished at CL 6 m (ERA 2022)

Figure 9-86: Picture taken 24 June after approx. 2,600 t of backfill has been placed in the decline (ERA 2022)

Figure 9-87: Picture taken after completion of backfilling to 22 mRL, (CL 06 m) with a total of 29,015 t waste rock placed (ERA 2022)

Closure of the vent shaft included backfilling the 2,065 m^3 void and installing a cement-rockfill (CRF) plug to prevent settlement in the shaft expressing as surface subsidence. The backfilling of the shaft commenced on 2 August 2021 and was completed on 9 August 2021 (ERA 2022). An 11 m length CRF plug was installed in the ventilation shaft from 15 m through to 4 m below the surface. Crushed rock was then placed above the CRF plug to surface.

The R3D closure plan stipulated that the CRF plug would be placed from 10 to 20 m below surface. This was modified, for operational reasons, to 5 to 15 m below surface in the scope of work that was appended to the 2021 notification (ERA 2022). It was moved closer to surface to be out of the ground water and enable observations on mix progress. The as-built location of the plug achieves a satisfactory tie-in to the corrugated steel liner and is considered fit-for-purpose (ERA 2022).

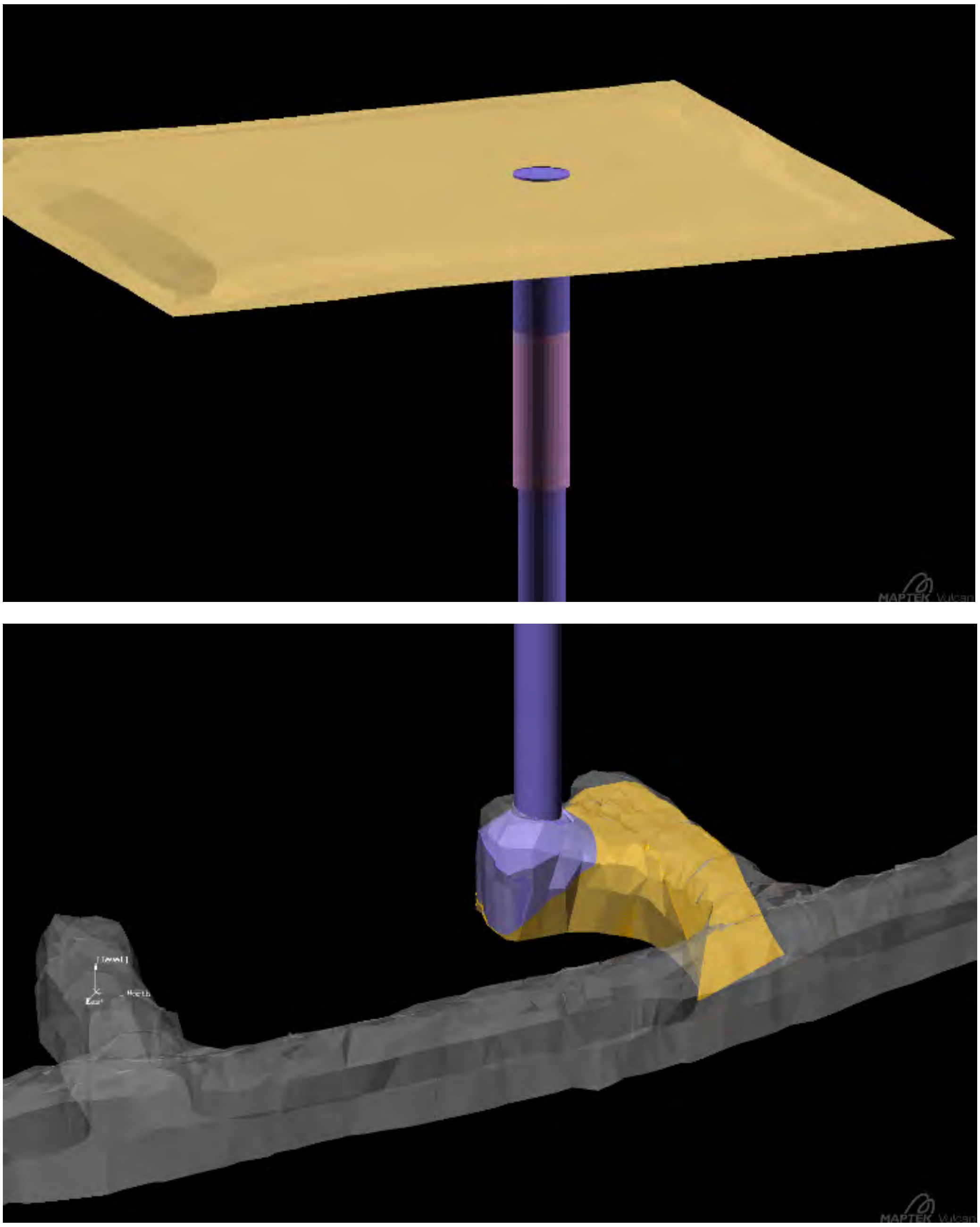


Figure 9-88: Oblique view of shaft and decline (grey), showing previously backfilled vent access in tan; rock backfilled shaft in purple and CRF plug in maroon.

Figure 9-89: Cement slurry being added to the rockfill at ventilation shaft to create the CRF plug (ERA 2022)

Figure 9-90: Top of CRF plug in the vent shaft to 4 m below surface (ERA 2022)

9.2.9.2 Current rehabilitation

There are currently no rehabilitation works occurring at Ranger 3 Deeps.

9.2.9.3 Planned rehabilitation

Remaining portal and ventilation shaft closure activities

The steel multi-plate tunnel will be dismantled/cut down to final ground level. The portal closure works will form part of the broader demolition works as described in Chapter 9.2.5. If this situation changes, a separate demolition plan and risk assessment will be completed prior to commencement.

Signage, fencing and other minor installations associated within controlling access to the vent shaft and portal area will also be removed.

Final landform and revegetation

Contouring to final landform and revegetation of the R3D area will form part of the broader final landform and revegetation schedule. This includes the portal area and the removal of the very course rock at the top of the ventilation shaft.

9.2.9.4 Contingency planning

The closure of the Ranger 3 Deeps decline is well advanced and so no contingency plans are required.

9.2.10 Miscellaneous

9.2.10.1 Gagudju Yard

Figure 9-91: Gagudju Yard

Completed rehabilitation

There has been no rehabilitation of this site Figure 9-91).

Current rehabilitation

There is no current rehabilitation activity at the site.

Planned rehabilitation

As mentioned in Section 9.2.5.3, it is planned that the gatehouse and security checkpoint will be relocated to near the Gagudju yard to maximise the efficiency of the Phase 1 demolition.

Progressively, as infrastructure is no longer required, it will be demolished and placed into Pit 3. Site works and revegetation will be completed as soon as practicable after the infrastructure is removed.

Contingency planning

No contingency planning is required for the rehabilitation of Gagudju Yard, other than remedial revegetation works if required.

9.2.10.2 Ranger Mine Village

Completed rehabilitation

The contactor camp, and nearby old workshop area, had all infrastructure and concrete removed (Figure 9-92). The accommodation and other demountable units were sold, where possible.

Figure 9-92: Ranger Mine Village

A 1.4 ha site was revegetated in February 2020 (Figure 9-93 and Figure 9-94). The natural soil surface was prepared with 20 cm deep rip lines at 1 m spacing using a grader. Approximately 2,000 stems of 44 species were planted, with a combination of overstorey, midstorey and understorey species. Several kilograms of additional understorey seed from 10 species was also sown in between tubestock. The revegetation occurred during a rainy period and no irrigation has been used in the area.

Figure 9-93: Ranger Mine Village area prior to planting (January 2020)

Figure 9-94: Rehabilitation site at Ranger Mine Village (June 2020)

Current rehabilitation

There are no current ongoing rehabilitation activities at the site.

Planned rehabilitation

As mentioned in Chapter 9.2.5.3, it is planned that site offices, facilities, amenities and carpark may be relocated to the site of the previous Ranger Mine Village to maximise the efficiency of the Phase 1 demolition.

Progressively, as infrastructure is no longer required, the remaining infrastructure disturbance at the site will be rehabilitated in a similar manner as described above and when services are disconnected.

Contingency planning

No contingency planning is required for this area. The workshop area may have some minor contaminated soils from old oil spills or similar. If this material is encountered during closure it will be removed and stored for eventual burial in Pit 3.

9.2.10.3 Nursery / core yard

During 2018 and early 2019, ERA converted the old exploration area in Jabiru East into a nursery to support closure operations (Figure 9-95). This work included the removal of exploration infrastructure and general clean-up of the area. In addition, benches to facilitate the propagation of seedlings have been installed along with associated irrigation system and security.

Figure 9-95: Nursery and old core yard at Jabiru East (May 2019)

The nursery will be required to support the revegetation through the Ranger Mine rehabilitation works and, subject to confirmation of continuing access to the RPA by ERA, could also be used into the monitoring and maintenance phase.

Completed rehabilitation

Fencing and security has been installed at the site which would facilitate utilisation following closure.

Current rehabilitation

No rehabilitation is currently underway as the site is actively functioning as a nursery and seed store.

Planned rehabilitation

In addition to the nursery, core is currently stored from the exploration of the Ranger 3 Deeps deposit, MLN1 and other exploration around the RPA. This diamond drill core is an important asset as it constitutes the fundamental data underpinning resource modelling of ERA uranium deposits on the RPA. Options for storing certain core, including transport to Darwin or another secure storage facility are being investigated. Core material that is not stored for future reference will be disposed to Pit 3 or RP2 during the backfill operations.

Progressively, areas of the core yard will be converted into additional nursery space to increase the capacity of the plant nursery.

Contingency planning

Appropriate approvals will be required prior to closer to enable the nursery asset to remain on the RPA. No further contingency planning is required.

9.2.11 Magela Levee

Figure 9-96: Magela levee (May 2019)

Completed rehabilitation

No rehabilitation has been completed as the levee is still utilised for water diversion (Figure 9-96).

Current rehabilitation

No rehabilitation is underway as the levee is still utilised for water diversion.

Planned rehabilitation

The levee will be able to be removed and rehabilitated as part of the Pit 3 final landform earthworks and revegetation. Levee material will be returned to the original borrow pit with any excess material either placed in Pit 3 or used for any site works requiring lateritic material.

Contingency planning

No contingency planning is required for the levee as it will not be removed until it is no longer required.

9.2.11.1 Borrow pits

Completed rehabilitation

No borrow pits have been rehabilitated.

Current rehabilitation

There is no current rehabilitation underway.

Planned rehabilitation

There are currently two borrow pits located on the RPA:

- borrow pit for the construction of a RWD lift located at the proposed site for Retention Pond 5 that was not constructed (Figure 9-97); and
- borrow pit for the construction of the Magela Creek levee (Figure 9-98).

Figure 9-97: Borrow pit for RWD lift

Figure 9-98: Borrow pit for Magela Creek Levee

The site of the old RP5 will be re-contoured as part of the final landform for the corridor creek catchment.

The levee borrow pit will have levee material returned, re-contoured to the natural contours and revegetated.

Contingency planning

If these borrow pits are required over the closure period, rehabilitation will be delayed until no longer required.

9.2.11.2 Landfill sites and bioremediation pad

All wastes generated at Ranger are managed on site. This has been primarily through the use of landfills or disposal in mined-out pits. In addition, ERA have managed any hydrocarbon contaminated soils though the use of bioremediation pads, located to the north west of Pit 1.

The following landfill sites are located at Ranger:

- historic industrial waste landfills to the south of the RWD;
- domestic waste landfills to the north of Pit 1; and
- temporary industrial waste landfill to the west of Pit 3 (Figure 9-99).

Figure 9-99: Temporary waste storage facility on the western edge of Pit 3 (May 2019)

Completed rehabilitation

Contaminated sites sampling of the historic landfills and the bioremediation pads were completed during 2019. Details of this are provided in *Section 5 KKN supporting studies*, Chapter 5.5.2.5. This information has been used to define a source term for inclusion into the whole of site groundwater solute transport model *Section 5 KKN supporting studies*. The results of this model will be used to assess remediation options via a best practical technology assessment. Several of the old domestic landfills to the north of Pit 1 were covered with waste rock during 2020 as part of the final backfill of the pit.

Current rehabilitation

There is currently no rehabilitation of landfills underway.

Planned rehabilitation

The temporary landfill to the west of Pit 3 will have the waste removed and for placement in Pit 3 with the other demolition waste.

Domestic landfills, once they are no longer required, will be covered by the final landform waste rock material.

The plan for rehabilitation of the historic industrial landforms to the south of the RWD, and the bioremediation pads will be finalised once the best technology assessments are completed and detailed included in updates to this MCP.

Contingency planning

No contingency planning is required for this site.

9.2.11.3 Explosives magazine area

Completed rehabilitation

All explosives have been removed from the magazine and it has been de-registered (Figure 9-100).

Figure 9-100: Old magazine site (May 2019)

Current rehabilitation

No current rehabilitation underway.

Planned rehabilitation

Demolition requirements at the old explosives magazine involve the removal of the magazine, concrete slab and associated footings. The surrounding fence will also be removed. The area will then be contoured and revegetated.

Contingency planning

No contingency plan is required for this site.

9.2.11.4 Trial landform

Completed rehabilitation

An 8 ha Trial Landform (TLF) constructed in 2008/2009 located near the north-western corner of the RWD is shown in Figure 9-101.

Figure 9-101: Trial landform (March 2022)

The TLF has allowed testing of landform design and ecosystem establishment strategy, including different types of surface substrates, different depths of mixed materials over the waste rock only layer, different planting methods and different irrigation regimes (Figure 9-102; adapted from Pugh et al 2008).

Three materials were used to construct the TLF; primary and weathered waste rock, and laterite material. Primary material (1P) consists of unweathered host rock, which primarily consists of altered quartz-feldspar schists and to a lesser extent cherts and carbonaceous materials. Weathered material consists of friable rock (usually quartz-feldspar schist) with altered mineral assemblages, but is generally still low in clay content (Figure 9-103). Laterite is a near surface, highly weathered and sometimes reconsolidated material that is generally high in iron and aluminium clays.

The surface substrates investigated on the TLF were: waste rock only; and waste rock blended with 30 percent volume/volume of laterite material (Figure 9-102). To facilitate treatments, the trial landform was divided into several areas. Areas 1A and 1B of the TLF were constructed with waste rock only substrate. Areas 2A and 3A were constructed as a five-metre thick layer of laterite/waste rock mix over a 1P rock base 0 to 2 metres thick. Areas 2B and 3B were constructed as a two-metre thick layer of laterite /waste rock mix over a base of 1P rock 3 to 5 metres thick.

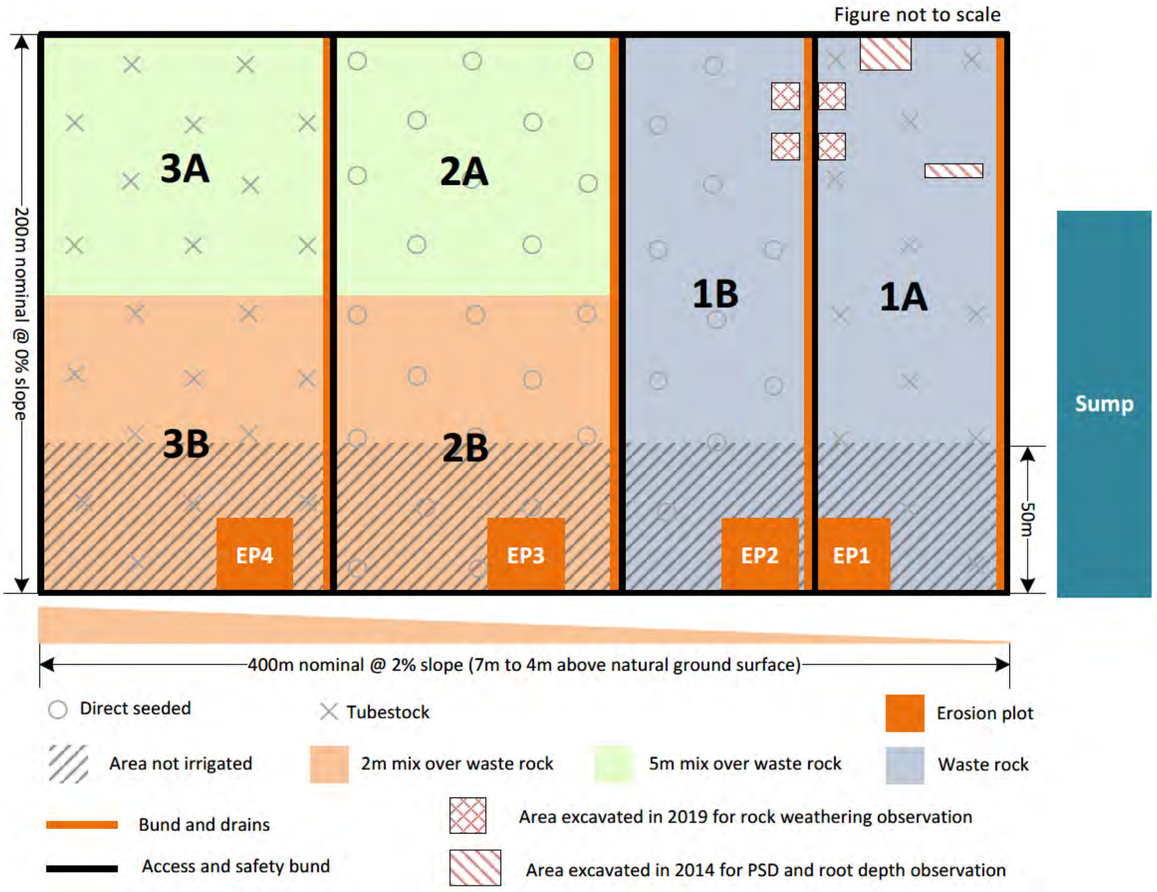


Figure 9-102: Trial landform – treatment design and associated infrastructure

Figure 9-103: Rock types used to construct the trial landform

The Ranger Final Landform (FLF) surface layer will be similar to the waste-rock only section of the TLF (Area 1), in that it will primarily be constructed with 1P and weathered waste rock without purposely mixing in laterite. Area 1 of the TLF was built by first constructing a base layer approximately 2 m thick, by tip-head dumping, and then placing another layer 2 m thick over it, by paddock dumping. As a result of this construction method, a sub-surface consolidated horizon was created by the activity of the dozers and dump trucks on the surface of the TLF base layer, underneath the final paddock dumped layer (Figure 9-104). Construction records show that the surface of the base layer of the TLF (prior to the commencement of paddock dumping) had a high proportion of visible fines compared to underlying material.

Bulk density of the substrate layer of the TLF is estimated at about 2.0 t/m3, with a specific gravity of solids of 2.65 t/m3 (Stephen Pevely, Senior Resource Geologist, ERA, pers. comm. Oct 2017). This equates to a void space of about 25% (void volume/ total volume). In its natural state this void space will be filled partially by air and water.

An extensive monitoring system was installed during the TLF construction to assess the soil water holding capacity, runoff and infiltration of the landform (Shao 2015). Instrumentation installed included 66 soil moisture probes, a weather station, and four erosion plots.

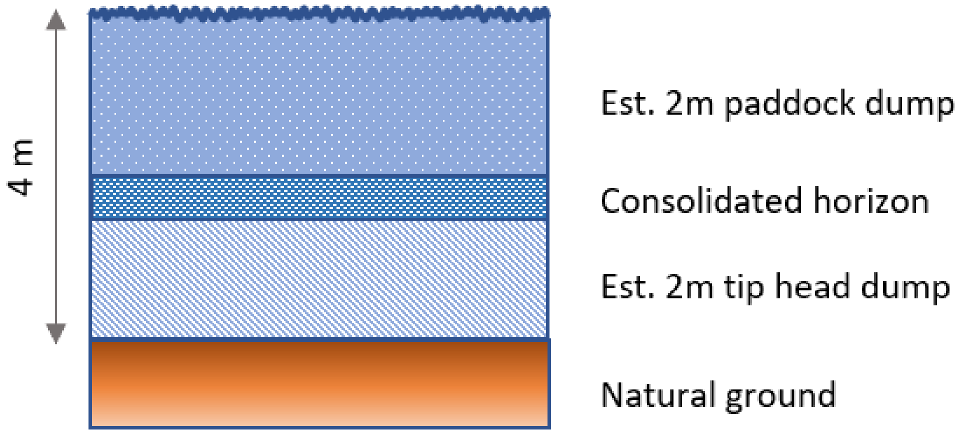


Figure 9-104 Profile of the waste rock only section Area 1 of the TLF

The completed TLF stands four to seven metres above the original natural ground surface, has a 2% slope and was constructed using 800,000 tonnes of waste rock and laterite material. The surface was ripped at 2 metre intervals down to approximately 0.5 m deep. Vegetation establishment commenced in March 2009 with tubestock planting in Areas 1A and 3; direct seeding was performed in Areas 1B and 2 in July and December 2009, and infill planting was performed in January 2010 and 2011. An area 50-metres wide on the front, north-eastern side of the TLF was left unirrigated. The revegetation trial results are discussed in *Section 5 KKN supporting studies*, KKN ESR3.

Current rehabilitation

Ongoing trials are underway on the TLF to further establish understorey and improve the overall biodiversity and weed management.

Planned rehabilitation

The TLF will be integrated into the final landform, requiring the removal of infrastructure and reshaping of edges.

This integration is somewhat unique across the final landform, as the combination of the desire to avoid vegetation disturbance on the TLF proper, the height of the TLF surface, the proximity of the TLF to the perimeter of the disturbed area and typical criteria for final landform slopes, requires the removal of a reasonably significant area of mostly undisturbed vegetation (Figure 9-105). This disturbance of additional vegetation was not viewed favourably by traditional owners, and alternative landform designs are currently being assessed.

The area of backfill required to blend the rectangular shape of the TLF into the natural topography was proposed to be one of the areas for catchment management trials. The use of this area for catchment management trial work may be revisited once questions around final landform shape in the area have been resolved.

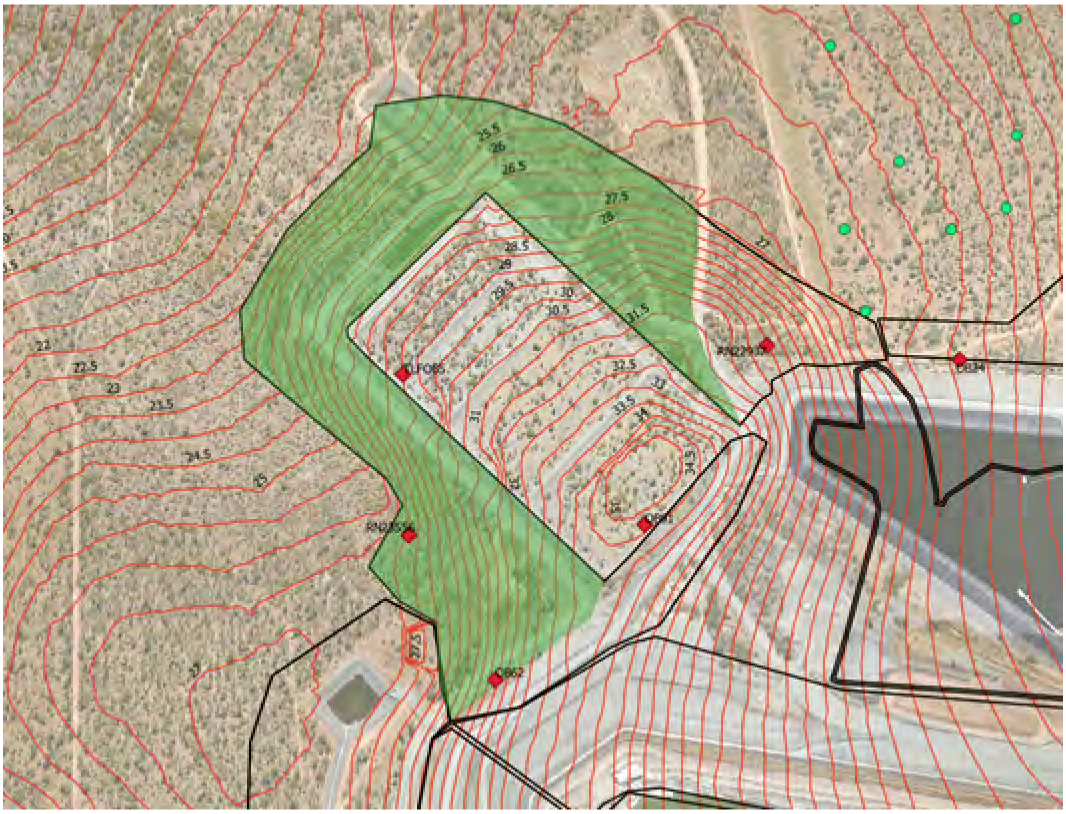


Figure 9-105: Final landform footprint around the TLF Green shading shows the area proposed to be backfilled as part of the catchment management trial.

Contingency planning

Appropriate weed and fire management will be implemented as necessary.

9.2.12 Airport

The airport at Jabiru East and other infrastructure, such as the Environmental Institute for the Supervising Scientist (ERISS) (Figure 9-106) and the Telstra building, are considered to be of high value to the community and, as such, are currently assumed to remain following closure of the Ranger Mine. Under the current arrangements, the Commonwealth is required to rehabilitate and restore the area occupied by ERISS before vacating, including the removal of the buildings.

Figure 9-106: Jabiru airport (May 2019)

Under the current legislative framework, ERA is obliged to rehabilitate the airport precinct. ERA is currently operating the airport largely for the benefit of third parties, including the Commonwealth and NT Governments. ERA is working with the Department of Industry, Science, Energy and Resources (DISER), the Northern Land Council (NLC) and the Gundjeihmi Aboriginal Corporation (GAC) to develop a plan that allows for the airport facility and associated infrastructure to continue to be in operation throughout the rehabilitation period.

Completed rehabilitation

No rehabilitation has been completed to date.

Opportunistic sampling and analysis of soils for metals, hydrocarbons and radionuclides was conducted in August 2020 and November 2021 to understand if contamination exists at Jabiru Airport. Sampling was undertaken using a source-pathway-receptor approach, using the locations of historical and current infrastructure such as storage tanks and wash down bays to better understand and delineate the potential contaminated sites at the airport and nursery areas. Results from the opportunistic investigations will be used to inform whether future works are required.

Current rehabilitation

No rehabilitation is currently occurring on the site as it is still operating as an active airport.

Planned rehabilitation

Planning for removal of the airport, should it be required, is in the initial stages. The access road to the airport will remain to allow access to the ERISS and Telstra buildings. The airport tourist centre contains asbestos. Demolition will include provision for the removal of this asbestos for burial in Pit 3.

Following the completion of the contaminated sites sampling described above, results will be reviewed to determine if any remediation is required.

Contingency planning

Any agreed plan for the continued operation of the airport by an operator other than ERA will include provisions confirming responsibility for the rehabilitation of the airport facility and associated infrastructure, including contaminated site management and remediation.

9.3 Closure activities

Closure activities are those that occur across multiple domains and, although referred to within domains, are discussed in this section.

9.3.1 Contaminated sites

This section provides details of contaminated sites that are not presented within a specific domain. *Section 5 KKN Supporting Studies*, Chapter 5.5.2.5 presents details regarding contaminated sites studies. The following chapter relates to closure activities required as a result of those studies.

The *Contaminated Site Land Register* (current version was last updated in 2021) has been developed and is maintained at the Ranger Mine, in accordance with the operational *Hazardous material and contamination control plan* (Appendix 9.2). The *Contaminated Site Land Register* identifies all sites where activities have occurred that have the potential to contaminate land.

A significant number of targeted contaminated land assessments have been undertaken previously on the RPA at known contaminated sites between 2006 and 2016. Whilst the focus of previous assessments was predominantly identifying groundwater contamination, soil and sediment profiles have also been assessed at known contaminated sites to define the lateral extent of contamination in the soils and sediments at the RPA.

As part of the feasibility study undertaken in 2018, a review of the *Contaminated Site Land Register* was undertaken to provide a register (at that point in time) suitable for closure planning purposes. The review involved ensuring all areas of potential contamination were captured as well as aligning historical investigations undertaken to date, thereby developing a current site contamination knowledge base. Sites were also classified according to risk (costs of remediation).

Following this review, a *Plume and contaminated site management plan* was developed during the feasibility study. The plan describes future work (site assessments and BPT assessments), post remediation validation assessments and post-closure monitoring. This plan was further reviewed for appropriateness in April 2019 to confirm whether broad remediation statements made during the feasibility study were supported by outcomes of previous studies and outcomes of the feasibility study. A gap analysis was also completed. Areas identified during the gap analysis as having insufficient data to adequately determine a remediation treatment option were identified for further investigation including depth and COPC data.

A Contaminated Sites investigation was completed to address these gaps between December 2019 and January 2020. This involved a targeted soil bore drilling campaign and installation of groundwater wells to facilitate future closure monitoring.

Soil sampling included a selection of analytes including hydrocarbons, metals and nutrients in line with the requirements detailed in the National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013) (ASC NEPM, 2013). The data (ERA, 2021a) has been used to inform the whole-of-site contaminant transport modelling and will inform the future rehabilitation and risk management of the site.

Additional opportunistic field sampling has been undertaken throughout 2021 and early 2022 where questions have arisen or gaps identified. Such areas have included the Jabiru Airport, Nursery (previously the exploration yard), Gatehouse, Heavy Vehicle Workshop, and the area around the Pond Water Tank.

Results from the historical work summarised above as well as any recent investigations will be used to inform BPT assessments to determine future actions if required. The outcomes of these assessments and details of any remediation plans will be included in future updates of the MCP.

9.3.1.1 Per- and Poly-fluoroalkyl Substances (PFAS)

As part of environmental investigations carried out in 2019 and 2020, Per- and Poly-fluoroalkyl Substances (PFAS) were found in several areas including the emergency dump tank area, Coonjimba Billabong (CB), pond water streams and most of the groundwater monitoring bores that were sampled. The majority of soil samples possessed low concentrations of PFAS, however concentrations in the majority of water samples exceeded relevant drinking water criteria. Concentrations in the vicinity of the emergency dump tank area presented the highest concentrations by an order of magnitude in comparison with groundwater results from other areas.

The understanding of the magnitude and extent of PFAS in soils, surface water and groundwater has further been assessed to a level where a robust and scientifically defensible risk-based assessment can be completed. A Sampling Analysis and Quality Plan (SAQP) was developed to outline a framework to assess the extents of PFAS impacts and their potential risks to downstream environments and receptors. As well as data collation and desktop review, field investigations were undertaken in accordance with the SAQP including:

- soil investigation and installation of additional groundwater monitoring bores (November 2021);
- concrete pad characterisation samples (April 2022);
- sediment and surface water investigation (February 2021, December 2021 and April 2022); and
- groundwater monitoring (December 2021 and May 2022).

A Detailed Site Investigation (DSI) Report is currently in preparation summarising the contamination magnitude and extent across the RPA. The DSI will also identify potential contamination sources, pathways and receptors (a Conceptual Site Model) with a view to identify potential and significant pollution linkages and related risks to human health and the environment. The Conceptual Site Model will assist in the assessment of risk, and where required, provide rational for the design of remedial solutions for areas of contamination. The Conceptual Site Model is a working hypothesis for the understanding of site contamination and is updated as new information is obtained.

9.3.1.2 Sediment investigation program

A sediment investigation program was conducted between November 2020 and February 2021. The objectives for this monitoring program were to characterise the acid sulfate soils (ASS) contamination potential and fill knowledge gaps in the inventory of sediment metal and radionuclide contamination on the RPA. Sampling was conducted at nine surface water bodies located on and surrounding the Ranger Project Area, these included:

- Mudginberri Billabong (ASS, Metals and Radionuclides);
- Gulungul Billabong (ASS , Metals and Radionuclides);
- RP1 (ASS, Metals and Radionuclides);
- GCT2 (ASS only);
- Georgetown Billabong (ASS, Metals and Radionuclides);
- GCMBL (ASS, Metals and Radionuclides);
- Sleepy Cod (ASS, Metals and Radionuclides);
- Indium (ASS only); and
- DJKRP (ASS only).

Results from this investigation have been used to inform the broader aquatic source-pathway-receptor model and risk assessment approach (Iles and Rissik, 2021). Future work will switch to ongoing monitoring by ERA of sediment contamination to inform and refine future aquatic pathway risk assessments and vulnerability assessments (where applicable), and will be included in the MCP as appropriate.

Additionally, ERA is undertaking supplementary studies to inform the TSF (Ranger Water Dam) deconstruction (which includes the Coonjimba catchment drainage line) and Final Landform applications, and any new data will be assessed using the risk assessment tool (Iles and Rissik, 2021) and updated accordingly in the MCP.

A summary of the complete aquatic sediments and the ASS assessment is provided in *Section 5 KKN Supporting studies*, Chapter 5.5.2.2 and Chapter 5.5.2.5.

9.3.2 Waste and hazardous material management

This section contains the management of waste and hazardous material that is applicable across numerous domains. Further details are provided within the Hazardous Material and Contamination Control Plan (Appendix 9.2).

ERA has identified that the following waste and hazardous material has remained onsite after cessation of ore processing activities up until time of writing:

- tailings;
- BC brine and sludge from the HDS plant;
- mineralised waste rock (2s rock or higher);
- non-mineralised waste rock (1s rock);
- materials to be demolished (steel, concrete, asphalt);
- listed wastes - non-radiation contaminated hydrocarbon, asbestos, rubber, tyres and other hazardous wastes;
- general waste (non-hazardous2) – domestic, HDPE pipe, concrete, fencing;
- heavy mining equipment and other vehicles;
- special items:
- radiation contaminated hydrocarbons
- calciner
- geological core samples.

The total volumes of each waste have been provided in Table 9-21.

Table 9-21: Waste materials for management and/or disposal at closure

Waste Material	Amount
Tailings	
Pit 1 tailings	25.2 Mt
Pit 3 tailings (June 2019)	36.7 Mt
RWD tailings (June 2019)	4.9 Mt
Estimated tailings produced in mill Jun 19 – Dec 20	1.27 Mt
Mineralised waste rock (2s and above)	
Pit 3 underfill (mixed rock of various grades)	32.5 Mt
Pit 3 forecast backfill	28.1 Mt
Pit 1 mineralised waste rock (below water table)	3.8 Mt
Pit 3 mineralised waste rock	6.9 Mt
Beneath RP6	0.7 Mt
1s waste rock	

[2] Current testing of samples indicates no significant radiation or contamination

Waste Material	Amount
Pit 1 (below water table)	1.7 Mt
Pit 1 (above water table)	7.1 Mt
Pit 3 (below water table/above tails)	20.3 Mt
Pit 3 (above water table)	12.6 Mt
Stockpile areas	14.1 Mt
Ranger Water Dam (RWD) (backfill from walls)	13.0 Mt
Site area fills to final landform	9.6 Mt
Brine	
BC Brine to Pit 3 underfill total	1.8 GL
Demolished material	
Demolished structural steel, concrete, asphalt	60,000 m^3 (150 kt)
Non-structural steel	11,000 t
Concrete up to 1.5m below ground	115,000 t
Asphalt	16,000 t (84,000 m^2)
Phase 1 demolition to Pit 3	40 – 50,000 m^3
Phase 2 demolition to RP2	10 – 20,000 m^3
Phase 3 demolition off site following closure	<1,000 m^3
Listed wastes	
Non-radiation contaminated hydrocarbons to offsite disposal	1,500 t
Asbestos to Pit 3	35 t
Rubber and other hazardous wastes	8,000 t
General waste	
General (non-hazardous) wastes	
General rubbish	3,500 t
HDPE	170 t
Fencing	75 t
Heavy Mining Equipment (18 heavy vehicles to RP2)	21,000 m^3
Special Items	
Radiation density gauges to be disposed in suitable location off site	20 – 30 units
Calciner to Pit 3	1 unit
Geological ore samples (mixed uranium content) to Pit 3	1,400 t
Radiation contaminated hydrocarbons to offsite disposal (blackjack, grease and oily rags)	120 t

9.3.3 Water treatment

This section describes the reduction of the water inventory, and separation of pond and process water. The closure of the physical areas, such as RP2 or the water treatment plants, are described previously under each specific domain. The overall management of water on site is detailed within the Ranger Water Management Plan.

The main water inventories relevant to closure are those associated with pond water and process water. Pond water is derived from rainfall that falls on the active mine site catchments and results in runoff that is of a quality that requires active management. Process water is the most impacted water class on site and is derived predominantly from water that has passed through or encountered the uranium extraction circuit, and from rainfall onto designated process water catchments.

To enable the successful closure of the Ranger Mine, both the pond and process water inventory on site must reduce to a zero balance. ERA uses a water balance model to forecast the pond and process water inventories until closure of the RPA. Details of the latest water model are provided in *Section 2 Project overview*, Chapter 2.2.9.9.

Pond water treatment will continue with the existing water treatment plants discharging permeate to available wetland filters and LAAs. The ultimate reject from pond water treatment, after further treatment using the Brine Squeezer, is discharged to the process water inventory.

The flow diagram provided in Figure 9-107 shows the flows on site relevant to process water treatment. Process water treatment for the current model is undertaken through a number of operational processes and infrastructure; namely, the BC, High Density Sludge Plant (HDS) and the Brine Squeezer, details of each treatment method are provided in the subsequent sections. The most recent water model, completed in July 2021, assumes the following for future active process water treatment:

- The BC continues to be the principal route for process water treatment. Distillate production capacity following the completion of the fan upgrade in early 2021 is 2.41 GL/a. BC treatment concludes once all process water sources have ceased. As described in Chapter 9.2.2, the concentrated brine produced by the BC is permanently disposed of by injection into the Pit 3 underfill, although there may be periods where the brine is recycled to the bulk process inventory.
- The HDS plant operates with a feed capacity of 2 ML/d, generating product water of a quality suitable for final treatment by the existing pond water treatment plants.
- When not treating pond water brine, the Brine Squeezer treats process water to produce 1.9 ML/d of release water. This reverse osmosis-based treatment commenced in July 2022.

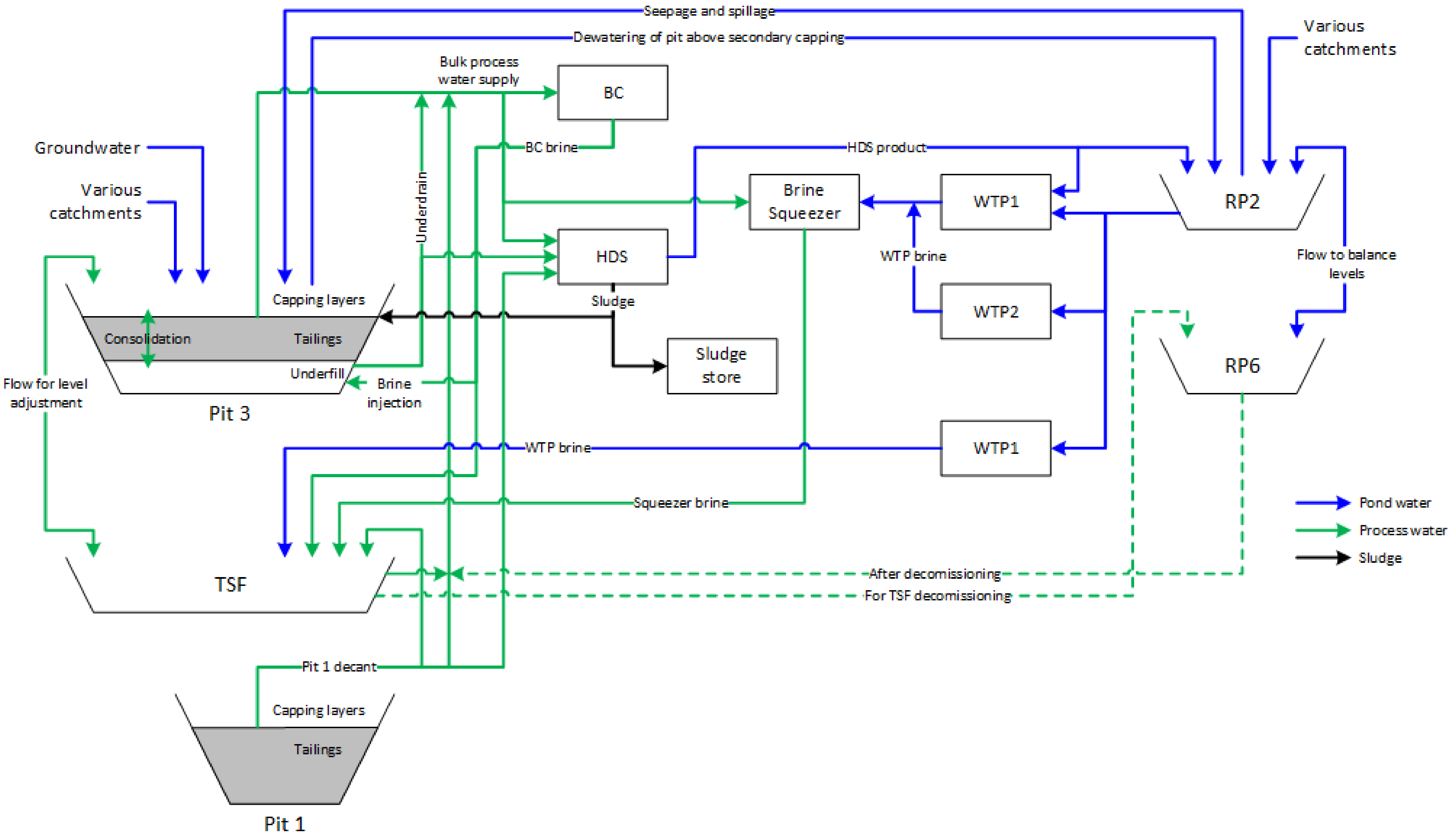


Figure 9-107: Process water flow diagram for the current water model

9.3.3.1 Brine Concentrator

The Brine Concentrator (BC) is a process water treatment plant, constructed in 2012 and commissioned in 2013. The BC consists of three trains: BC1, BC2 and BC3. Each train comprises of a falling film evaporator and a vapour recompression fan. The three trains are arranged so that BC1 and BC2 are fed in parallel, with their combined concentrate, along with additional process water, fed to BC3 (Figure 9-108).

Process water is delivered via overland pipeline to the BC. The plant produces a clean distillate product that is discharged to available release storages, and a concentrated brine, which is either injected into an underfill layer of waste rock deep inside Pit 3 or diluted with process water and returned to the process water inventory. Injection of concentrated brine into the Pit 3 underfill is the primary method to dispose of salt from the process water inventory.

BC capacity is specified via the flow of product distillate. The assumed BC capacity of 7 ML per operating day is based on observed distillate production rates following the completion of a fan upgrade in early 2021. An allowance of twenty days of downtime for planned and unplanned maintenance then gives an annualised rate of distillate production of 2.41 GL/a.

Once the free process water inventory has been drawn down to zero, the supply of process water to the BC is expected to be less than the treatment capacity of the BC.

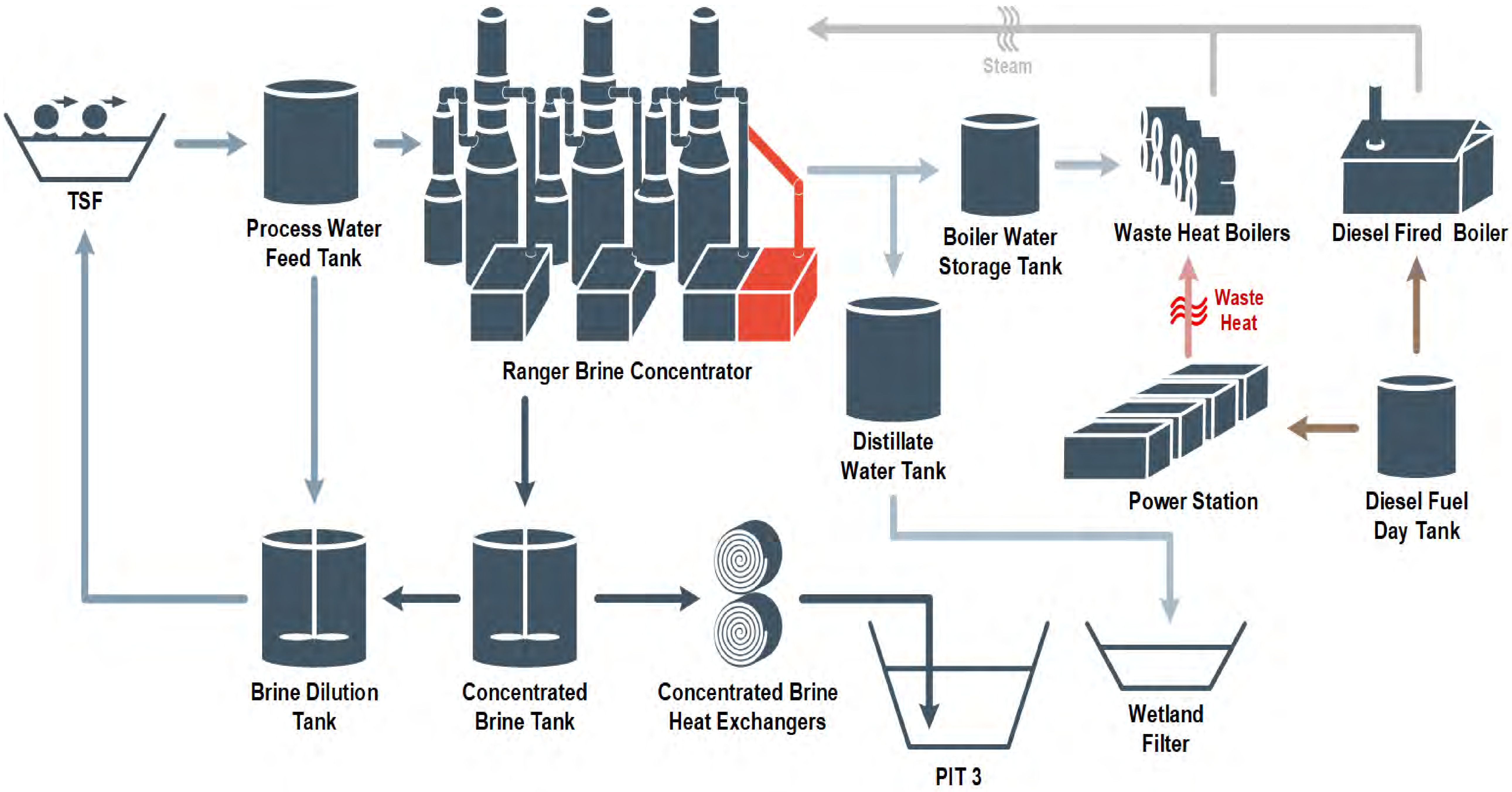


Figure 9-108: Block flow diagram for the Brine Concentrator following BC3 fan upgrade

9.3.3.2 HDS Plant

The HDS plant treats process water, through to a water quality similar to pond water, through two processing stages (Figure 9-109). In the first stage (primary softening), acidic process water is mixed with alkaline milk of lime, resulting in the precipitation of gypsum and the precipitation of most of the metals originally in the process water as metal hydroxides. The precipitates are separated from the solution in a thickener as a sludge, some proportion of which is recycled to act as a seed for precipitate growth, the remainder is sent for disposal. The separated solution, known as primary softened water, is saturated in calcium from the milk of lime and is sent onward for secondary softening.

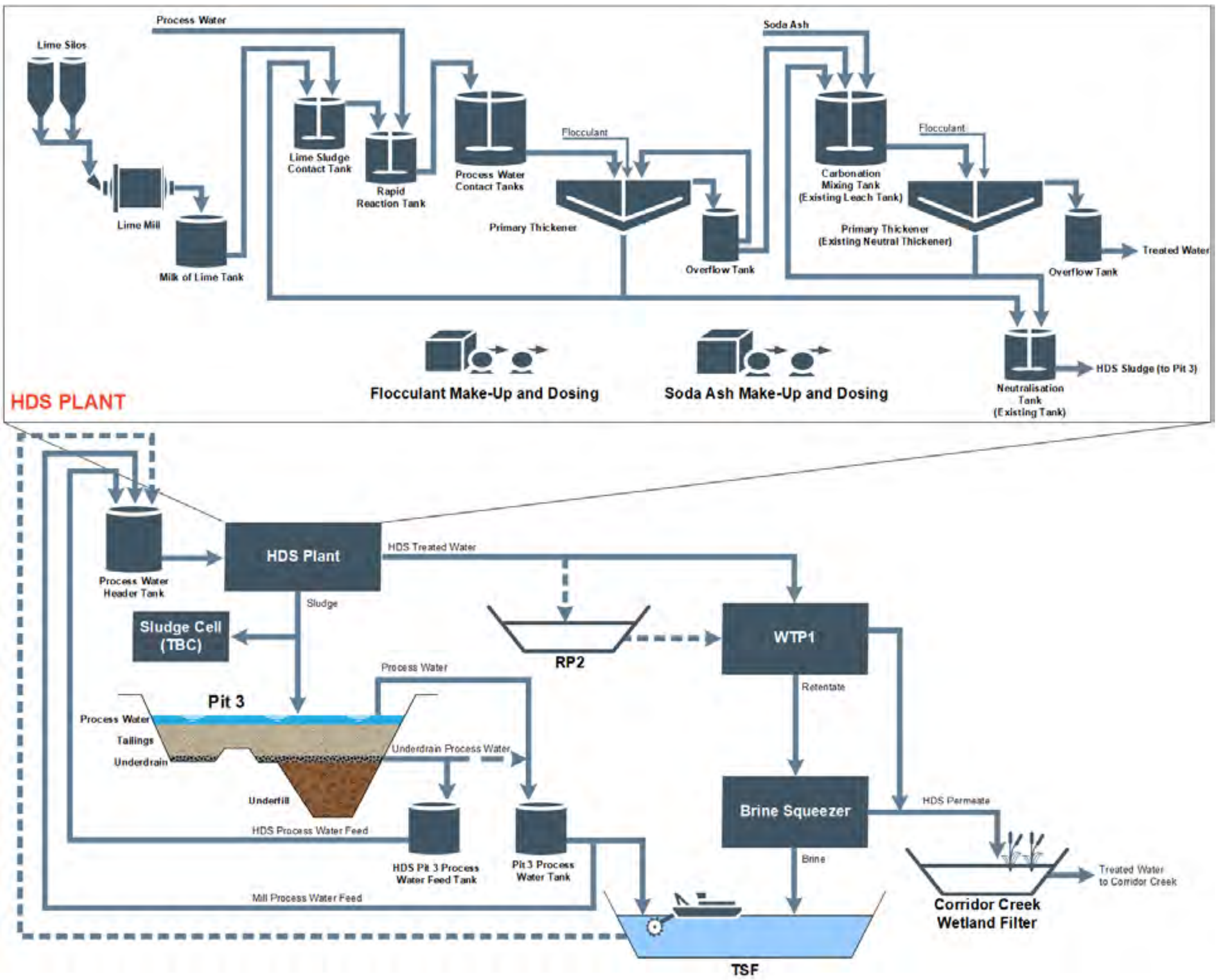


Figure 9-109: HDS Plant Block Flow Diagram

In the second stage (secondary softening), a solution of soda ash (Na_2CO_3) is dosed into the primary softened water, precipitating most of the contained calcium as calcium carbonate ($CaCO_3$). Again, the precipitate is separated from the solution as a sludge, some proportion is recycled as a seed for precipitate growth and the remainder is sent for disposal. The alkalinity of the separated secondary softened water is neutralised by addition of a small quantity of sulfuric acid solution and discharged from the plant to either the pond water inventory (via RP2) or directly to water treatment plant (WTP) 1 depending on water treatment plant requirements and the condition of the pond water inventory. HDS product discharged to the pond water inventory may be then treated by any of the pond water treatment plants.

HDS product water contains ammonium that is originally present in the feed process water to the plant – this ammonium is not removed by the primary and secondary softening stages of HDS treatment. HDS product also contains some sodium that arises from the soda ash dosing in secondary softening. Treatment of HDS product water through the pond water treatment plants removes the vast majority of the ammonium and sodium present in the HDS product. If further ammonia removal is required, options are available such as passage through wetland filters, additional holding time in RP2, or partial recycling through additional polishing stages within the pond water treatment plants.

The HDS plant was built in 2005 and overhauled in 2009. Operations ceased due to operability issues with the HDS plant and the impending installation of the BC. Subsequently, parts from the plant were re-purposed elsewhere on site.

In 2019, the plant was restored to its 2009 condition. ERA subsequently obtained approvals to operate the recommissioned plant with discharge of the product water to the pond water inventory or directly into the feed for pond water treatment plant 1 (WTP1). In recent years the plant has been preferentially treating water from low salt sources such as the Pit 1 decant, with the sludge from the plant being directed through the Pit 3 sub-aqueous tailings disposal infrastructure where it combines with the Pit 3 tailings mass.

It is expected that the ability to dispose of the sludge with Pit 3 tailings will cease shortly after Pit 3 wicking activities commence in the second half of 2022. Continued operation of the plant beyond this time requires an alternative sludge disposal location.

In 2020 an order of magnitude study was conducted into a range of future sludge disposal locations and methods. A preferred option - pumping of sludge to a dedicated disposal repository to the west of RP2 – was selected after a BPT assessment and progressed through further engineering studies, but the option was subsequently set aside due to cost and conflict with other closure activities.

Consequently, HDS operations are expected to cease in late 2022. The plant will be retained in a mothballed state as a contingency against changes in the site process water treatment context. The plant will ultimately be demolished either in conjunction with the Brine Concentrator or WTP1.

9.3.3.3 Brine Squeezer

The Brine Squeezer is a water treatment plant that further extracts clean water from the reject of pond water treatment. The plant consists of two stages of reverse osmosis treatment in series; the permeate from the first stage of high salt tolerance membranes is subsequently passed to a second, polishing stage of reverse osmosis treatment that yields a high quality permeate suitable for direct release. Prior to the installation of the Brine Squeezer, a significant proportion of the reject from pond water treatment was directed to the process water circuit.

The implementation of the Brine Squeezer effectively intercepts and minimises the volume of this process water source.

An application to discharge permeate from the Brine Squeezer was approved by the MTC in the first half of 2019. Permeate from the Brine Squeezer is discharged through the existing pond water treatment permeate system and is subject to the same release conditions and controls. Reject from the Brine Squeezer is sent to the process water circuit.

The process water treatment strategy requires use of the Brine Squeezer to also generate permeate for release from process water. Pilot scale testing of process water treatment by the membranes used in the first stage of the Brine Squeezer was conducted in the second half of 2020. This pilot was successful in the generation of suitable quality first stage permeate under practical membrane maintenance conditions when treating process water drawn from the bulk inventory and water that had been subjected to some degree of pre-treatment by the HDS plant. Contrary to expectations, the squeezer membranes were unable to practically generate permeate when treating lower salt sources such as Pit 1 decant, due to oxidation of iron and manganese species in the water resulting in precipitation of solids and fouling of the reverse osmosis membranes

Informed by the results of the pilot testing, detailed engineering has commenced to allow modifications to the Brine Squeezer for its use in process water treatment. These modifications include the installation of pre-filtration units ahead of the Brine Squeezer proper (these pre-filtration units are similar to those at the front end of the pond water treatment plants), upgrades to the membrane feed pumps, installation of additional membrane cleaning infrastructure and process water feed and reject delivery systems.

The process water treatment strategy assumes that the Brine Squeezer will continue to treat pond water brine, typically during the wet season, in priority to process water treatment. Upgrades to enable process water treatment enable the plant to generate 2 ML/d of process water permeate.

9.3.3.4 Pond water treatment

The three water treatment plants are the primary method of managing pond water on the RPA. Each is a micro-filtration reverse osmosis plant. The water treatment plants treat pond water from RP2 and RP6, and produce a clean water stream (permeate) and a reject stream (pond water treatment brine). Permeate from the pond water treatment plants is directed to the release water catchments of either Corridor Creek or RP1. Currently, reject is typically discharged to the process water inventory, though it may be recycled back into the pond water inventory if pond water quality permits. With the availability of the Brine Squeezer, reject from WTP1 and WTP2 may be diverted to the Brine Squeezer, whilst reject from WTP3 will continue to be handled as before.

The water treatment plants are operated on an as-required basis to manage the accumulation of pond water from rainfall in the wet season, and a relatively small quantity of HDS product. Based on a median rainfall scenario, the total pond water treatment capacity delivers 1,400 kL/a of permeate to release. Treatment capacity across the three plants is approximately

14,100 kL/d, allowing for the discharge of most permeate to Magela Creek during the wet season with the remainder disposed of by irrigation to land during the dry season.

Operation of the pond water treatment plants is triggered based on total pond water inventory. Trigger volumes will be set consistent with the water management plan and water treatment strategy. The pond water treatment plants will continue to treat water until the entirety of the

9.3.3.5 Contingency plans

The final volume of process water that will require treatment prior to the end of process water treatment is directly dependent upon rainfall. The current closure strategy is based on a median forecast (or a 50th percentile – i.e. P50 case) of outcomes given historical variation in rainfall.

In the case where current process water treatment rates are not achieved, or higher than average rainfall is experienced earlier in closure, then the contingency plans for water treatment, in turn, are potentially to:

- purchase a second Brine Squeezer;
- construct and operate additional evaporative plant; and/or
- further extend the duration of process water treatment.

There is potential for rainfall scenarios to exceed the practical amount by which water treatment capacity can be expanded, particularly if a significant rainfall occurring late in the closure phase. Should this occur, extension in duration of process water treatment is the only practical contingency.

It is noted that whilst the cumulative volume of water to be treated will depend on many factors, predominantly rainfall, the inventory of contained salt is much less variable and thus there is a high degree of confidence in the capacity of the Pit 3 underfill void space for brine disposal.

Additional evaporator

The additional evaporator is a small scale standalone evaporative plant. The plant will operate similarly to the existing BC, with a distillate production of 1.8 ML/d. The plant can be located so as to not interfere with other decommissioning and closure activities.

This contingency strategy is not constrained by the closure demolition schedule, can be implemented at any time and can operate as long as necessary. This option will require engineering development, an implementation plan and approval. The plan must include the trigger for proceeding so as to optimise evaporator impact on process water treatment in the closure phase.

9.3.4 Bulk material movement

The bulk material movement (BMM) plan was updated during 2020 and is under regular review. It includes the movement of all waste rock to final destination and the construction of the final landform.

The bulk of the BMM activities will be executed after tailings has been transferred from the RWD to Pit 3 and after Pit 3 is prepared for capping activities. The BMM mining equipment is not able to start backfilling Pit 3 until a geotechnically stable capping layer is installed. The BMM interfaces with the tailings capping methodology described in Chapter 0.

The BMM works cover the specific disturbed footprint area of 795 ha. A dynamic mine model, including haulage simulations, has been created to assist in producing the closure strategy. This model determined a complex sequence of material movements to ensure all mineralised material ended up in Pit 3 below the vadose zone. Using predominantly excavators and trucks, a total of approximately 96 Mt of material will be moved.

Mining of stockpiles and final landform creation has already commenced with the backfilling of Pit 1 and stockpiling of material for crushing and screening for Pit 3. The final landform construction will be an ongoing process to enable areas to be released progressively for revegetation.

The BMM plan excavates areas above the final landform (stockpiles and RWD). However, mineralised material will be mined below the final landform in many of the stockpiles to be placed into Pit 3. A minor amount of mineralised material in the RP6 area will be excavated very late in the closure project and will be buried in the low part of RP2 because Pit 3 backfilling will have reached the point where no more mineralised material can be placed into Pit 3. The plan for excavation and placement areas are shown in Figure 9-110 and Figure 9-111 respectively.

Manual and dynamic mine modelling was performed as an iterative process where output was reviewed, and assumptions and constraints modified as required. Material was only scheduled to be mined, where necessary, as a proportion of material in stockpiles remains in place due to not having mineralised material and being already below final landforms level. The location and alignment of haul roads was optimised and determined by the dynamic mine model.

The feasibility study investigated individual stockpiles, the material make-up (presence of 2s and high 1s material) and the volumes within each mining excavation area for each of the material groups. The ability to bury mineralised material in Pit 3 below the 2s material cap (defined by forecasted permanent water table) generally requires material in the southern stockpiles to be prioritised for initial bulk movements. The non-mineralised material in the central and northern stockpiles, will be moved later to form final landforms.

Stockpiles have variable content of uranium oxide (U_30_8) present. Grade class 1s material is categorised as non-mineralised rock, whereas grade class 2 materials are categorised as mineralised material.

In 2008 an extensive drilling program was conducted to allow a stockpile block model to be developed, and tonnages and grades to be further evaluated. This block model has been maintained via GPS locations of sources and destinations of materials since that time. The block model was used as the base information for the closure mine plan. The material grades distribution across the main stockpile areas are shown in Figure 9-112. The majority of mineralised material is in the southern stockpile areas. The majority of non-mineralised material is in the central and northern stockpiles as well as within the RWD walls. Non-mineralised material is present in the southern stockpiles as well, as confirmed in the block model.

All mineralised material will be placed in Pit 3 as described above and non mineralised rock is scheduled to be used for the final landform. Due to overall cut and fill being balanced, mining of 2s material is prioritised so that it can be placed below this non mineralised rock.

During active mining operations, extracted material was transported by truck to pass beneath a radiometric discriminator, which uses scintillometer heads to measure the gamma particle emissions of each load and categorise the material. Material was allocated to tipping locations based on grade classification. A discrimination plan has been developed for stockpiles to ensure the correct final emplacement of material. More discrimination is planned on the southern stockpiles than the northern stockpiles, due to more mineralised material being present. The discrimination plan has a reduced level of discrimination compared to that which occurs for milling, as it is unnecessary to determine whether material should be milled or re-stockpiled.

All the material used in the construction of the RWD walls was confirmed as un-mineralised during construction; therefore, can be used for final landform shaping and does not require to be buried in RP2 or below the Pit 3 2s material cap.

Details of the material movements plan by mining source and placement location are shown in Figure 9-110 to Figure 9-111. Details of the tonnes are provided in Table 9-22.

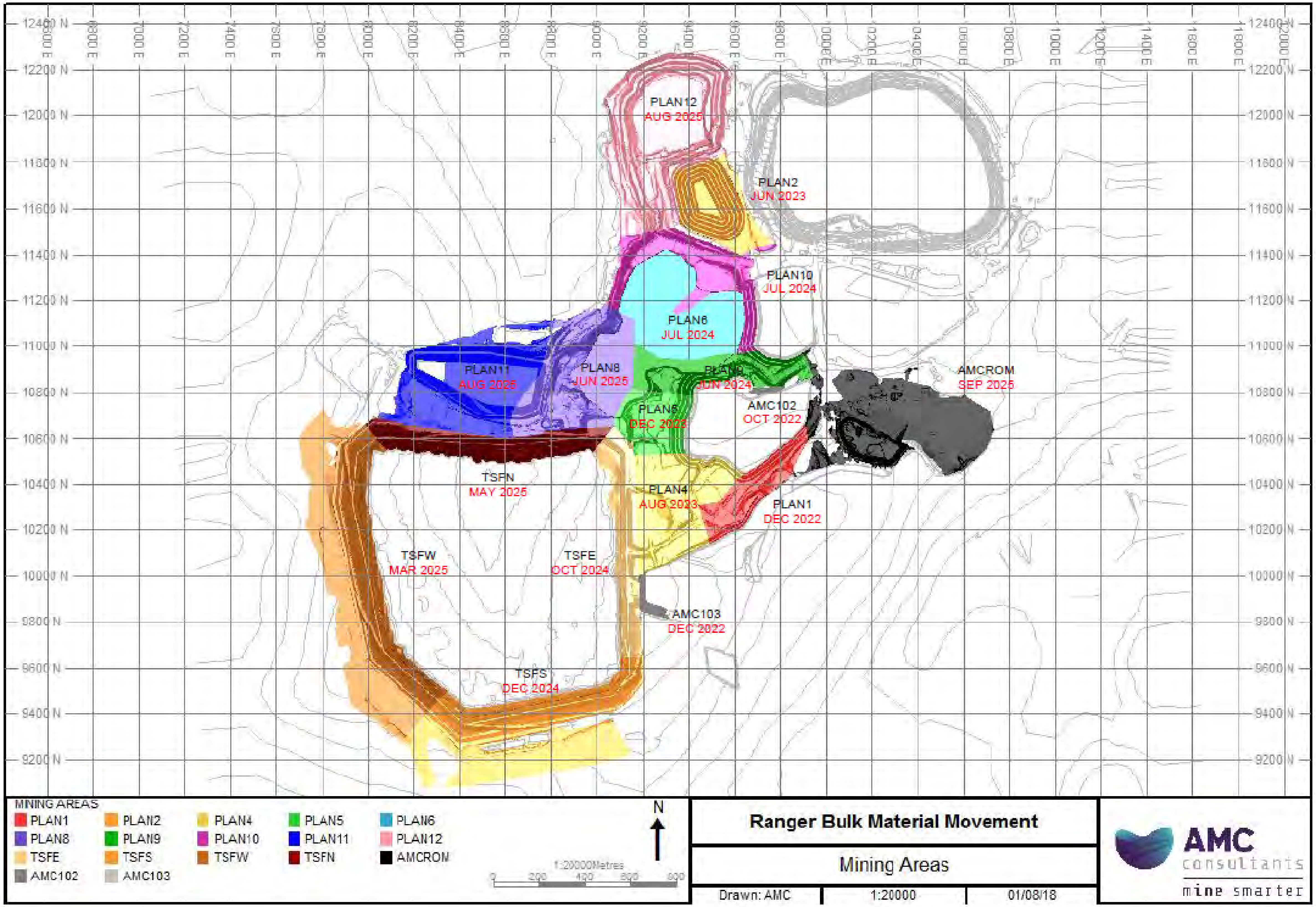


Figure 9-110: Material movement excavation areas

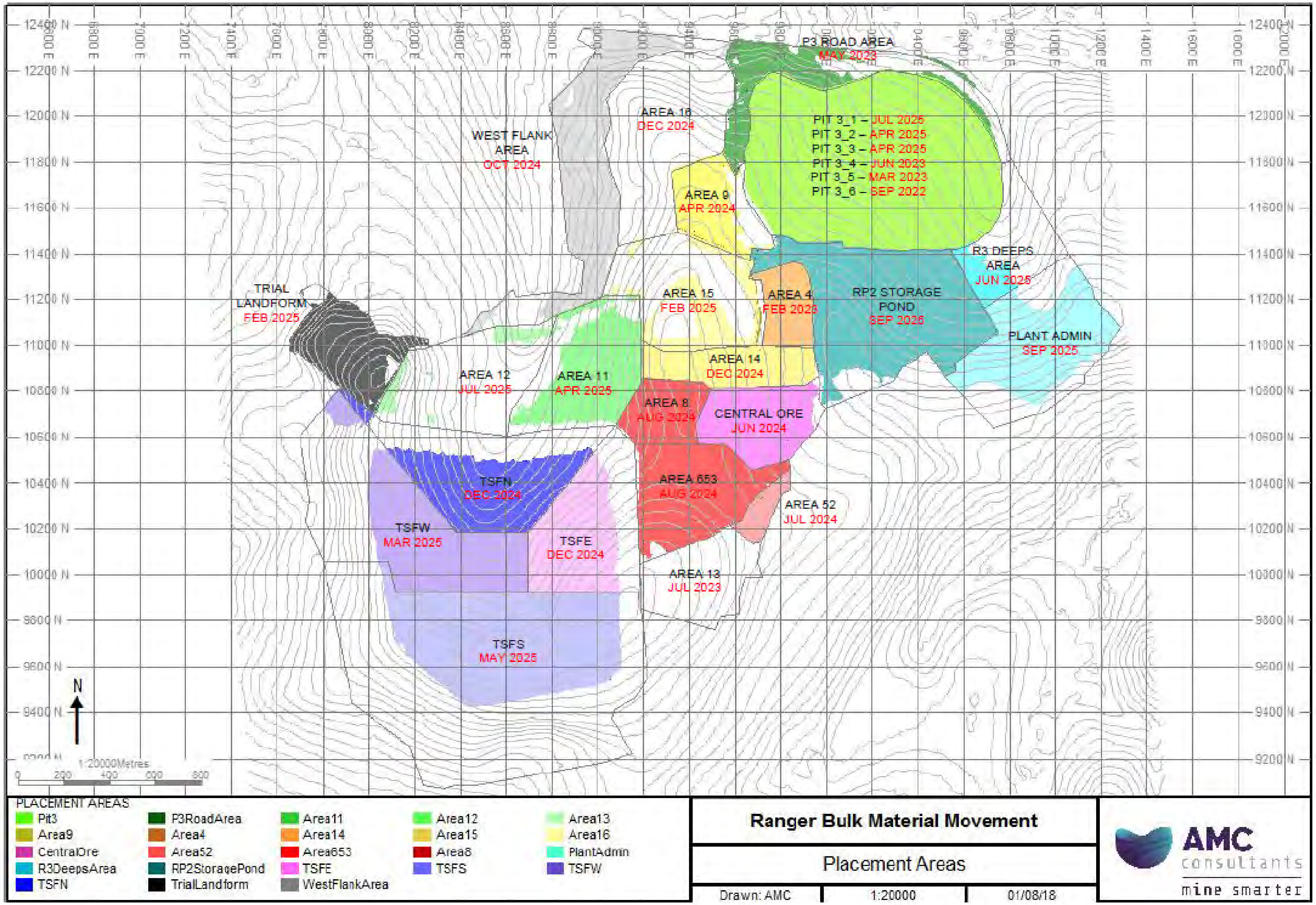


Figure 9-111: Material movement placement areas

Table 9-22: Bulk material movements

Excavation Area	Material movement quantity (t)	Pit 3	Other / Final Landform	TSF	RP2
Plan 1	1,368,486	1,210,465	158,022	0	0
Plan 2	6,305,221	4,676,466	1,628,755	0	0
Plan 4	7,905,547	5,867,893	2,037,653	0	0
Plan 5	7,172,219	6,378,274	793,945	0	0
Plan 6	12,683,261	12,036,622	646,639	0	0
Plan 8	8,617,015	7,556,059	1,060,956	0	0
Plan 9	6,296,065	4,196,980	2,099,085	0	0
Plan 10	2,591,330	2,280,646	310,684	0	0
Plan 11	3,295,667	0	81,040	0	3,214,627
Plan 12	15,525,962	13,443,634	1,130,661	0	951,667
TSFE	2,429,966	0	954,429	1,475,537	0
TSFS	3,484,063	0	1,175,859	2,308,203	0
TSFW	4,958,672	0	244,688	4,713,984	0
TSFN	5,488,161	0	1,230,670	4,257,491	0
AMCROM	2,344,560	0	533,461	0	1,811,099
AMC102	0	0	0	0	0
AMC103	339,715	43,147	296,568	0	0
TOTAL	**90,805,909**	**57,690,186**	**14,383,114**	**12,755,215**	**5,977,394**

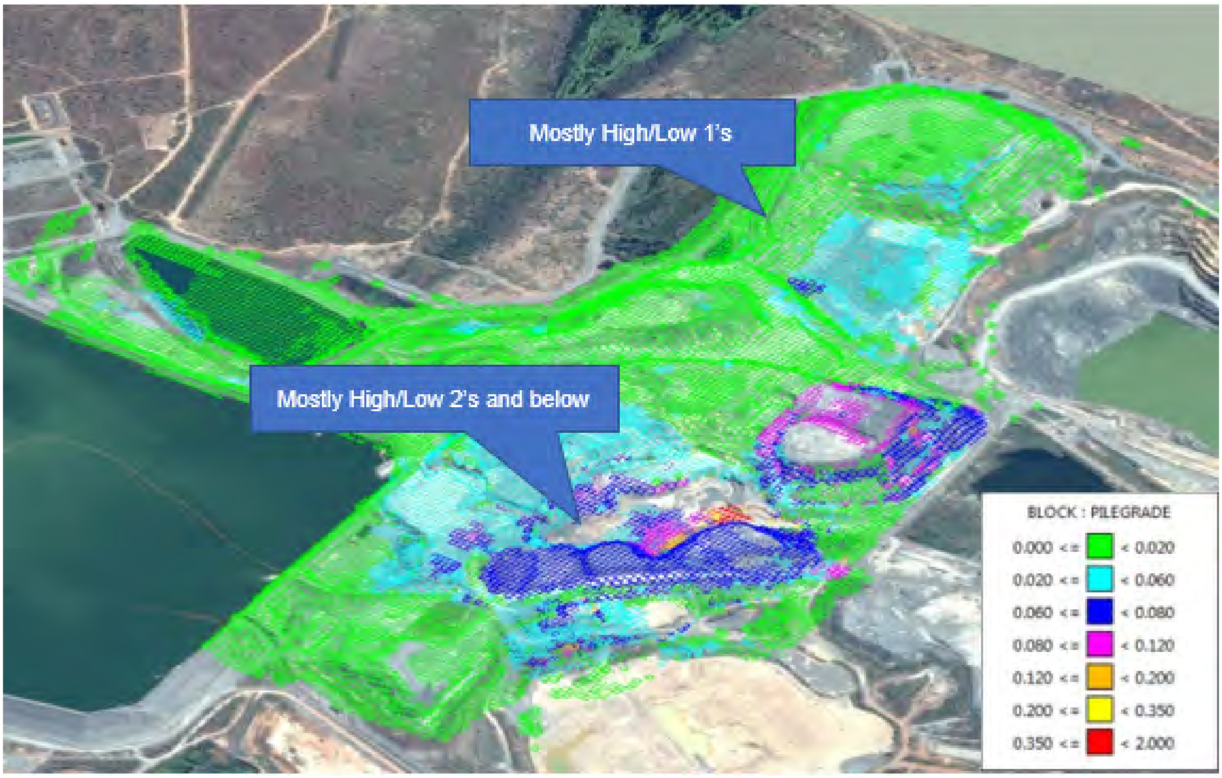


Figure 9-112: Stockpile material grades variance

9.3.5 Final landform / surface preparation

The Final Landform total area will be 795 ha, with the boundary shown in Figure 9-113.

During the closure feasibility study, the final landform topography was updated to create Digital Elevation Model (DEM) Version FLV6.2 which included progression of the following aspects:

- material balance for closure works defining the total material available;
- flood modelling for erosion;
- location of drain flow paths to prevent channels forming over pits;
- overall landform slope gradient to minimise sediment transport;
- slope contour ripping to minimise sediment transportation and improve water ingress;
- in-stream environmental rock bars to slow sediment transportation;
- in-stream sediment control structures to prevent as far as practical the loss of sediment from the disturbed area; and
- learnings from land evolution modelling conducted by the SSB.

The final landform design continues to mirror the original topography as much as possible. The proposed Final Landform topography (FLv 6.2) is shown in Figure 9-114 and Figure 9-115. In February 2022, the landform design optimisation was progressed to incorporate stakeholder comments and lessons learnt from Pit 1 final landform construction, as well as progressive erosion and sediment control management. The landform evolution model, CAESAR-Lisflood, was used to evaluate the effectiveness of each iterative new element introduced to the landform design version (*Section 5, KKN Supporting Studies*, Chapter 5.1.1.1). Final Landform Version 7 (FLv 7) will additionally incorporate into the design landform constructability, short-term and long-term sediment and erosion control if practical.

Figure 9-113: Final landform boundary

Figure 9-114: Final landform topography contours (FLv 6.2) overlain on the most recent aerial photo

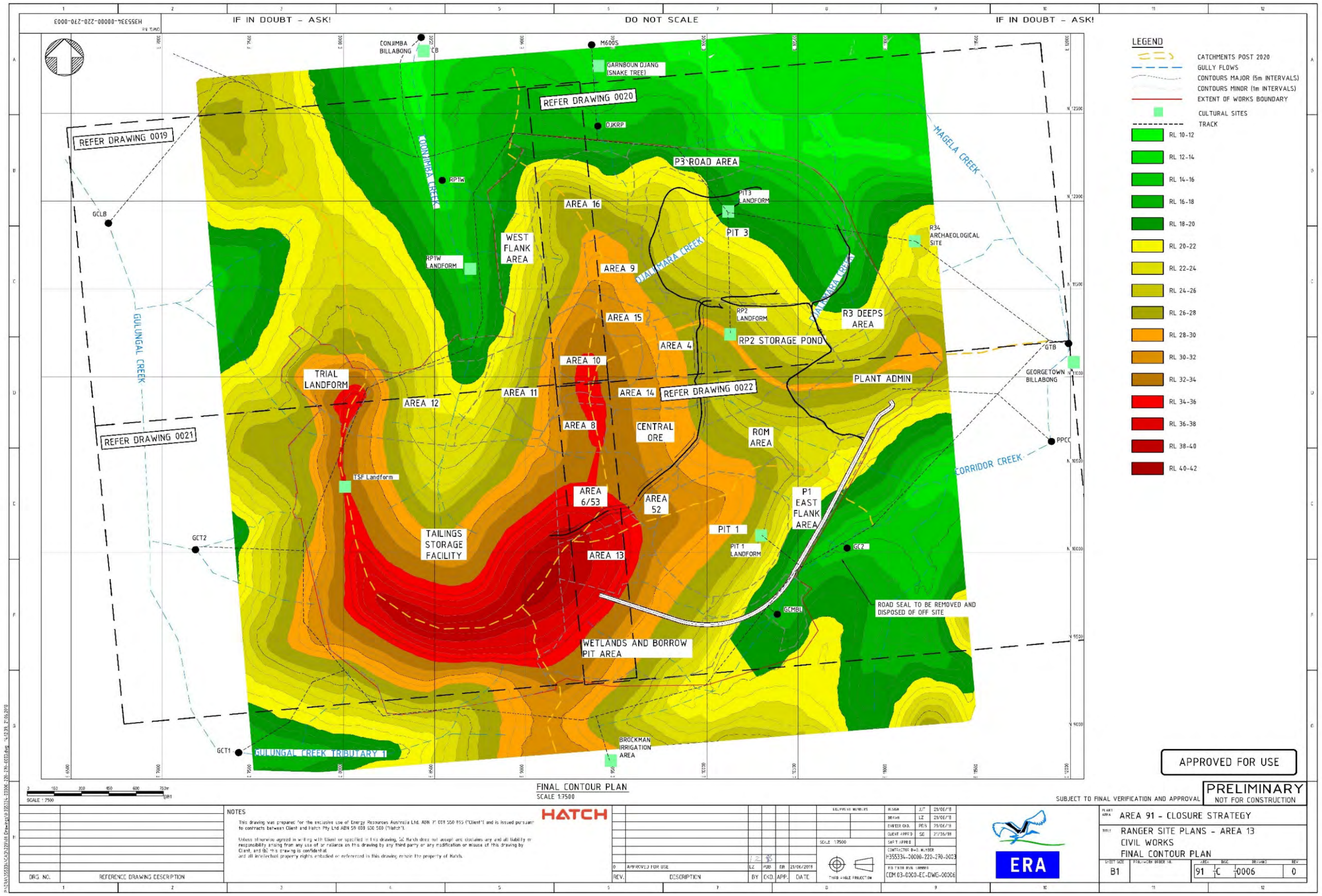


Figure 9-115 Final landform contours

9.3.5.1 Source of waste rock for surface layer

The surface layer of the final landform will be constructed from non-mineralised 1s waste rock to ensure that radiation doses are as low as reasonably achievable (ALARA). The results of an extensive drilling program in 2008 resulted in the development of a block model of the stockpiles and identified non-mineralised 1s material in several stockpile locations (Chapter 9.3.4). The block model has been used to identify potential sources of 1s waste rock for construction of the final landform. Commonly used mine planning systems inform the schedule of the material required for construction of the surface layer. The source and destination of waste rock material for final landform construction will be driven by waste rock type and timing of landform construction.

ERA will include in its routine operational records information on the general source and destination locations of surface layer material. Other activities during construction of the final landform will include surveying and mapping of the excavation and fill surfaces as part of mine rehabilitation. Checks of the Tritronics database and reconciliation against the predicted model grades will be completed as landform construction progresses. Any major portions of above grade fill materials detected will be excavated and redirected to the correct location.

9.3.5.2 Surface layer construction

To achieve the revegetation objectives, design and construction of the surface layer requires consideration of plant available water, depth and heterogeneity of the waste rock surface layer, material chemical characteristics, and surface treatments to optimise nutrient cycling.

There is a range of vegetation community types in areas outside the mine footprint that represent the spectrum of environments likely to be found across the rehabilitated Ranger Mine final landform and RPA. By understanding the environmental features that are associated with the normal range of native vegetation community types, the conditions required to support these communities and/or the community types that best suit particular environmental conditions of the Ranger Mine final landform can be identified (Humphrey *et al*. 2009). This information informs the final landform design and construction techniques, including the maximisation of the potential plant available water (PAW) stored in the final landform cover (*Section 5 KKN Supporting Studies*, KKN ESR7).

The design and construction methodology for the final landform has been based on the studies outlined in *Section 5 KKN Supporting Studies*. The methodology is based on outcomes of additional WAVES modelling and sensitivity analysis on PSD (particle size distribution) and surface layer thickness, as well as review of literature on the effects of dumping and construction methods on particle size distribution, consolidation of placed materials, and macropores and preferential flow.

The final landform surface layer over mined out pits is planned to be between 4 m and 6 m thick (depending on location) in order to provide sufficient PAW to sustain vegetation. As a conservative approach, a layer of at least 6 m will be provided wherever possible. The surface layer will be constructed in at least two lifts, similar to the TLF. Constructing the layer in two lifts will result in a consolidated layer between lifts, as observed in the TLF, which will be beneficial in cutting off preferential flow paths, thus improving steady water percolation and improving water-holding capacity.

The first layer will be constructed using end-tipping methods. This method results in heavy equipment traffic over the layer and the development of a consolidated layer. The second (and final) layer will be constructed using paddock dumping methods and dozed using GPS-guided dozers to create the final landform.

The final landform will be constructed to achieve the approved final landform model. The current Digital Elevation Model (DEM) is Version FLV6.2. ERA is currently undertaking landform evolution modelling to enable the final landform DEM to be optimised and achieve the closure criteria (refer *Section 5 KKN Supporting Studies*). Once completed the updated model will be provided to MTC stakeholders for review and approval.

Frequent surveying and GPS guidance will enable the approved design landform topography to be followed with a high degree of accuracy. Non-compliances will be discovered by survey during backfilling and can be rectified as operations continue or if any consolidation or compaction requires in-filling after construction. Tolerances on the final construction compared to design are driven by the size of equipment and rock material being handled, these are likely to be in the order of +/- 0.5 m at drainage boundaries and +/- 1 m elsewhere.

9.3.5.3 Erosion and sediment controls

In 2017 Water Solutions Pty Ltd undertook the *ERA Ranger Mine Final Landform Preliminary Flood Modelling and Hydraulic Design* associated with flooding, sediment and erosion control for the proposed Ranger Mine final landform profile. This was further developed as part of the Ranger Closure Feasibility study with drainage channel and sediment basin designs and locations finalised (Figure 9-122). The key changes to the final landform design (FLv 6.2) surface are:

- diversion of flow paths further from the Pit 1 region a previously raised concern;
- modelling which included sediment control structures demonstrated a reduction in velocities upstream; and
- comparison between ten per cent and one per cent annual exceedance probability (AEP) events to the (probable maximum precipitation) PMP highlight the low velocities expected through the main channels. Stream velocity rarely exceeds the recommended limit of 1.5 m/s for events up to the one per cent AEP event. Velocities would only approach the 2 m/s to 2.5 m/s in the unlikely event PMP occurs.

The changes to the final landform design surface were incorporated into the DEM Version FLv6.2. The changes included the diversion of all major drainages away from the pits and areas identified in the modelling predictions on the landform version FLV5_02 (Supervising Scientist, 2016).

Management of water and sediment are key issues during the construction phase of the final landform. ERA plans to construct temporary drainage structures and sumps with appropriate pumping infrastructure. These will be installed as required with details provided in the Ranger

Water Management Plan. Temporary structures will remain in place until the installation of the permanent erosion control measures.

Surface treatment

A variety of surface treatments have been identified by ERA to limit erosion and sediment discharge on the general surface of the landform. If erosion can be limited, then the amount of sediment that travels downstream can be reduced significantly. The treatments applied to the various areas of the final landform will depend upon various factors, including slope and location.

The two main surface treatments are revegetation and ripping/scarification. Revegetation is critical to reducing erosion from the site as plant roots bind the soil together, the canopy intercepts direct rainfall on the soil surface, and the leaf matter and woody debris falling from vegetation will, in the longer term, help to protect the surface.

The current areas of the final landform identified as requiring ripping or scarification are shown in Figure 9-116. These were the locations of higher flow identified in flood modelling undertaken during the Ranger Closure Feasibility Study. In addition to erosion controls, some shallow ripping and/or scarification of the landform surface is required to allow water to infiltrate and capture other resources locally for plants use and soil development, such as fine sediments, seeds, litter/organic matter and nutrients. However, advice received through stakeholder consultation with the Northern Land Council (NLC) and the Gundjeihmi Aboriginal Corporation (GAC) have indicated that ripping of the landform may impact traversability, and should be minimised wherever possible. To address these stakeholder concerns ERA conducted a small ripping trial on the Pit 1 landform (Figure 9-117). This, in conjunction with previous ripping and scarification completed at Ranger (Figure 9-118 and Figure 9-119) will be used to inform the final ripping and/or scarification plan included in the final landform application and future MCP updates.

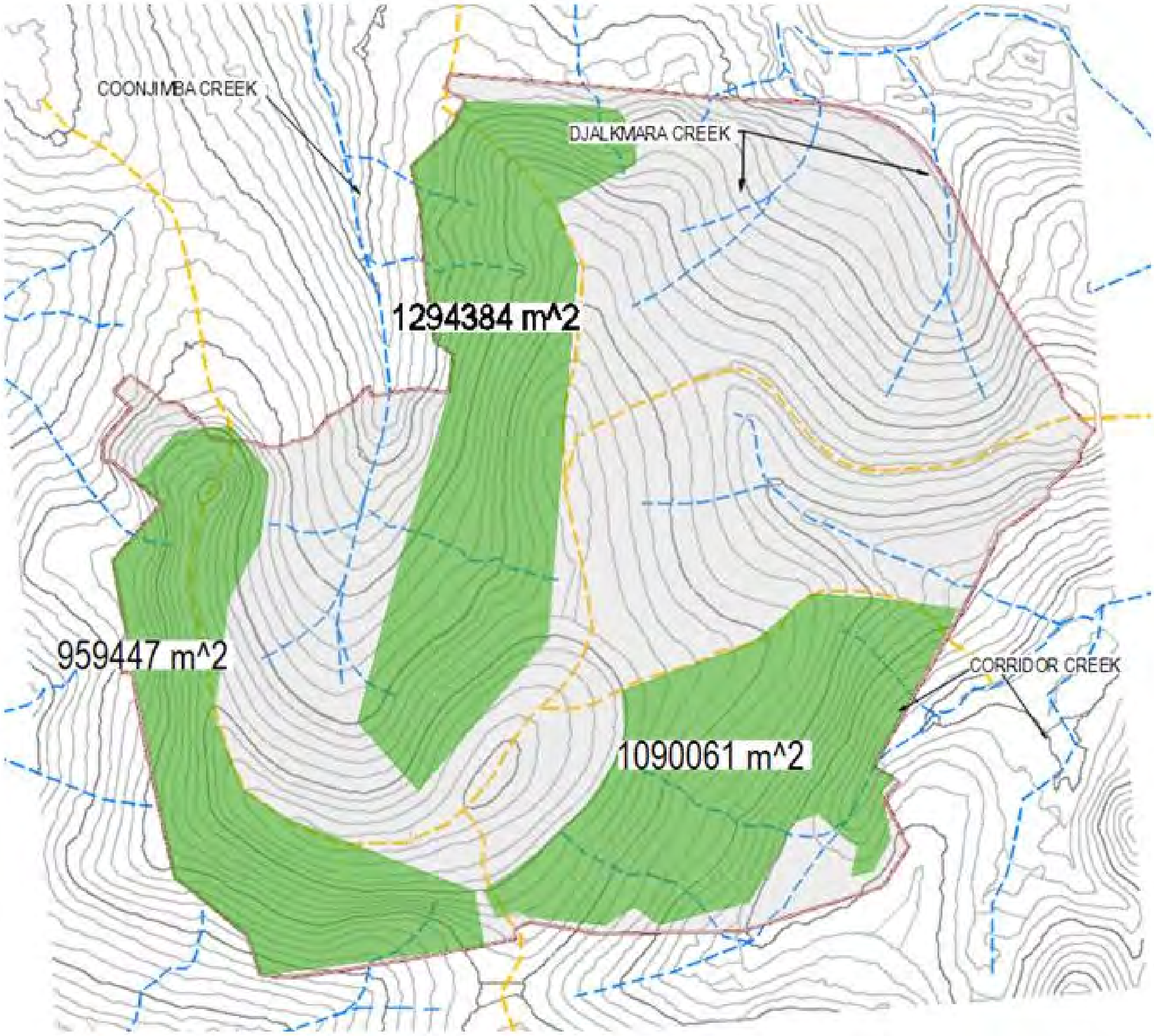


Figure 9-116: Footprint of final landform requiring contour ripping

2 tyne grader scarification

7 tyne grader scarification

Modified grader scarification blade

Figure 9-117 Small scarification trial on Pit 1 (2020)

Figure 9-118: Contour ripping on trial landform trial of 2m interval (2010)

Figure 9-119: Contour ripping on Stage 13, with 3 m intervals (March 2020)

Environmental rock bars

Where the streambeds exceed the maximum desired slope of two per cent or flood modelling has indicated that stream velocity exceeds 1.5 m/s, environmental rock bars will be installed to mitigate streambed erosion. The alignment of environmental rock bars ensures both edges are tied into the crest height level for proper functionality.

The following catchments will have environmental rock bars:

- Coonjimba Creek (CJ) (four rock bars);
- Djalkmarra Creek (DJ) (three rock bars); and
- Corridor Creek (CR) (two rock bars).

Additionally, environmental rock bars will be placed upstream as one of the main sediment control structures in the major flow paths near key areas such as Pit 1, Pit 3 and the RWD. Figure 9-122 shows the location of erosion control structures along with the storage data based on FLV 6.2. Figure 9-120 shows the typical section for the environmental rock bars. Table 9-23 provides design details for typical rock bars.

Table 9-23: Environmental rock bar design features

Environmental rock bar design features	
Height at centre	0.8 m
Crest width	0.8 m
Rip rap sizing	d_{50}=400 mm
Downstream slope	1V :4H
Upstream slope	1V :2H
Key trench depth	300 mm
Geotextile	A44 BIDIM or equivalent

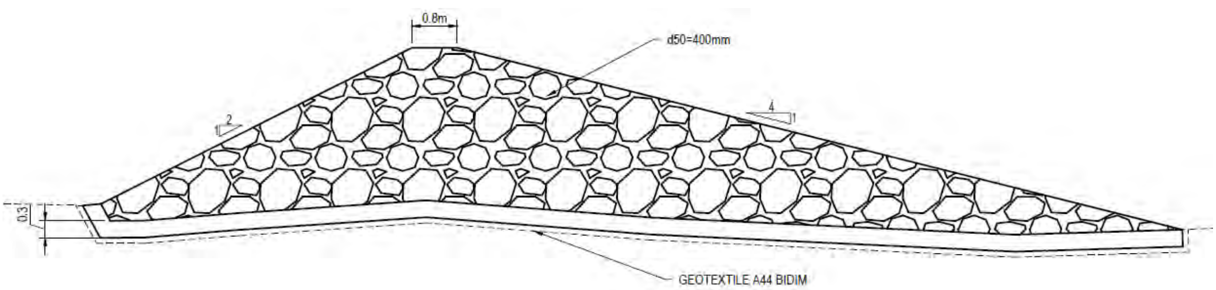


Figure 9-120: Environmental rock bars – section view

The general drawings of the environmental rock bars planned for installation on the final landform are provided in Appendix 9.1.

Sediment control structures

There are 18 boundary sediment control structures to be installed in streambeds to prevent sediment from leaving the current disturbed areas. Figure 9-122 shows the location of each along with the sizing and storage volume. The control structure consists of a leaky wall with a fine filter on the upstream side of the embankment. The structures are similar but larger than the environmental rock bars and include additional features. The design features and positioning of the structures are summarised in Table 9-24 shown in Figure 9-121. The designs in these figures are typical for these structures.

Table 9-24: Sediment control structure design features

Sediment Control Structure Design Features	
Height at centre	1.2 m
Crest width	1.2 m
Rip Rap sizing	d_{50}=400 mm
Downstream slope	1V :4H
Upstream slope	1V :2H
Key trench depth	300 mm
Upstream rock pad	Length=5 m, d_{50}=200 mm, thickness=400 mm
Downstream rock pad	Length=2.4 m, d_{50}=200 mm, thickness=400 mm
Filter layer	300 mm thick, 15-25 mm aggregate
Geotextile	A44 BIDIM or equivalent

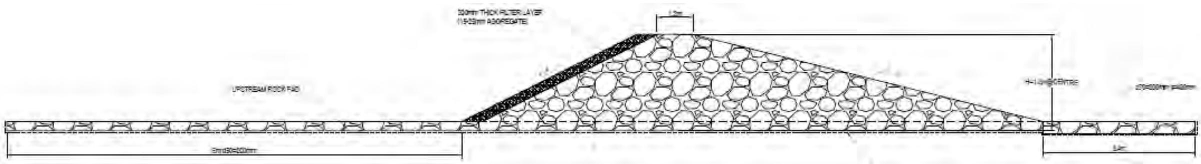


Figure 9-121: Boundary sediment control structure – section view

The height of the structures will vary based on the width / depth of drain. The locations and design of erosion and sediment control features on the final landform are provided in Appendix 9.1. The short-term sediment and erosion sediment control infrastructure have been identified as a requirement for interim landform shape as the landform progressively constructed to achieve Final Landform. Catchment Conversion Trial project design in Stage 52 was being finalised at the time of writing of the 2022 MCP. A series of infrastructure designs, once constructed, will be located to enable collection of water and sediment monitoring data. This will in turn inform the future sediment and erosion plan as part of the mine area rehabilitation and progressive construction of the Final Landform.

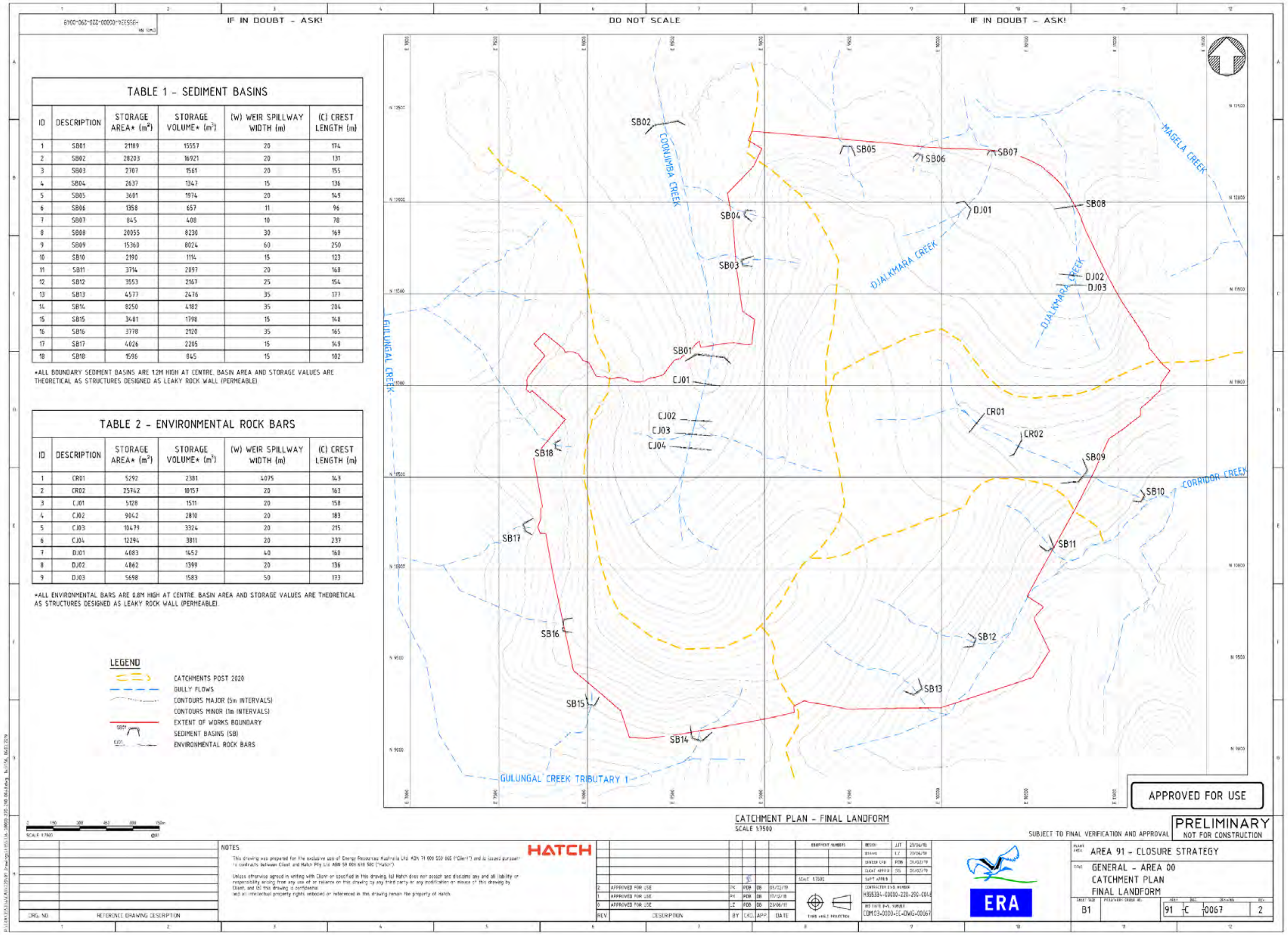


Figure 9-122: Catchment plan for final landform with sediment basins and environmental rock bars

9.3.5.4 Surface rock structures

Excess large rocks on the landform surface may pose increased safety risks for revegetation execution activities (personnel and equipment) and later access by Traditional Owners traversing the land. However, these rocks may be in high demand for construction of water management features and provide an opportunity to improve early revegetation ecological variability and habitat quality through increased surface heterogeneity.

Many large rocks (e.g. between approximately 500-1,500 mm diameter) exposed on the landform surface following construction shall be relocated for use in constructing water management features, such as rock lined drains or sediment traps.

There should be few rocks larger than this, but in areas where very large rocks occur, there is an opportunity to pile them together to form structures that will provide important habitat refugia to encourage early colonisation by fauna and specialist plant species. For example, some reptiles have been found to more-rapidly recolonise degraded landscapes where rock pile habitat is provided (e.g. Croak *et al.* 2013; Goldingay and Newell 2017; McDougall *et al.* 2016).

These structures have been installed on Pit 1 in consultation with the traditional owners (refer Chapter 9.3.1.3).

9.3.5.5 Access track installation

Revegetation Execution tracks

Revegetation execution tracks provide access for equipment and teams undertaking:

- irrigation installation and removal;
- tubestock planting; and
- irrigation operations and maintenance.

These tracks will be located across the area requiring revegetation to provide access to the trucks, excavator and vehicles required for revegetation execution activities. As revegetation execution concludes, some of these tracks can be removed (e.g. prepared and revegetated in the following wet season) to reduce the remaining track network to those required for ongoing monitoring and maintenance.

Monitoring and Maintenance tracks

Monitoring and maintenance tracks provide access for teams undertaking:

- water, vegetation and weed monitoring;
- weed control activities;
- minor revegetation maintenance works (e.g. infill planting, secondary introductions); and
- site perimeter access for fire and weed control.

These tracks need to be suitable for 4WD access and at a general frequency of at least every 100-200 m (loose grid formation) across the landform (this is based on the reach of a hose from a standard slip-on herbicide spray unit). The tracks will be required to remain for at least 2 years following planting, and can be removed (rehabilitated / revegetated) as the vegetation develops and weed risks reduce (e.g. across a 5-10 year period).

Long-term access tracks

Long term access tracks provide access for:

- long term monitoring and maintenance of the developing, rehabilitated site (water, vegetation, weeds);
- stakeholders to inspect the landform, undertake cultural criteria assessments; and
- Traditional Owners to access the area.

9.3.5.6 Schedule of progressive tasks

The final landform construction of Pit 1 commenced in Q2 2020 and was completed in September 2020. The remainder of the final landform construction will be ongoing to enable areas to be released progressively for revegetation.

9.3.5.7 Contingency planning

Following construction of the final landform the post closure monitoring and maintenance phase will commence. Adaptive management processes will be used to manage erosion and ensure long term revegetation success.

9.3.6 Revegetation implementation

Revegetation planning and implementation will be guided by the ERA Ecosystem Establishment Strategy that has been developed based on the learnings from over 30 years of revegetation trials and research and an understanding of the natural surrounding ecosystems.

Initial revegetation activities commence after site preparation is complete for an entire revegetation area. However, revegetation planning and preparation begins several years earlier; for example, with seed collection. The initial revegetation process broadly includes:

- planting design (planting density and distribution according to domain);
- seed collection and plant production;
- revegetation activities such as:
- site preparation (irrigation installation, herbicide application, , planting site cultivation), and
- tubestock planting (hole digging, fertiliser application, planting, watering in and/or irrigation).

Post-planting monitoring and maintenance activities including vegetation monitoring, infill planting and secondary species establishment, weed, fire and feral animal management are covered in *Section10 Closure Monitoring and Maintenance*.

Site revegetation plans will be prepared for each area to be revegetated. These plans will detail all revegetation activities, how these activities will be implemented and the schedule of implementation. Included will also be maps, field layout plans, monitoring and reporting requirements for each area. The plans will also include any on-ground activities required with respect to the identification of planting boundaries, planting configuration and location of species, monitoring plots and service tracks. This approach will ensure that lessons learnt from previous revegetation trials are incorporated in the future revegetation activities.

There is approximately 1,062 ha of land to rehabilitate for the successful closure of the Ranger Mine, including 795 ha of waste rock covered area. Unless specified in the respective domain descriptions in Chapter 9.2 previously, all areas shall receive the following standard revegetation implementation.

9.3.6.1 Reference ecosystem and species selection

As described in detail in *Section 5 KKN Supporting Studies*, KKN ESR1, natural community variability and potential constraints that may impact the type of ecosystem that is able to be re-established have been considered when developing a conceptual reference ecosystem (CRE) for Ranger (Table 9-25). Agreed CRE(s) will form the basis of the species list and target densities for revegetation planning and implementation. Whilst the CRE(s) are yet to be finalised, the intention is to revegetate the majority of the post-mining landform as *Eucalyptus tetrodonta / miniata* savanna woodland, which is one of the ecosystems in the surrounding areas near Ranger.

ERA have developed a Species Establishment Research Program (SERP) database of 165 flora species (mostly terrestrial), including 21 overstorey tree species, 74 midstorey tree and shrub species, and 70 understorey species (or genus). The selection of these species is based on previous stakeholder-agreed lists, historic and recent reference site surveys, and consultation with CDU researchers, Bininj ecology experts, and Traditional Owners. The species included in the database will continue to be refined as outcomes from ongoing CRE work, revegetation trials, risk assessments and further stakeholder consultations are completed. Currently, approximately 110 of the SERP species have been identified for initial revegetation.

The majority of stems (approximately 70%) used for revegetating the Eucalyptus savanna woodland domain on the FLF will consist of a handful of species, including dominate Eucalyptus and Corymbia trees, Acacias, and common fruiting shrubs. The remaining stems will be a range of tree, shrub and groundcover plants that, although in smaller densities, contribute significantly to the ecosystem's species richness, provide food and shelter for fauna, and/or are important species for Traditional Owners.

For further details on the research behind species selection and the ecosystem establishment strategy, see *Section 5 KKN Supporting Studies* in KKN ESR1 and ESR3.

Table 9-25: Information available for the major physical and/or chemical substrate constraints for ecosystem establishment.

Potential Constraint	Planning Information Source
Material type and relationships to plant water availability, rooting depth and so on	• The final landform design indicates where waste rock will generally be located and the depth of waste rock over natural soils. • Stockpile inspections, observations during construction and upon final handover inspection shall identify localised areas of particularly low or high fines. • LAAs and other areas of disturbance have been mapped as separate closure domains
Surface hydrology and subsurface hydrogeology, including seasonal variations.	• The post closure Ranger groundwater modelling (INTERA 2019) will indicate locations where groundwater exfiltration is likely to occur identifying where increased seasonal water logging may be expected
Substrate chemical status, including nutrients and contaminants of potential concern.	• Contaminated land assessments • Groundwater quality monitoring and modelling

9.3.6.2 Seed collection and tubestock propagation

ERA has been working extensively with Kakadu Native Plants Pty Ltd (KNPS), a locally owned and run indigenous supplier, to collect seed and provide seedlings for progressive revegetation that has occurred both at Ranger Mine and Jabiluka over the past 17 years. This supplier has extensive expertise in local plants including seed biology, propagation, revegetation and weed and fire management.

Seed Collection

ERA and KNPS have developed a collaborative process of planning and implementing the seed collection program that is visually presented in the flowchart provided as Figure 9-123.

Area-specific revegetation plans based on the rehabilitation schedule and the most current CRE(s), including required species stems per hectare, determine the tubestock and seed plan. The seed collection plan is underpinned by a wealth of knowledge, research and data, including a comprehensive understanding of native species phenology, seed processing and storage requirements, seed viability and germination testing, and previous nursery experience. These aspects of the SERP are discussed in more detail in *Section 5 KKN Supporting Studies* in KKN ESR3.

With consideration of the rehabilitation schedule and the storage specifics of the different species, ERA issues a monthly ‘order’ to KNPS to proceed with seed collection. This monthly frequency enables routine update and review of the status of the stock on hand against plan, modification of the collection plan to respond to any low collections, and to take advantage of any opportunities (such as a group of plants flowering / seeding earlier than usual due to localised seasonal variations).

KNPS undertake ongoing field reconnaissance (including during other 'on country' activities such as weed and fire management) to continuously build on their knowledge of what looks likely to flower and fruit and when. Following collection, KNPS air-dry and process the seed based on a species-specific approach to optimise viability and longevity (when stored). ERA is accountable for final storage of the delivered seed and maintains the seed management database with all relevant information for each seed lot.

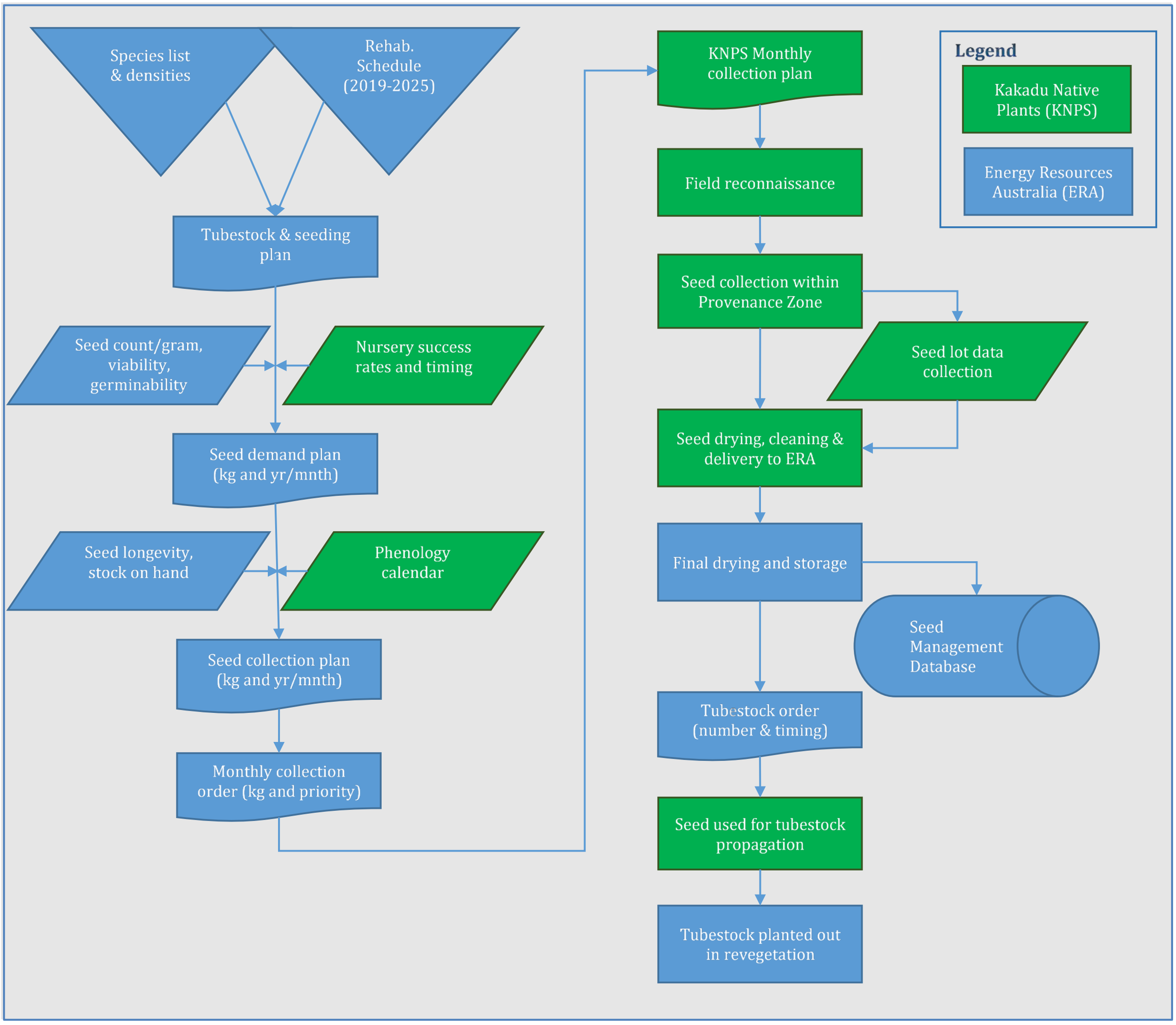


Figure 9-123: Flow chart of seed collection program

The closure revegetation program is highly influenced by the timing of the rehabilitation schedule, especially the bulk material movement and final landform handover process. Whilst some tubestock (and therefore seed) is required for research trials and small progressive revegetation areas, the majority of planting will occur late in the rehabilitation schedule. Fortunately, the majority of species seed needed for revegetation have sufficient longevity to be collected early and stored until required. Collection of these species has already commenced and is progressing well to be fully stocked before the peak tubestock propagation and planting period commences. A small portion of the species have seed with limited storage life, which either require propagating immediately after collection (termed 'perishable') or within one year of collection (termed 'fresh'). For these species, collections must be timed to optimise seed availability and time from planting.

Regardless of carefully thought-out seed collection plans, there remains a risk that seed availability is impacted by uncontrollable factors such as repeated 'failed' wet seasons, high levels of herbivorous predation (e.g. cockatoos), or high fire frequencies or intensities within the provenance collection zone, all of which can reduce the seed of many species. For these species, ongoing reconnaissance will ensure that collection tactics are primed for the instance when they are available and required, to make sure that targets can be achieved, and quality is maintained. ERA also take a conservative, proactive approach when collecting seed of important, dominant species required for revegetation. For example, if a species is known to have highly variable seed production or is sensitive to fire, herbivory etc. and the seed has a long storage life, that species may be 'over collected' when good quality and quantities of seed are available to minimise risk from poor collection years.

Tubestock propagation

Tubestock is propagated in the recently commissioned ERA Nursery, refer Chapter 9.2.10.3. Current annual capacity is 250,000 seedlings which is more than sufficient for the majority of revegetation requirements. For any peak demand it may be necessary to temporarily expand the facility and/or engage additional, approved suppliers; options for this are being explored (Chapter 9.3.6.7).

Tubestock is propagated to meet an agreed specification to ensure that seedlings have the best chance of survival after planting out. The ERA tubestock specification is based on best practice (NGIA 2018; Standards Australia 2018), field trials, observations and local knowledge and includes criteria relating to plant form, health, size, and rooting characteristics (Table **9-26**).

Propagation of tubestock for any given area of revegetation commences approximately 2-6 months before the target planting out date, depending on the expected growth rate of the species and the growing season (e.g. some species germinate and grow slower in the cooler dry season months). If any particular species does not have seed available exactly on time for propagation (e.g. species with perishable seed or due to seasonal impacts to seed collection), they can always be introduced later on during the infill planting program or through alternative methods (Chapter 9.4.6.8). It is highly unlikely that these will ever be the dominant Eucalyptus, Corymbia or Acacia species as these generally have long seed storage times and collection can start early and cover a number of years.

Table 9-26 Seeding specifications for nursery tubestock

Title	Specification for Ranger Mine Revegetation
Pot condition	Seedling supplied in specified pot, without significant damage, holding shape when handled and with appropriate growing media within 5 mm of pot lip.
Size and Age	Seedling is appropriate size and age as verified by reference material and/or ERA supervisor, i.e. with multiple sets of leaves and without major signs of root bounding.

Title	Specification for Ranger Mine Revegetation
General Health	Leaf colour and size is true to species form, without signs of active pests, disease, dieback or injury.
Seedling structure	Seedlings should be growing in accordance with natural habit (i.e. free standing where applicable without staking or tip pruning).
Stem position	The seedling stem base should be at least 10 mm from the edge of the pot.
Arrange ment	Prior to planting, seedlings must be arranged into planting trays of up to 18 pots as specified by the area-specific planting plan.

9.3.6.3 Irrigation installation and operation

On the waste rock final landform, newly planted seedlings will be irrigated to ensure good plant survival rates across all species during the dry season, and during wet seasons which can have erratic rainfall. Irrigation infrastructure will be installed after final land forming is complete and prior to pre-emergent herbicide application and tubestock planting. Irrigation will generally be applied for a maximum of six months, depending on the season of planting and prevailing weather conditions.

Tubestock will be irrigated frequently throughout planting and during the days immediately following planting to maintain moisture levels in the upper substrate profile and minimise transplant shock. After this initial period, irrigation will gradually be reduced to nightly soaks over the course of a few weeks and less frequent, heavier soaks over several months. This is important for root development, encouraging resilience during a typical dry season and for withstanding strong winds. Seedling condition will be monitored as irrigation is adjusted to ensure the hardening off is not too sudden or extreme. In the last few months of irrigation once seedlings have properly settled (e.g. Post-planting mortality rate has stabilised, plants are showing signs of growth etc.), the irrigation will be significantly reduced so that the soil profile is saturated but allowed to dry before further irrigation. Specific irrigation amounts applied to each area will depend on the season of planting, substrate type, temperatures, wind, evaporation, infiltration and rainfall.

The current proposed irrigation design will utilise a combination of rotational solid-state sprinklers and travelling large-scale pivot systems, connected by polypipe networks to generator-powered pumps at the two water sources (RP1 and GCMBL). If required, additional bore field water sources can also be utilised. Wherever possible, irrigation equipment will be relocated and reused following each six month irrigation period.

Monitoring and maintenance of the irrigation system during operation is critical. Issues that have arisen previously, or may arise in the future, include animal interference and/or mechanical damage to piping, sediment clogging up filters and smaller-aperture fittings, pump failures, inadequate water being delivered to plants and more. Any damage or malfunctioning of the irrigation equipment must be recognised within 48 hours of occurring to minimise impact upon vegetation. The use of pressure-based alarms and a log recording the operation of each panel will ensure that any incidents are recognised and rectified. A stock of critical spares will be maintained so that most maintenance activities can be undertaken without delay.

9.3.6.4 Preventative weed control

Substrates used to create the final landform shall be carefully managed during construction to prevent site contamination with weeds or their seeds. Furthermore, a weed control buffer zone (approximately 200 m wide) around the revegetation sites will be established to assist in preventing weed incursion into revegetation areas.

The revegetation areas will receive a blanket spray of Cavalier 500 (1.9 L/ha) and Sulfomac 750 (300g/ha) herbicide four weeks prior to planting to ensure no weeds are present that may threaten young establishing seedlings.

9.3.6.5 Mechanical planting site cultivation

Initial planting of tubestock will be at a density of between 800-1,200 stems per hectare (averaging approximately 1,000 st/ha) which requires spacing of between 2.5 - 3.5 metres. To achieve a ‘natural’ planting effect planting sites shall be positioned non-uniformly across the prepared surface. Planting sites shall be cultivated by an excavator auger attachment (Figure 9-124) or similar mechanical device. This will ensure there are no large rocks directly in the planting location and loosen the substrate in preparation for manual planting that follows soon after hole digging (Figure 9-125).

Figure 9-124: Example of a specially modified auger cultivator attached to a small excavator, here seen being trialled in waste rock on the Trial Landform in March 2020.

Figure 9-125: A mechanically cultivated planting site.

9.3.6.6 Tubestock planting

Once the preceding steps are completed, the required tubestock in the nursery shall be prepared for planting out. Tubestock of the different species shall be arranged into each tray to reflect the planned species distribution in the field and any plants targeted for ongoing monitoring will be tagged. The revegetation area will be irrigated prior to planting to moisten the substrate and reduce plant stress. The key steps of the planting procedure are:

- Planting locations should already be in place, being the mechanically cultivated site holes.
- Where sites have not been cultivated (or the cultivated hole has collapsed), check the revegetation plan for location and use a forestry shovel (or similar) to prepare a planting hole approximately 400 mm deep and 150 mm wide (Figure 9-126, Step 1).
- Add one slow release fertiliser tablet (e.g. Agriform® or Typhoon®) and, if planting without irrigation (e.g. at the LAAs), a small handful of pre-soaked Earthcare® or Aquasorb 3005 KL® water crystals to the base of each planting hole. Cover the tablet with a small amount of soil to avoid root burn (Figure 9-126, Step 2).
- Place tubestock into the planting hole. Plants in biodegradable pots can be placed directly into the hole, with the biopot lightly crushed immediately before being placed to increase rate of pot material breakdown. Plants in plastic pots shall be removed from the pot and carefully placed into the hole to minimise loss of any loose potting mix that is not held together by the plant roots. The holes will then be backfilled with the surrounding loosened substrate, focusing on fines and removing large rocks. The surface of the potting mix should be just below the final surface leaving a very slight depression which will assist with collecting water for the plant. The rims of biodegradable pots should be buried below the surface to improve thermal insulation of the root ball and prevent moisture wicking. Taking care not to damage the root system, the soil should be pressed firmly into place to ensure there are no air pockets (Figure 9-126, Step 3).
- Newly planted tubestock shall be watered in, either by the irrigation system or low pressure hoses.
- For individual plants requiring monitoring, a stake or tag shall be placed into the ground at least 10 cm from the base.

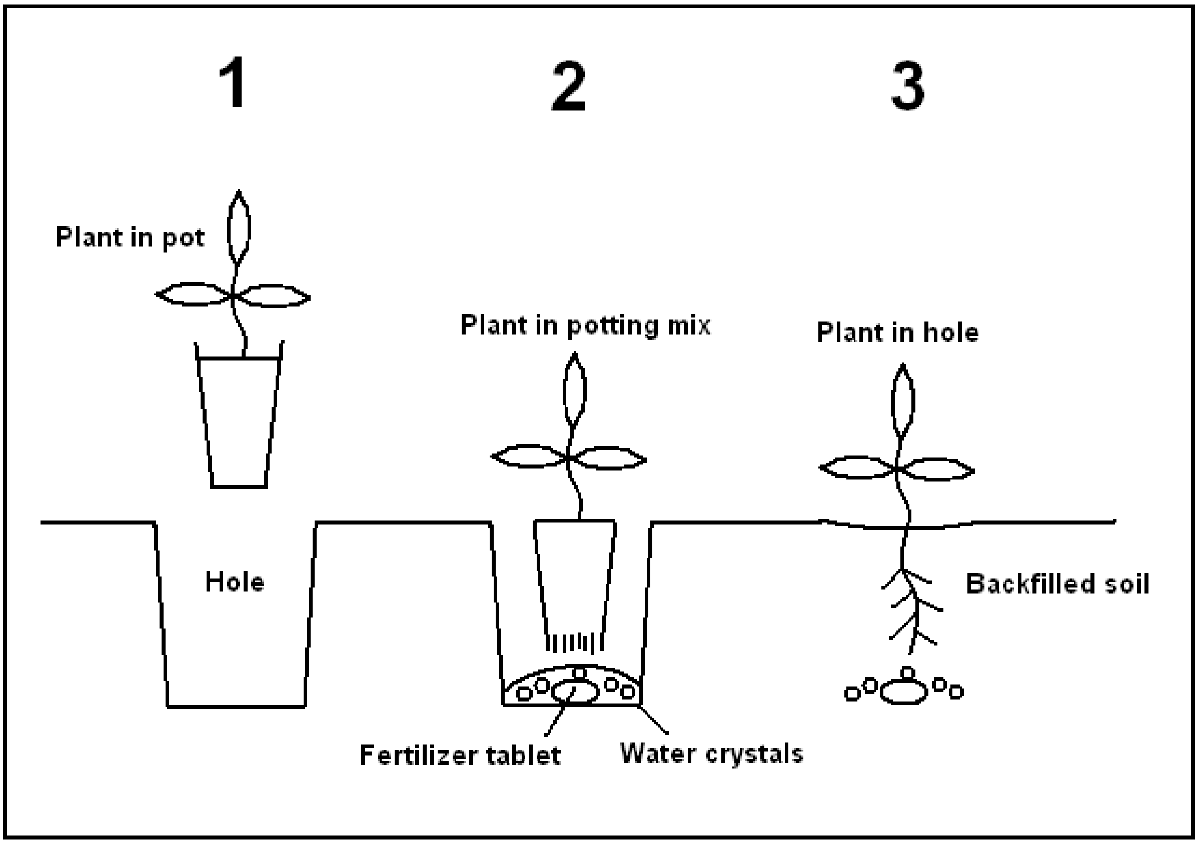


Figure 9-126: Tubestock planting out steps

9.3.6.7 Contingency plans

Tubestock production

The Ranger Mine nursery has been commissioned with a current annual capacity of 250,000 plants. ERA has begun planning for an expansion of the nursery facility to boost annual capacity to approximately 400,000 plants.

A contingency option to mitigate potential issues associated with tubestock production, should the need arise, is to establish an additional arrangement with a suitably qualified service provider to grow tubestock from seeds provided by ERA. Under this option, the provider would be required to supply tubestock in accordance with the intended nursery and seedling specifications (e.g. soilless substrate, seedling quality etc.). ‘Offsite’ nursery trials are currently underway to investigate this potential contingency option.

Seed collection and propagation

More than 150kg of clean seed and 50,000 fresh fruit of the target species is required to raise the 760,000 plus seedlings for the initial planting of the Ranger final landform. A permit to collect seed within Kakadu NP has been obtained for more than 500 kg of seed and 60,000 fresh fruit to allow for variable seed quality and also any final adjustments of the target species lists and/or densities.

It is highly unlikely that the required quantities of seed could be obtained for all species in any one collection campaign due to a number of factors, including:

- seasonal variation in seed set and availability due to environmental conditions such as rainfall, predation and/or bushfires;
- logistical constraints associated with finding sufficient plants within the approved collection area with mature fruits/seeds before seeds are naturally dispersed; and
- timing requirements for matching tubestock propagation and planting with rehabilitation earthworks schedule.

Thus, the seed collection program is a multi-year exercise with many ‘moving parts’ that requires a structured yet agile management approach. Despite the proactive collection strategies ERA implements, some species may not have adequate seed available exactly when needed, particularly perishable seeded species during year-round propagation. These species (especially those of particular cultural importance) are candidates for alternative propagation or revegetation introduction strategies, such as:

- careful use of limited seed to establish ‘source’ populations in the revegetation to provide for ongoing self-colonisation of the ecosystem as it develops;
- use of older, larger plants that were propagated when seed was fresh and have been stored in the nursery for longer than usual periods (transferred into larger pots when necessary to maintain optimal seedling health) until required for planting;
- propagation of tubestock from vegetative material (rather than seeds); and
- introductions as part of the secondary introduction program, whenever seed becomes available, and/or conditions are more favourable such that plants from any seed obtained will be more likely to survive and establish.

These, and other methods, are being investigated by ERA and KNPS as part of the continued refinement of the revegetation program, and are discussed further in *Section 5 KKN Supporting Studies.*

REFERENCES

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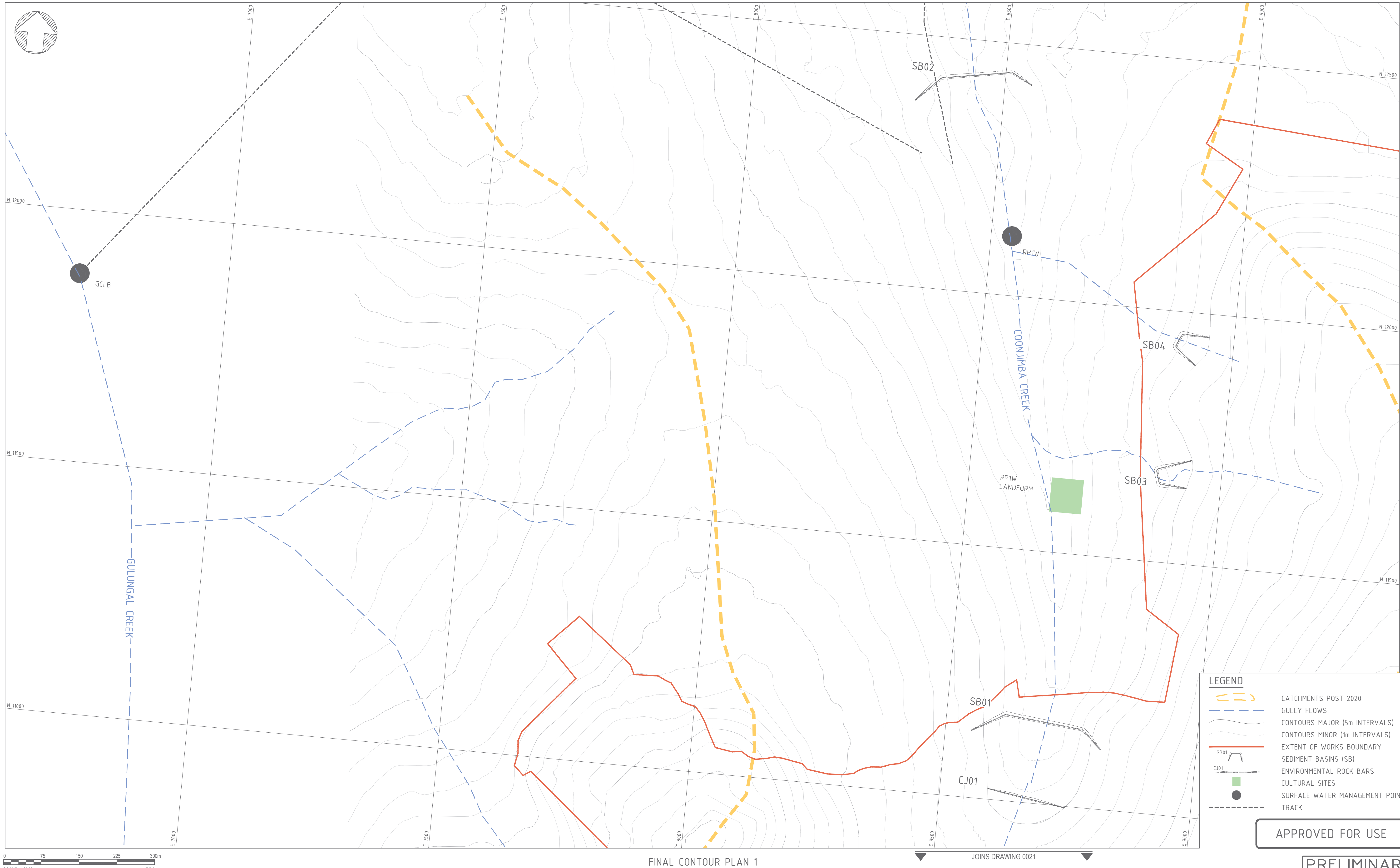
APPENDIX 9.1: FINAL LANDFORM DRAWINGS



APPROVED FOR USE

FINAL CONTOUR PLAN 1

SCALE 1:3000

SUBJECT TO FINAL VERIFICATION AND APPROVAL

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DRG. NO.	REFERENCE DRAWING DESCRIPTION

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1	APPROVED FOR USE	PK	PDB	DB	17/12/18
0	APPROVED FOR USE	LZ	PDB	DB	21/06/18

EQUIPMENT NUMBERS

SCALE 1:3000

THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER
H355334-00000-220-272-0001

RIO TINTO DWG. NUMBER
CDM.03-0000-EC-DWG-00019

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: RANGER SITE PLANS – AREA 13
CIVIL WORKS
FINAL CONTOUR PLAN 1

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC.	DRAWING	REV
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H355334-00000-220-272-0002
DWG No.

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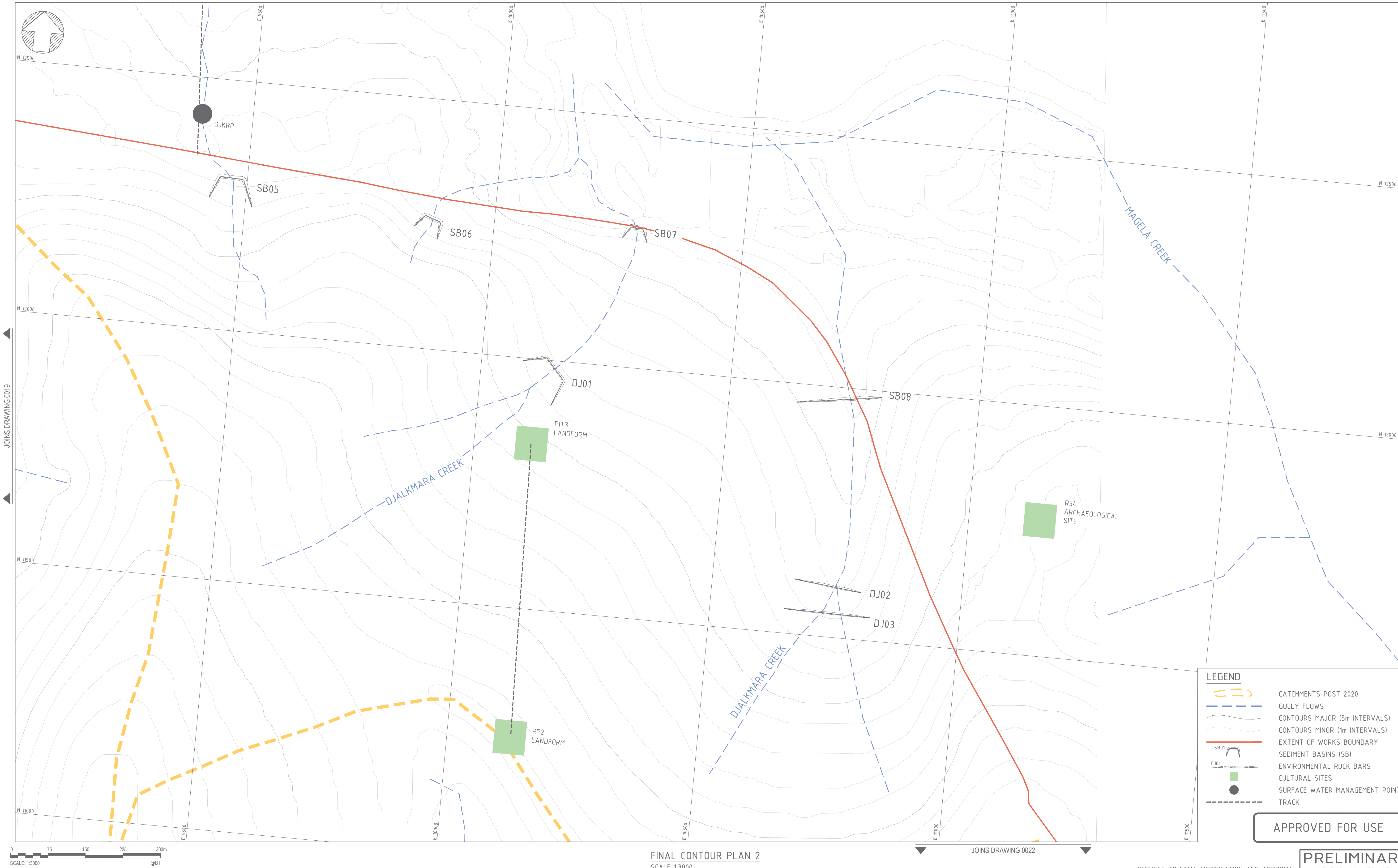

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FINAL CONTOUR PLAN 2

SCALE 1:3000

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REV.	DESCRIPTION	BY	CKD.	APP.	DATE
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1	APPROVED FOR USE	PK	PDB	DB	17/12/18
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EQUIPMENT NUMBERS

SCALE 1:3000

THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER
H355334-00000-220-272-0002

RIO TINTO DWG. NUMBER
CDM.03-0000-EC-DWG-00020

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: RANGER SITE PLANS – AREA 13
CIVIL WORKS
FINAL CONTOUR PLAN 2

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC.	DRAWING	REV
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IF IN DOUBT – ASK!

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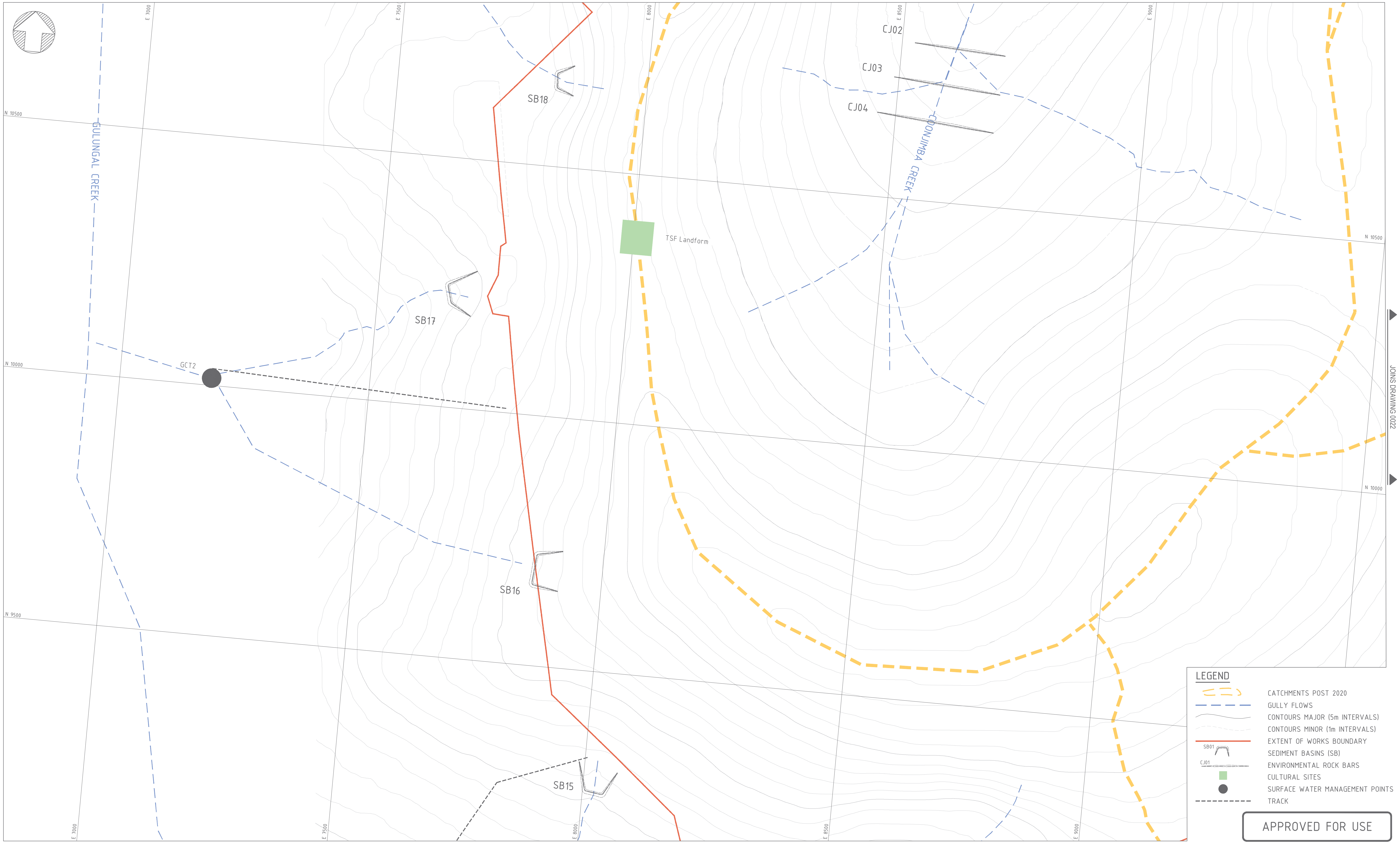

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APPROVED FOR USE

FINAL CONTOUR PLAN 3

SCALE 1:3000

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1	APPROVED FOR USE	PK	PDB	DB	17/12/18
0	APPROVED FOR USE	LZ	PDB	DB	21/06/18

EQUIPMENT NUMBERS

SCALE 1:3000

THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER
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RIO TINTO DWG. NUMBER
CDM.03-0000-EC-DWG-00021

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: RANGER SITE PLANS – AREA 13
CIVIL WORKS
FINAL CONTOUR PLAN 3

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC.	DRAWING	REV
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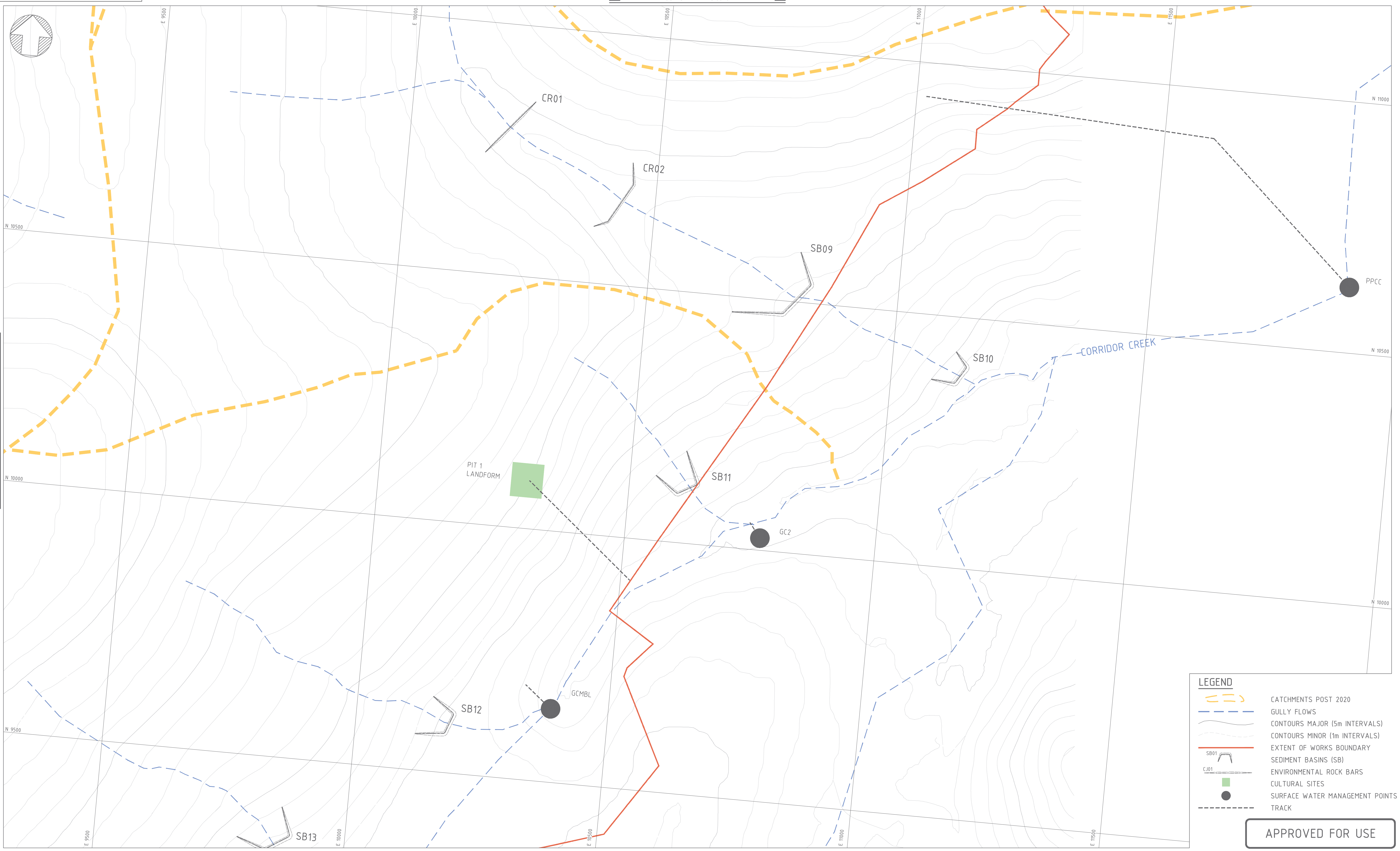

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SCALE: 1:3000 @B1

FINAL CONTOUR PLAN 4
SCALE 1:3000

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PRELIMINARY
NOT FOR CONSTRUCTION

DRG. NO.	REFERENCE DRAWING DESCRIPTION

NOTES

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EQUIPMENT NUMBERS

SCALE 1:3000

THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER
H355334-00000-220-272-0004

RIO TINTO DWG. NUMBER
CDM.03-0000-EC-DWG-00022

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: RANGER SITE PLANS – AREA 13
CIVIL WORKS
FINAL CONTOUR PLAN 4

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC	DRAWING	REV
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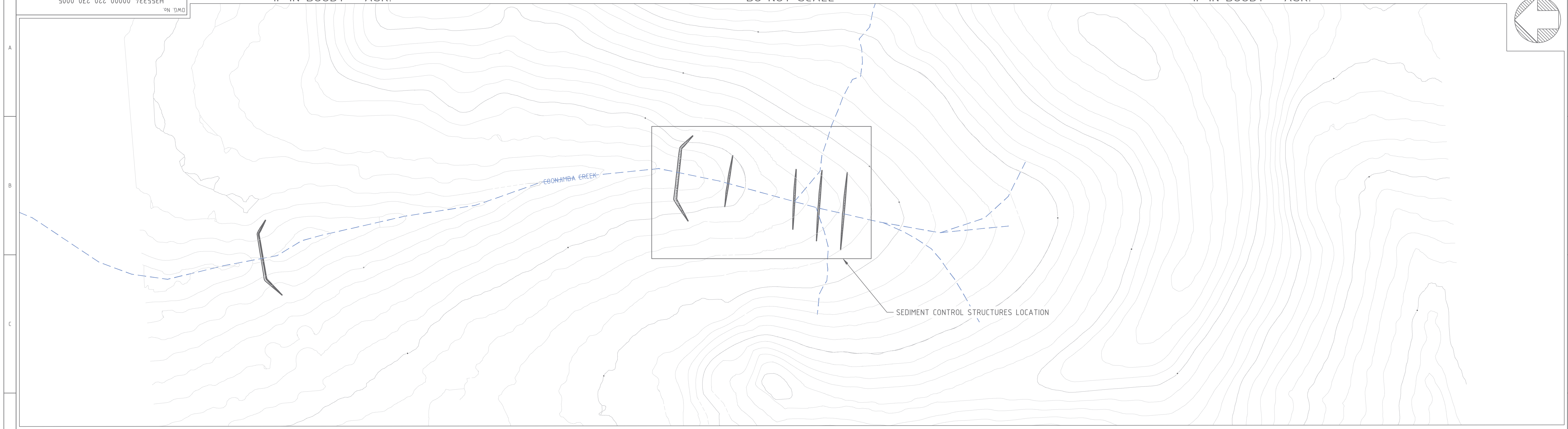
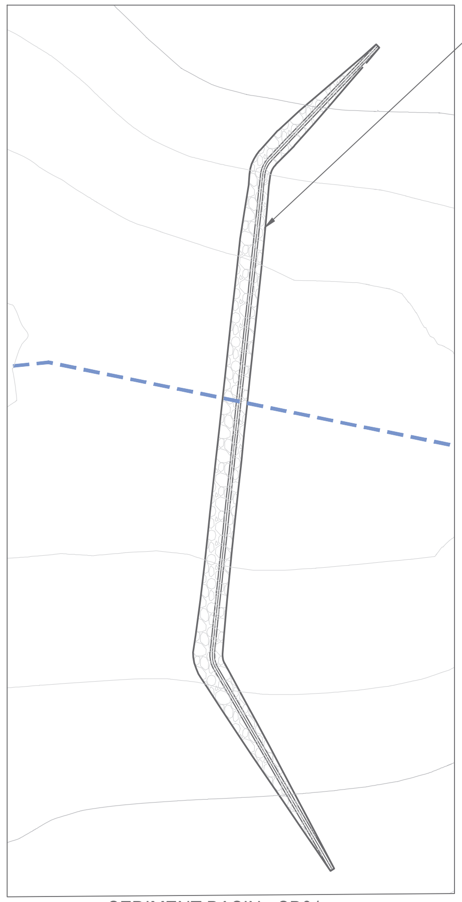
DWG No. H355334-00000-220-270-0005



KEY PLAN - SEDIMENT CONTROL STRUCTURES
SCALE 1:5000

FOR TYPICAL SECTIONS FOR SEDIMENT BASIN AND ENVIRONMENTAL ROCK BARS REFER DRAWING 91-C-0071.

NOTES:
1. ALL WORKS REQUIRE 300mm STRIPPING AND FOUNDATION PREPARATION.
2. DESIGN SURFACES BASED ON PROVIDED SURVEY. LEVELS SHOULD BE CONFIRMED ON SITE.



SEDIMENT BASIN - SB01
SCALE 1:1000

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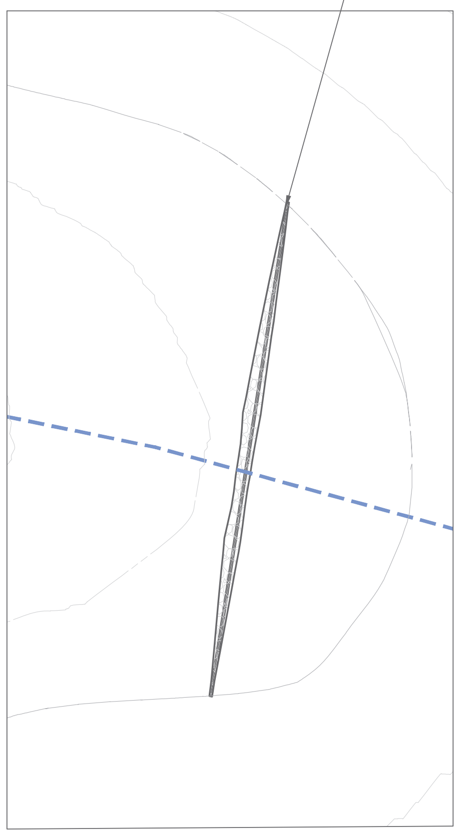
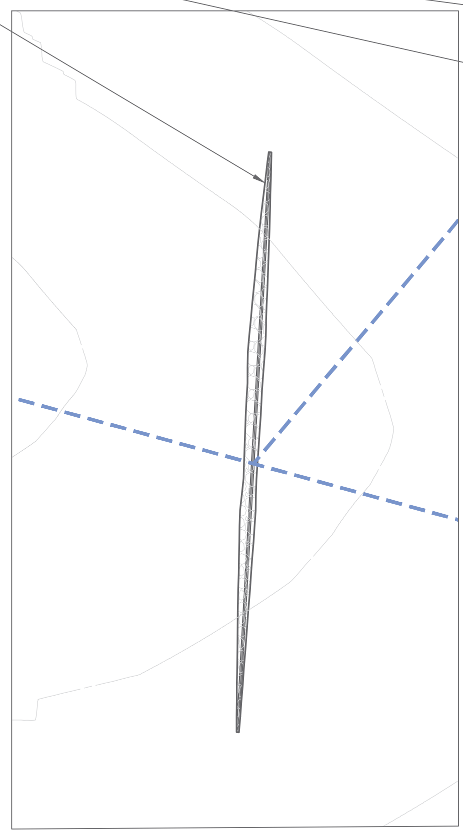
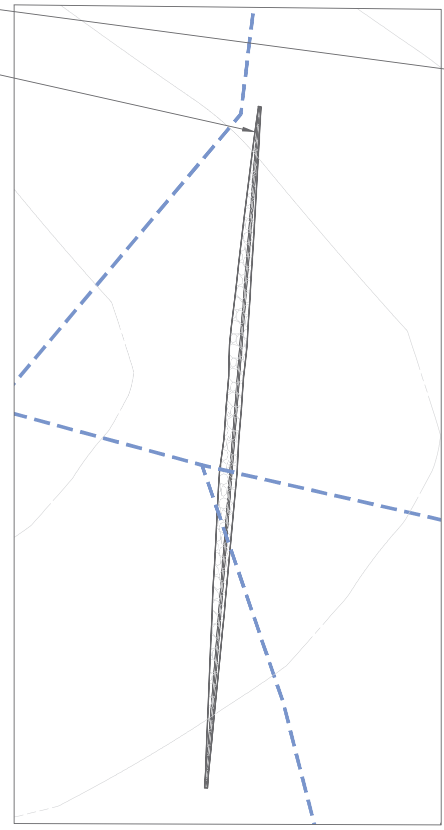
SCALE: 1:20　@B1



ENVIROMENTAL ROCK BAR CJ01
SCALE 1:1000



ENVIROMENTAL ROCK BAR CJ02
SCALE 1:1000



ENVIROMENTAL ROCK BAR CJ03
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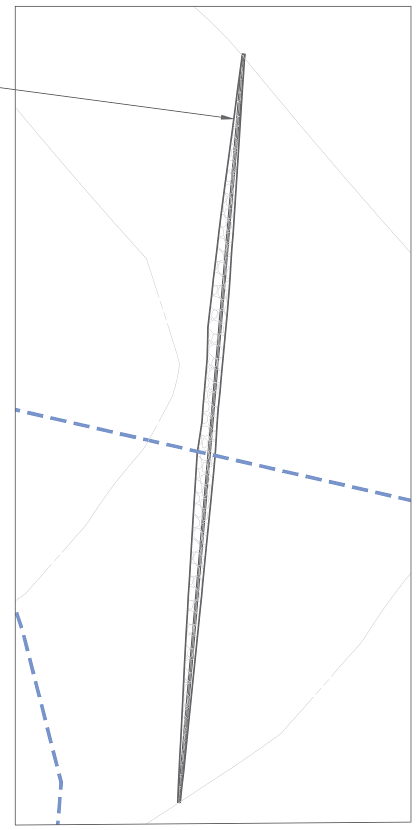

ENVIROMENTAL ROCK BAR CJ04
SCALE 1:1000

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REV.	DESCRIPTION	BY	CKD.	APP.	DATE
1	APPROVED FOR USE	PK	PDB	DB	06/02/19
0	APPROVED FOR USE	LZ	PDB	DB	21/06/18

EQUIPMENT NUMBERS

SCALE AS NOTED

THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D		
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER: H355334-00000-220-270-0005

RIO TINTO DWG. NUMBER: CDM.03-0000-EC-DWG-00053

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: GENERAL ARRAGEMENT
CIVIL WORK
ENVIRONMENTAL ROCK BARS

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC.	DRAWING	REV
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H355334-00000-220-290-0048
DWG No.

IF IN DOUBT – ASK! DO NOT SCALE IF IN DOUBT – ASK!

TABLE 1 – SEDIMENT BASINS

ID	DESCRIPTION	STORAGE AREA* (m^2)	STORAGE VOLUME* (m^3)	(W) WEIR SPILLWAY WIDTH (m)	(C) CREST LENGTH (m)
1	SB01	21189	15557	20	174
2	SB02	28203	16921	20	131
3	SB03	2707	1561	20	155
4	SB04	2637	1347	15	136
5	SB05	3601	1974	20	149
6	SB06	1358	657	11	96
7	SB07	845	408	10	78
8	SB08	20055	8230	30	169
9	SB09	15360	8024	60	250
10	SB10	2190	1114	15	123
11	SB11	3714	2097	20	168
12	SB12	3553	2167	25	154
13	SB13	4577	2476	35	177
14	SB14	8250	4182	35	204
15	SB15	3481	1798	15	148
16	SB16	3778	2120	35	165
17	SB17	4026	2205	15	149
18	SB18	1596	845	15	102

*ALL BOUNDARY SEDIMENT BASINS ARE 1.2M HIGH AT CENTRE. BASIN AREA AND STORAGE VALUES ARE THEORETICAL AS STRUCTURES DESIGNED AS LEAKY ROCK WALL (PERMEABLE).

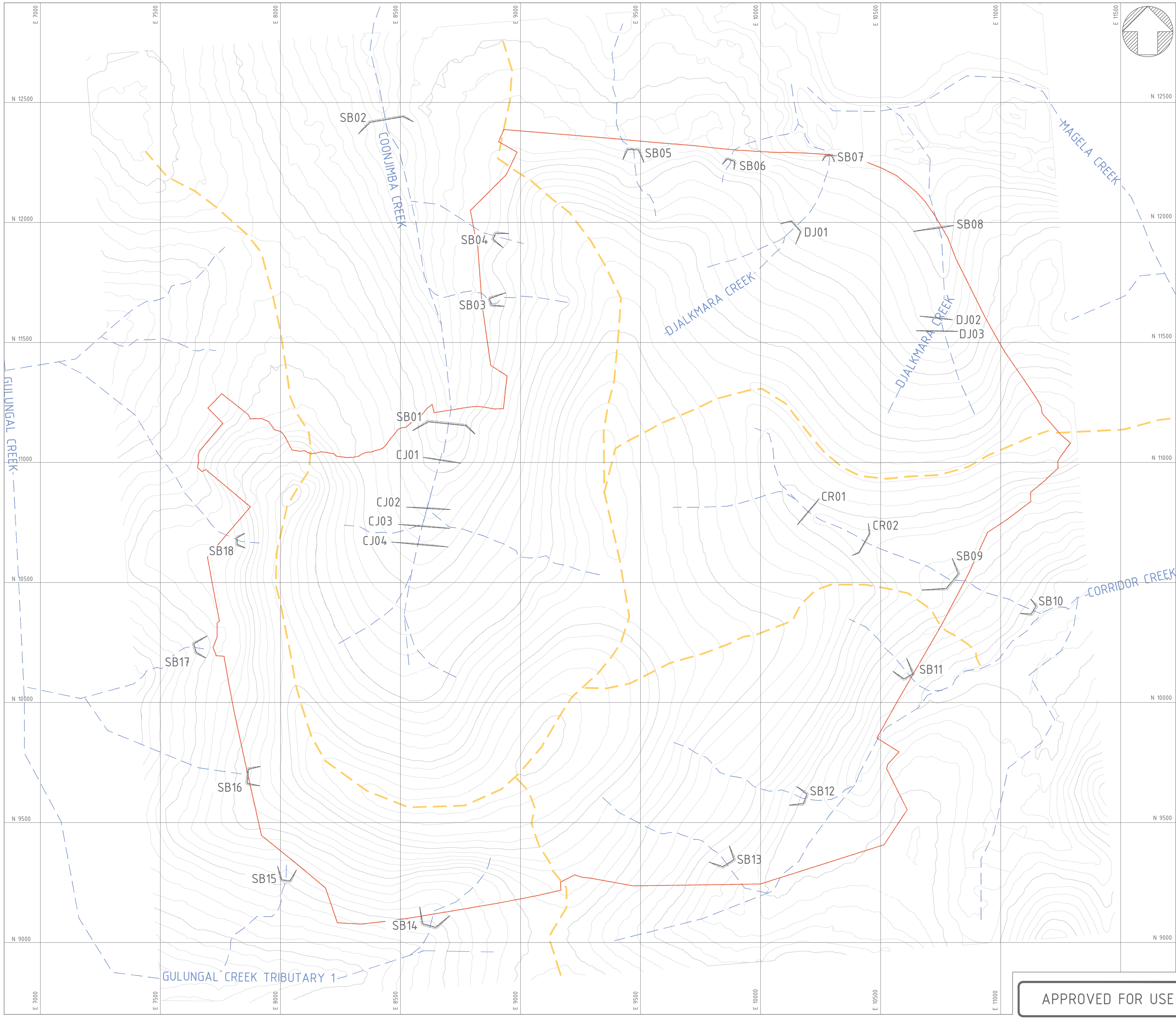
TABLE 2 – ENVIRONMENTAL ROCK BARS

ID	DESCRIPTION	STORAGE AREA* (m^2)	STORAGE VOLUME* (m^3)	(W) WEIR SPILLWAY WIDTH (m)	(C) CREST LENGTH (m)
1	CR01	5292	2381	4075	143
2	CR02	25742	10157	20	163
3	CJ01	5128	1511	20	158
4	CJ02	9042	2810	20	183
5	CJ03	10479	3324	20	215
6	CJ04	12294	3811	20	237
7	DJ01	4083	1452	40	160
8	DJ02	4862	1399	20	136
9	DJ03	5698	1583	50	173

*ALL ENVIRONMENTAL BARS ARE 0.8M HIGH AT CENTRE. BASIN AREA AND STORAGE VALUES ARE THEORETICAL AS STRUCTURES DESIGNED AS LEAKY ROCK WALL (PERMEABLE).

LEGEND

CATCHMENTS POST 2020
GULLY FLOWS
CONTOURS MAJOR (5m INTERVALS)
CONTOURS MINOR (1m INTERVALS)
EXTENT OF WORKS BOUNDARY
SB01 SEDIMENT BASINS (SB)
CJ01 ENVIRONMENTAL ROCK BARS



APPROVED FOR USE

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CATCHMENT PLAN – FINAL LANDFORM
SCALE 1:7500

SUBJECT TO FINAL VERIFICATION AND APPROVAL

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EQUIPMENT NUMBERS
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THIRD ANGLE PROJECTION

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DRAWN	LZ	21/06/18
ENG'EER CKD.	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER: H355334-00000-220-290-0048
RIO TINTO DWG. NUMBER: CDM.03-0000-EC-DWG-00067

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY
TITLE: GENERAL – AREA 00 CATCHMENT PLAN FINAL LANDFORM

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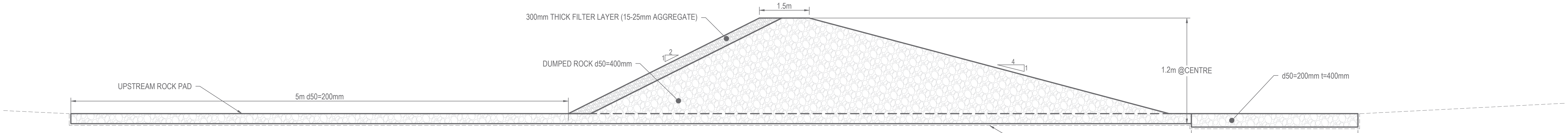

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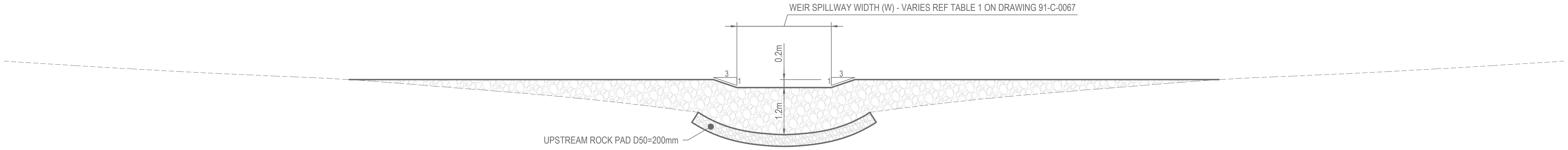

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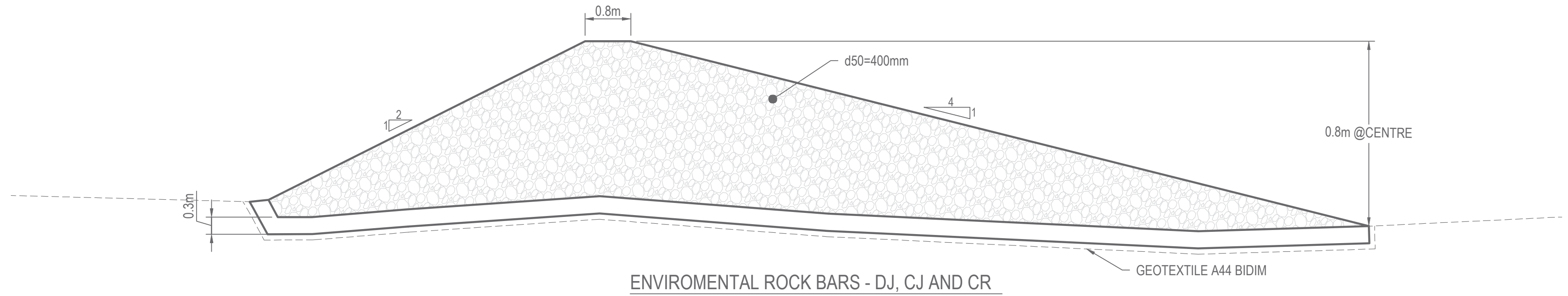

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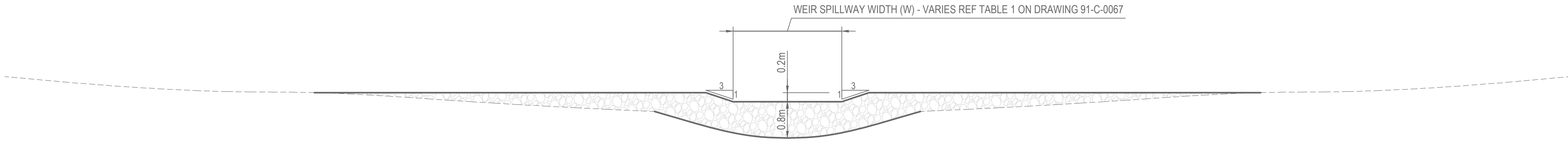

LONG SECTION - ENVIROMENTAL ROCK BARS
N.T.S

NOTES:
1. ALL WORKS REQUIRE 300mm STRIPPING AND FOUNDATION PREPARATION.
2. DESIGN SURFACES BASED ON PROVIDED SURVEY. LEVELS SHOULD BE CONFIRMED ON SITE.

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EQUIPMENT NUMBERS
SCALE AS NOTED
THIRD ANGLE PROJECTION

DESIGN	JJT	21/06/18
DRAWN	LZ	21/06/18
ENG'EER CKD	PDB	06/02/19
CLIENT APPR'D	SG	06/02/19
SUP'T APPR'D		

CONTRACTOR DWG. NUMBER H355334-00000-220-273-0034
RIO TINTO DWG. NUMBER CDM.03-0000-EC-DWG-00071

ERA

PLANT AREA: AREA 91 – CLOSURE STRATEGY
TITLE: ENVIROMENTAL ROCK BARS & INTREAM CHECK DAMS SECTION DETAILS

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC	DRAWING	REV
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APPENDIX 9.2 HAZARDOUS MATERIAL AND CONTAMINATION CONTROL PLAN

Hazardous Material and Contamination Control Plan HMP001

Approvals

	Name	Position	Signed	Date
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Checked	Peter Lander	Environment Superintendent	P.Lander	04/04/2019
Approved	Julie Crawford	Manager HSEC	J.Crawford	04/04/2019

Revisions

	Date	Description	By	Check	Approved
0.14.0	28/05/14	Internal Distribution	M Bush	P Lander	T Simms
1.16.0	22/06/16	Major review – incorporate revised RT Environment and Health Standards	A Lonergan/A Reid	P Lander	S Miller
0.19.1	05/02/19	Minor review	A Cullen	P Lander	J Crawford

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1. Purpose

The purpose of this plan is to ensure the safe and responsible use, storage, transport, disposal and control of all hazardous materials handled by Energy Resources of Australia Ltd (ERA).

The purpose of this is also to ensure that contaminated sites are appropriately characterized and managed in accordance with the Rio Tinto Environmental Standards. A range of standard operating procedures have been developed that relate to specific aspects of hazardous materials and contamination management. This plan provides the overarching strategy for hazardous materials and contamination management on ERA managed lands.

2. Scope

This plan applies to all ERA managed lands including but not limited to Ranger Uranium Mine (Ranger). It covers the management of hazardous materials through mine life from exploration, construction and operation to closure. This document also includes the evaluation and approval through storage, transport and disposal of hazardous materials as well as prevention and remediation of contamination. Asbestos is addressed separately in ERW103 Asbestos and Non-Asbestos Fibrous Silicates Management Work Instruction and radiation hazards are addressed in RAP001 Radiation Management Plan.

3. Planning

3.1 Objectives and Targets

The objective of hazardous material and contamination control at Ranger is to eliminate, as far as practicable, high risk chemicals and hazardous substances used at ERA.

To support achievement of this objective, ERA will target reviews (e.g. periodic audits) of stockholdings and storage of high risk chemicals and hazardous substances with a view to eliminating and/or reducing high risk chemicals and hazardous substances where practicable.

3.2 Legal and Other Requirements

ERA has a COR001 Compliance Obligations Register in order to identify and record all compliance, conformance and other legal obligations imposed by environment, safety and health legislation applicable to ERA's operations. The ERS002 Compliance Standard together with ERW002 Compliance Work Instruction provide details in relation to the identification of legal requirements, the maintenance of legal information and also the means by which employees seek legal information.

Management of hazardous materials and contamination on ERA managed lands must be in compliance with the requirements of Schedule 6 Other Services, Operations and Requirements of the most up-to-date version of Ranger Authorisation 0108. Corporate legal and regulatory requirements for hazardous materials and contamination management exist in the following documents:

Rio Tinto - The Way We Work

Rio Tinto HSE Performance Standards - Environment

Rio Tinto HSE Performance Standards - Health

Rio Tinto Closure Standard

ERA Environment Policy

3.2.1 Auditing

The Hazardous Materials and Contamination Control Plan and its implementation are subject to periodic audits via Rio Tinto Business Conformance Audit and other audit internal and external processes.

In accordance with the Rio Tinto Health Performance Standard H1 – 'Chemicals and hazardous substances exposure control', written procedures for the use, storage and disposal of hazardous substances with a health, safety or environment risk classification of critical must exist and must be internally audited at least annually. Also, through the Departmental HSE representatives and the relevant RT Health Standard Team, ERA also undertakes periodic inspections of hazardous substances storage areas throughout the year. The purpose of these audits and inspections is to reconcile stock holdings and storage locations and to monitor for conformance to the Standard.

4. Hazardous Material Management

The overarching document relating to risk management at ERA is ERS003 Hazard Identification and Risk Management. ERS057 ERA Standard Hazardous Substances outlines the process for purchasing, handling, storage, use and disposal of chemical substances and other hazardous substances, and the roles and responsibilities relevant to this. The HSEQ Risk Register includes several risks relating to hazardous materials.

4.1 Approval for New Hazardous Materials

Introduction of a new hazardous substance to ERA is controlled by standard operating procedure ERW022 Introduction of a New Chemical to ERA. This procedure ensures the Safety Data Sheet (SDS) is obtained and the hazardous substance is assessed and relevant controls applied prior to introduction to a work area. Such controls may include, subject to risk, hazardous substances and/or spill response training, for example.

ERA's chemical management system ChemAlert is used to register and record details of new hazardous substances once approved for use in a work area. If ChemAlert rates a substance as amber or red, a risk assessment must be completed using the Risk Assessment module on ChemAlert. A new chemical request form (F0096) must be completed for the introduction of a new hazardous substance to a work area. The form must be accompanied by the current SDS for the product and a completed risk assessment (where applicable) for review by the Hazardous Substances Coordinator.

4.2 Hazardous Materials Inventory

ERA maintains the Hazardous Substances Register within ChemAlert. SDS's for each product stored and used on site can be sourced through ChemAlert. All employees and contractors (through ERA work supervisors) can access ChemAlert via ERAs intranet. Hardcopies of SDS's are available at point of use at Ranger and Energy House Darwin.

4.3 Handling, Storage and Transport of Hazardous Materials

Employee exposure to hazardous substances and their associated potential impacts to the environment should be eliminated or minimised through the appropriate application of the hierarchy of controls. Risks and control measures associated with the use of hazardous materials have been identified and documented in ERAs Risk Register in accordance with ERS003 HSEQ Hazard Identification and Risk Management.

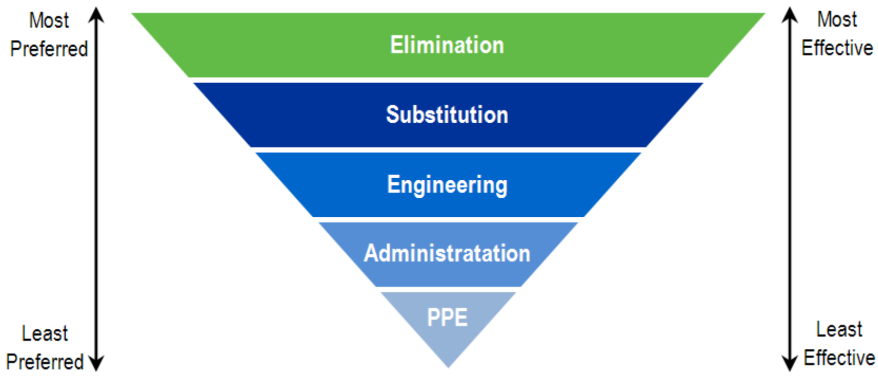

Figure 1: Hierarchy of Controls

It is the responsibility of the department and work area handling and storing a hazardous material to ensure all materials are managed and stored in accordance with the SDS for that material. The labelling, storage and segregation of hazardous materials shall be in full compliance with all relevant legislative requirements and codes of practice.

The ChemAlert system identifies where each material is stored and ERS057 Appendix A Segregation of Dangerous Goods details segregation requirements for dangerous goods. Hazardous materials shall be stored in bunded areas with secondary containment mechanisms, and bunding shall comply with the relevant Australian and Rio Tinto Standards.

4.4 Disposal of Hazardous Materials

Each department is responsible for disposing of chemicals produced by normal process activities and those which may arise from accidental leaks or spillage in their work area. ERP028 Off-Site Hazardous Substance Disposal Procedure outlines the process for disposing of a chemical substance at ERA. Most hazardous substances are disposed of off-site via a Licensed Waste Handler (i.e. a business licensed under the Waste Management and Pollution Control Act).

Hazardous substances which have been stored, used or generated in a controlled area or which fail a radiation clearance must be stored or disposed of on-site. All hazardous materials to be removed from site shall be dispatched through the warehouse. The warehouse dispatch process ensures relevant ERA and legal requirements are complied with. A Waste Transport Certificate must be completed for any transport of hazardous waste off-site. Environment Department approval is required for on-site disposal of hazardous substances (via EVF045).

4.5 Emergency Response Measures

In the event of a spill or incident involving a hazardous material, ERA standard operating procedure SFP030 Responding to Emergencies shall be followed. The procedure provides specific guidance for incidents with a serious threat to people, the environment or property. Emergency drills for HAZMAT incidents are carried out by the Emergency Response Team (ERT).

In the event of a spill or other incident requiring Emergency Response, the incident reporter must contact Emergency Services by dialling 222 from a Cisco phone. The Business Resilience and Response Plan (BRRP) has been established to coordinate the sites' response to emergency situations.

The Emergency Response Plan (Ranger) describes the tasks for specific roles in the event of a HAZMAT incident both on and offsite. Annual BRRP exercises are conducted to ensure that the BRRP continues to meet the sites' business requirements and legal obligations. After the occurrence of an emergency incident where the BRRP has been invoked, ERA debriefs the involved teams and action is taken to improve the efficiency and appropriateness of the BRRP.

4.6 Training

An overview of hazardous substance management at ERA is provided as part of the general induction (online, occupational health and environment inductions) that is required for all employees and contractors to complete. Training on managing hazardous substances at ERA is available as a web-based course for employees and contractors. ERA training co-ordinators can advise on role specific training in chemical and hazardous material management.

5. Contamination Control Management

5.1 Contaminated Site Assessment

Site investigations have been undertaken to assess soil and groundwater contamination in the Ranger processing plant area. The findings of these investigations have been used to develop a risk assessment of relevant sites following AS/NZS4360 Risk Management and National Environmental Protection Council (NEPC) guidelines. These investigations and risk assessments contribute to development of remediation strategies for closure.

The Closure Criteria Working Group (CCWG) has been established as a working group of the Ranger Mine site Technical Committee (MTC). Progress towards establishing closure criteria for Ranger mine is tracked through discussion and negotiations with stakeholders and is supported by ongoing research from both ERA and the Environmental Research Institute of the Supervising Scientist (ERISS). Research and monitoring related to the key knowledge needs associated with closure planning is reviewed by the Alligator Rivers Region Technical Committee (ARRTC). Final landforms are required to be constructed such that wastes will be securely contained to provide long-term protection of human health and the environment, as per the Ranger Authorisation.

ERA currently conditionally adopts criteria presented in the National Environmental Protection Measure (NEPM) Assessment of Site Contamination for the purpose of providing guidance on contaminated site investigation matters on a day to day basis only. The conditions on which the adopted NEPM Assessment of Site Contamination criteria is subject to include:

- The adopted criteria is interim only, secondary to and will be replaced by the Ranger mine closure criteria once approved by the MTC;
- The purpose of the adopted NEPM Assessment of Site Contamination criteria is to provide day to day guidance on matters relating to the assessment of site contamination only (for example, assessment and verification of the suitability of bio-remediated hydrocarbon impacted soil) in the absence of and until Ranger mine closure criteria are established and approved;
- The adopted NEPM Assessment of Site Contamination criteria will not be used for ERA Ranger mine site closure, closure planning, treatment and or remediation of potential or actual site contamination;
- Closure criteria approved by the MTC will be those applied to assess the adequacy of site closure, contribute to closure planning and for treatment and or remediation of potential or actual site contamination.

5.2 Contaminated Sites Register

The Contaminated Sites Register identifies all sites (including Jabiluka and Djarr Djarr) that have supported land use activity having the potential to contaminate land. The Contaminated Site Register is warehoused in GIS format and includes, but is not limited to, information on the location, land use activity, potential contaminants and risk. The register is maintained by the Environment Team.

Allowance has been made in the Ranger Mine Closure Plan for the investigation and remediation of sites identified as having potential or actual contamination. Notwithstanding this, in the event actual contamination is identified that is assessed as posing potential to harm the surrounding environment or human health, ERA shall consider containment, mitigation and/or remedial measures to manage the risk.

5.3 Remediation of Contaminated Sites

Remediation of contaminated sites may occur as progressive rehabilitation throughout the remaining life of operations at Ranger, or be addressed through the closure process. The CCWG has agreed that closure criteria will be developed under six themes:

- Landform
- Radiation
- Water and sediment
- Flora and fauna
- Soils
- Cultural

Where appropriate, closure criteria from each theme will be applied to remediation of contaminated sites as per the contaminated sites register as well as to guide closure across Ranger.

5.4 Prevention

Prevention of contamination on site is managed through (but not limited to):

- Assessment of alternative substances through the chemical approval process;
- Bunding of relevant materials to relevant standards;
- Integrity inspections for relevant under and above ground tanks and pipelines;
- Condition monitoring and housekeeping inspections to detect leaks / cracks;
- Preventative maintenance on equipment;
- Groundwater monitoring;
- Incident / spill response and clean up;
- Stock reconciliation;
- Standard operating procedures for hazardous substances and associated tasks;
- Informing all workers at ERA of their requirements with respect to managing hazardous substances, reporting spills and incident response / clean up.

5.5 Containment Systems

ERA has a suite of standard operating procedures relating to the management of hazardous substances. Hazardous material containment is addressed (but not limited to) the following documents:

- AS1940 Storage and handling of flammable and combustible liquids
- ERP003 Waste Hydrocarbon Disposal Procedure
- ERS057 ERA Standard Hazardous Substances

Secondary containment systems are also in place at locations where there is a higher risk of hydrocarbon / process spills or leaks. These locations include but are not limited to the bulk diesel tanks, sulphuric acid tanks, powerstation diesel day tanks, warehouse product and waste oil tanks, acid leach tanks, CCD's, tailings pump station, tailings and brine pipelines and the sand filters.

Containment valves must be locked in the closed position except under supervision when opened to release clean storm water. It is noted that any storm water that has accumulated in a controlled area is managed as pond or process water as appropriate.

Relevant work area owners are responsible for routine and non-routine inspections and maintenance of containment systems (including bunds) to ensure:

- Containment systems are free from product spillage;
- Storm water is identified and removed to ensure adequate containment capacity is maintained; and
- Containment systems are competent and fit for intended purpose.

5.6 Monitoring

Groundwater monitoring is conducted on site through targeted routine bore monitoring programs. As additional bores are installed on site they are incorporated into the programs. Groundwater monitoring is undertaken by the Water Management team, who are also custodians of the data obtained from the monitoring program.

5.7 Third Party Transport and Disposal

The third party transport of hazardous substances is managed through a services contract which allows ERA to competently apply controls to manage the associated risks. Transport providers and any waste receivers and/or disposers shall be appropriately licensed to transport and receive such waste.

It is noted that the interstate movement of hazardous wastes may trigger the need for additional State & Federal government approvals including but not limited to the National Environmental Protection (Movement of Controlled Waste between States and Territories) Measure.

Uranium oxide produced at Ranger is transported from site by road. The requirements for transport and incident response in the event of a spill are addressed in the UTP001 ERA UOC Transport Plan. Compliance with the requirements of the aforementioned document exceeds current statutory requirements.

6. Spill Response and Incident Reporting

6.1 Spill Response

ERA procedure MTP007 Hydrocarbon Spill Clean-Up details the guidelines and procedures for spills of different materials. Spill response kits (yellow bins labelled 'spill kit') containing the appropriate spill response equipment are available for requisition through Stores. Spill kits shall be readily available at those locations where spills have a likelihood to occur, such as at fuel bowsers, workshops and transfer points. Each work area is responsible for ensuring that their spill kit is maintained and re-stocked.

Contaminated spill kit materials shall be recovered and disposed of as per ERP003 Waste Hydrocarbon Disposal procedure.

The Ranger Environment induction outlines the requirements for every worker for spill response and clean up.

6.2 Incident Reporting

Environmental incidents are reported to regulatory authorities in accordance with Section 29 of the Mining Management Act and via the monthly Environmental Incident Report.

Health, Safety and Environment incidents are managed through the Rio Tinto Business Solution in accordance with ERS014 Non-Conformance Incident and Action Management Standard. Reporting an incident via this system requires information about spilled volume, response action and recovered volume where practicable.

Complaints are considered an incident and must be reported as above. In the event of an incident or complaint, an investigation is conducted to determine the root causes and to determine if additional controls are required.

7. Hazard Reduction

ERA shall pursue the reduction of hazardous substance use in the workplace and endeavour to substitute less hazardous substances where practicable. ERA regularly reviews the hazardous substances inventory and practical application purposes to identify redundant chemicals along with recommendations to seek alternate non-hazardous substances or less hazardous substances where practicable. Form F0096 New Chemical Request, along with work instruction ERW022, assesses the environmental risk of hazardous substances and details controls required to reduce hazards during the use, storage and transportation of the hazardous materials.

8. Accountabilities

Role / Title	Responsibility
General Managers	• Ensure adequate resources are allocated to departments to facilitate compliance with the Hazardous Materials and Contamination Control Plan (the Plan).
Department Managers	• Maintain the requirements of the Plan and all associated procedures. • Ensure employees and contractors are appropriately trained in the correct methods for handling and storage of hazardous materials. • Ensure that onsite storage facilities are inspected and maintained and inventories are kept up to date.
Manager HSE & Communities	• Ensure that ERA implements and maintains the requirements of the Plan and all associated procedures. • Ensure the Plan is regularly audited and reviewed according to Rio Tinto Standard E15.
H&S Advisor	• Maintain the HSEMS risk register, including items related to hazardous materials
Environment Team	• Provision of environmental advice relating to new hazardous substances, spills and clean up • Periodically review and maintain the Contaminated Sites Register • Assessment of requests to dispose of chemicals off site
Environment Superintendent	• Ensure the Plan and associated procedures are reviewed and maintained at periodic intervals. • Periodically review hazardous waste transporters and receivers.
Hazardous Substances Coordinator	• Ensure the Hazardous Substances Register is maintained and SDS' are available for all substances on ChemAlert. • Assessment of requests for new chemicals and hazardous substances.
ERA Company Rep	• Ensure contractors comply with the Hazardous Materials and Contamination Control Plan and all associated standard operating procedures and other associated documents.
Document Controller	• Maintain authorised system procedures, department procedures and other related documentation on the ERA drive • Ensure that the most recent issues of the documentation are available.

Role / Title	Responsibility
All ERA Employees and Contractors	• Adhere to the requirements of the Plan and all associated procedures. Specifically: o Follow approvals process for bringing new hazardous substances to site, or to a new work area o Refer to and understand Safety Data Sheets (SDS') when handling hazardous materials o Participate in induction and training programs o Wear personal protective equipment (PPE) provided, as specified o Assist in audits as required o Comply with the guidelines set out in this plan o Comply with ERA and regulatory requirements for spill response, clean up and reporting

9. Review

The Hazardous Materials and Contamination Control Plan will be reviewed and updated no later than every three years from the date of last review. A review may occur sooner consequent to a material change in risk, legal requirements or an incident relevant to hazardous materials management.

10 Closure monitoring and maintenance

Issued Date: October 2022

Revision number: 1.22.0

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GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Airborne radiometric survey	Estimation of the concentration of radioactive elements in the surface of the landform via the detection of gamma radiation using low flying aircraft.
Closure criteria	Direct, measurable and quantifiable target values or tiered assessment processes, developed to demonstrate achievement of the closure objectives.
Contaminated Land Risk Register	Register of all sites where activities have occurred that have the potential to contaminate land on the RPA.
Constituents of potential concern	Chemical elements identified by the Supervising Scientist Branch as being of potential concern to the receiving environment.
Diameter at breast height	Measurement of tree diameter taken at 1.3 m above ground level (an adult's approximate breast height).
Digital Elevation Model	Digital representation of the land topography.
ERICA Assessment	Exposure/dose/effect assessment for radiological risk to terrestrial, freshwater and marine biota.
Groundwater conceptual model	Calibrated numerical groundwater flow model encompassing all hydrogeologic elements governing groundwater flow and transport at the Ranger Mine to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions.
Groundwater solute transport modelling	Prediction of the temporal and spatial mobilisation of constituents of potential concern from the RPA to the surrounding environment through groundwater using the groundwater conceptual model.
Hydrolithologic unit	A grouping of soil or rock units or zones based on common hydraulic properties.
LiDAR	Remote sensing technique using pulsed laser to measure distances.
Long Lived Alpha Activity	Abbreviated to LLAA. The presence, generally in airborne dust, of any of the alpha emitting radionuclides in uranium ore, except for the short lived alpha emitting radon decay products.
Mirarr	Mirarr is primarily a patrilineal moiety system. Within the Mirarr People, there are descent groups often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Monitoring and maintenance phase	Period after rehabilitation works have been completed (currently estimated to be 25 years). Completion criteria monitoring (and maintenance rehabilitation works if required). Site access pending.

Key term	Definition
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321 %.
Pit 1 Progressive Rehabilitation Monitoring Framework	Overarching framework of environmental monitoring for the rehabilitation of Pit 1.
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Potential Alpha Energy Concentration	The concentration of the total alpha energy emitted in air during the decay of radon-222 progeny. Usually measured in $\mu J\ m^{-3}$.
Radon exhalation	Activity of radon gas leaving the surface of the landform
Trigger, Action, Response Plan	Abbreviated to TARP. Plan of tasks to be undertaken should monitoring detect a change in parameters of a level that requires preventative or remedial action. Designed to be adaptive in nature.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
COPC	Constituents of Potential Concern
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DWPZ	Deeps Water Producing Zone
EC	Electrical Conductivity
ERICA	Environmental Risk from Ionising Contaminants: Assessment and management
GAC	Gundjeihmi Aboriginal Corporation
GCC	Gulungul Creek Control
GCLB	Gulungal Creek water monitoring site
HLU	Hydrolithologic unit
LEM	Landscape Evolution Model
LLAA	Long Lived Alpha Activity
LiDAR	Light Detection and Ranging
MCP	Mine Closure Plan
MCUS	Magela Creek Upstream water monitoring site
NLC	Northern Land Council
NP	National Park
PAEC	Potential Alpha Energy Concentration
RPA	Ranger Project Area
RWD	Ranger Water Dam
RWMP	Ranger Mine Water Management Plan
RWMS	Ranger Water Management Strategy
SERP	Species Establishment Research Program
SSB	Supervising Scientist Branch
S&TM	State and Transition Model
TARP	Trigger, Action, Response Plan
TPH	Total Petroleum Hydrocarbon
TSF	Ranger Water Dam formerly the Tailings Storage Facility
WASWG	Water and Sediment Working Group
WoNS	Weeds of National Significance

10 CLOSURE MONITORING

This section describes the monitoring programs that will be implemented by ERA to demonstrate successful rehabilitation of the Ranger Mine, and to comply with clause 13.3 of the Environmental Requirements: *"… the company must carry out a monitoring program approved by the Supervising Authority or the Minister with the advice of the Supervising Scientist following cessation of operations until such time as a relevant close-out certificate is issued"*.

For the purpose of the MCP, mine closure and monitoring programs are discussed in two separate phases:

1. Closure Phase: the period between 8 January 2021 (when on-site processing was completed), throughout the period of decommissioning and bulk material movements to achieve the final landform, and up until the completion of initial rehabilitation works; and
2. Monitoring and Maintenance Phase: the period after the Closure Phase and continuing until results of the monitoring demonstrate that the site has met the required closure objectives and relinquishment of the RPA is achieved (currently estimated to be 25 years).

An adaptive management approach will be critical during this monitoring and maintenance phase because the landform may settle over time, there is the potential for subsidence and/or erosion to occur, and revegetation will be young and developing. Adaptive management will help promote continued progress towards a stable landscape and self-sustaining ecosystem. Adaptive management planning is a fundamental component of State and Transition Models (S&TM; the ecosystem model development is discussed in Section 5) and include three key elements:

- routine monitoring to track that the rehabilitation is on the desired trajectory, and to identify potential risks that might threaten the desired outcome;
- maintenance activities to proactively ensure that the rehabilitation remains on the desired development trajectory; and
- management actions to implement when a risk has been identified to avoid the rehabilitation transitioning into a deviated state, or to revert a deviated state back into a desired state if a transition has already occurred.

Adaptive management, whereby monitoring results are analysed to identify issues and inform maintenance activities, will occur during both phases mentioned above. However, and purely because of time, adaptive management is likely to be applied more often during the longer monitoring and maintenance phase.

The monitoring programs discussed below align with the following closure themes:

- Landform;
- Radiation;
- Water and sediment;

- Ecosystem (flora & fauna); and
- Cultural.

An overview of the monitoring programs for each of the closure themes is provided the following sections.

ERA have summarised much of the monitoring and maintenance activities into a series of Trigger, Action, Response Plans (TARPs). TARPs provide a practical guide to identify early warning signals that a rehabilitated area is moving away from the desired state. The triggers within each TARP represent the primary drivers to be monitored. Each trigger will eventually have a threshold so that monitoring results can clearly identify the risk of transition and the need for action. TARPs are discussed further in Section 10.6.

10.1 Landform theme

10.1.1 Closure research, monitoring, maintenance and adaptive management

A number of studies (Section 5) have been undertaken to address key closure issues and risks associated with landform: including removal of 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 SSB on the trial landform, have informed the overall design and predicted performance of the final landform.

10.1.1.1 Trail landform and final landform monitoring

The trial landform was constructed in 2009, and studies on the trial landform have been used to validate design attributes such as landform stability, erosion, topography and visual amenity; and inform the current landform model predictions. The outcomes of these studies have resulted in a final landform topography that incorporates low elevation and slopes to enhance landform stability and visual aesthetics to blend with the surrounding landscape.

Landform monitoring will continue throughout the closure phase, and monitoring and maintenance phase, to assess the condition of the landform, stability and suitability for revegetation. The primary objective of monitoring during the closure phase is to assess adherence to the planned landform design, including material transfer and placement. In the monitoring and maintenance phase, parameters such as settlement and subsidence performance, surface topography, erosion and sediment controls, bedload and sediment control, and suspended sediment will be monitored.

The design of the landform, including erosion and drainage control, will minimise the development of gully erosion. Sediment basins and drainage channels will be inspected after each wet season to confirm that the basins and channels continue to operate according to design. Inspections will identify any unplanned gully erosion and channels and inform subsequent maintenance, if required, as well as validate modelling outputs. The SSB has indicated that whilst it is expected that gullies will form on the landform within the modelled 10,000 years, the tailings will be below the natural landscape and are therefore not expected to be exposed (SSB, 2017). Active management of erosion and sediment control structures will continue into the maintenance and monitoring period, however it is expected that maintenance requirements will progressively decrease as the landform stabilises and dynamic equilibrium is reached. The outcome criterion will be achieved when drainage channels are considered to have been reached or are trending towards functional dynamic equilibrium. At functional dynamic equilibrium, there will be no unplanned gully erosion and the landform will be comparable to the surrounding landscape.

Changes in geotechnical conditions will be monitored to identify the presence, and measure the extent of, subsidence, slumping, deformation and/or settlement. This will provide a mechanism to track progress towards the closure objectives. Maintenance will be undertaken, where necessary.

10.1.1.2 Pit 1 tailings consolidation monitoring

The tailings consolidation model comprises two stages (deposition and consolidation). The deposition phase includes tailings distribution, rate of rise and hence the level, while the consolidation phase involves pore water dissipation (expression) with resultant settlement. The monitoring of Pit 1 tailings consolidation now focusses on the consolidation stage, which can be informed by the settlement. Pipes attached to 28 settlement plates were installed over the tailings in Pit 1 prior to placement of the backfill material in 2017, at locations shown in Figure 10-1. The top of the pipes was surveyed every month during and after completion of the final landform to estimate the tailings level and hence settlement. The measured settlements were compared to the predicted settlements (Figure 10-2) and the results closely agreed, demonstrating the accuracy of the model.

The last survey was conducted in July 2021 and the results showed plateauing of the settlement curve, an indication of a minimal rate of change of settlement. It was also determined that the degree of consolidation is about 98 %, and therefore greater than the targeted value of 95 %. The monthly settlement monitoring has been discontinued and most of the pipes have been cut (reduced) and capped to about 500 mm below the final landform level, which allowed for the installation of a pivot sprinkler to water the trees planted on the landform. The reduced pipes coordinates, including the elevation, were recorded before backfilling.

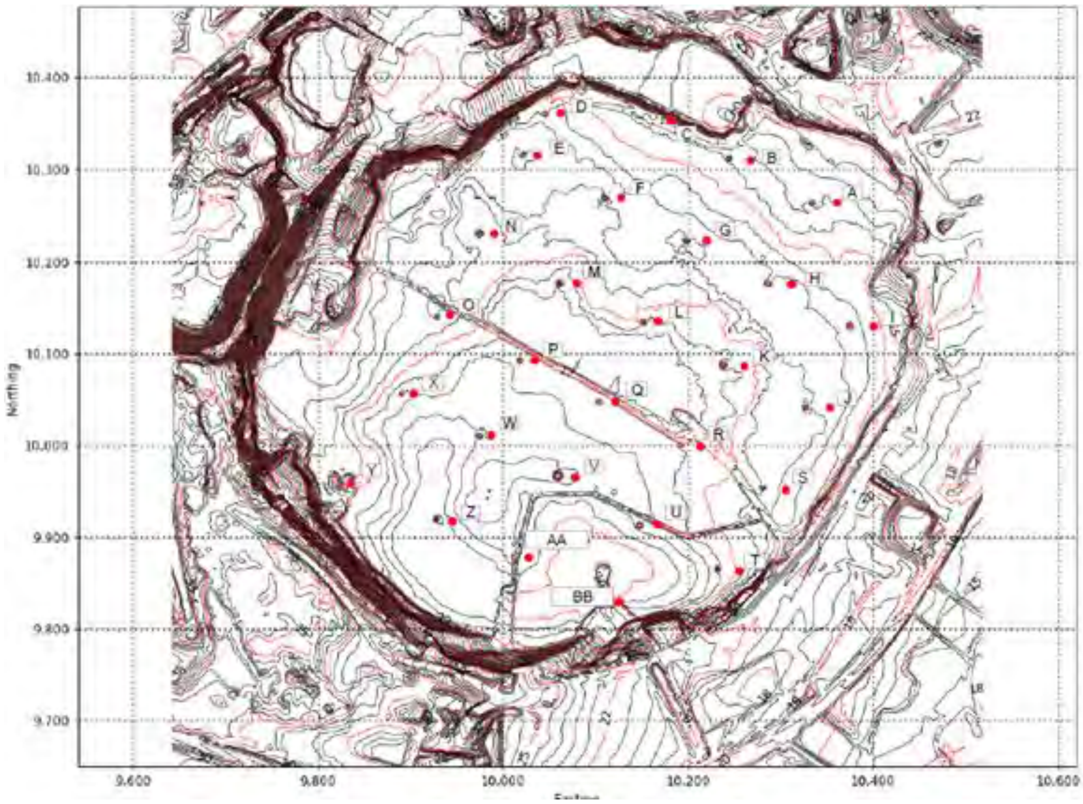

Figure 10-1: Settlement plates locations (locations indicated by red dots)

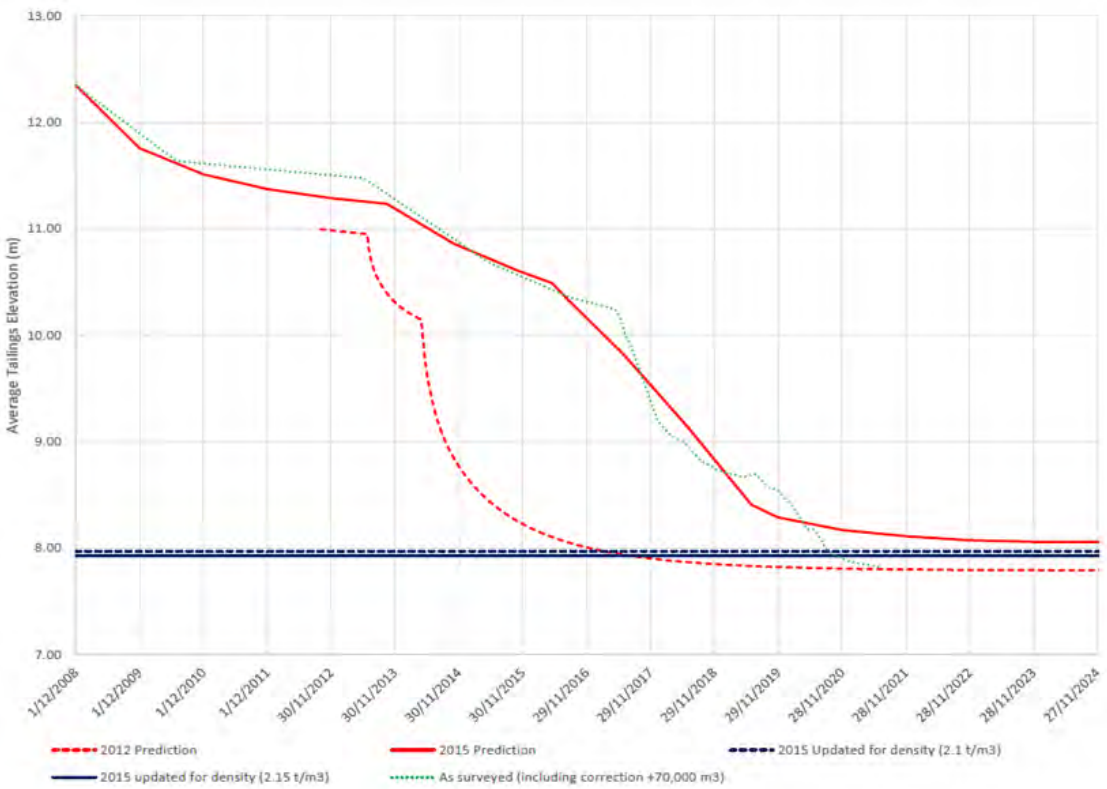

Figure 10-2: Measured versus predicted tailings settlement

10.1.1.3 Pit 3 tailings consolidation monitoring

The deposition phase for Pit 3 tailings consolidation has been monitored since 2017. This has been done by two methods: conducting monthly bathymetric and topographic surveys to determine the tailings level and compare the results to the model prediction (Figure 10-3); and yearly geophysical (bathymetric and seismic) surveys to monitor (confirm) the tailings distribution including fine/coarse ratio, fine/coarse interface and the tailings level. Additionally, some geotechnical investigations have been conducted to monitor (confirm) the fine/coarse tailings interface, tailings level, and pore pressure profiles. Further information on the geotechnical investigations is provided in Section 9 of this MCP.

The consolidation phase monitoring will commence once tailings deposition has been completed and capping has commenced. The Pit 3 capping design includes consolidation monitoring during capping, and the monitoring approach will be similar to that used in Pit 1 in that it will determine the *in-situ* tailings settlement and compare it with the modelled prediction and targeted value.

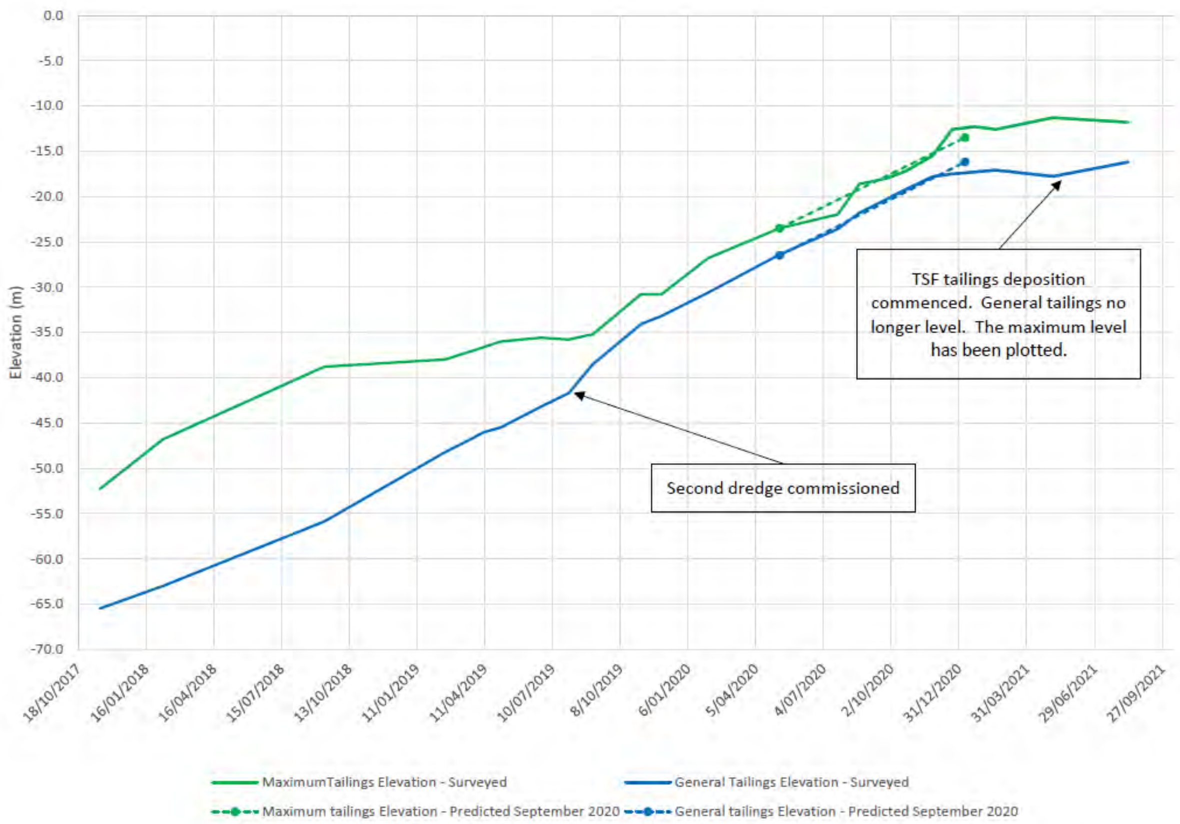

Figure 10-3: Predicted versus measured Pit 3 tailings levels

The tailings settlement will continue to be monitored during the secondary capping and bulk backfill layers construction utilizing settlement monitoring and decant towers installed at locations shown in Figure 10-5.

This is a similar concept as for that used in Pit 1. A set of twenty settlement towers will be installed across the Pit 3, with the base of the tower located as close as practical to the top of tailings surface. Survey of the location of the top of the tower, less the known height of the tower, will provide a measurement of the location of the tailings surface underneath the tower. This will be conducted monthly as per Pit 1.

Towers in Pit 1 were constructed by placing a horizontal settlement plate near the top of tailings, connected to a riser constructed from segments of known length of 100 mm diameter steel pipe, with the height of the tower progressively raised with segments as backfill progressed. A variation of this approach will be used for Pit 3, with the settlement towers constructed from sections of nominally metre diameter concrete or HDPE pipe. Use of larger diameter pipe provides more resistance to buckling as the waste rock moves during tailings consolidation, and also permits the settlement towers to be used as backup decant towers, or for water level and conductivity profile monitoring.

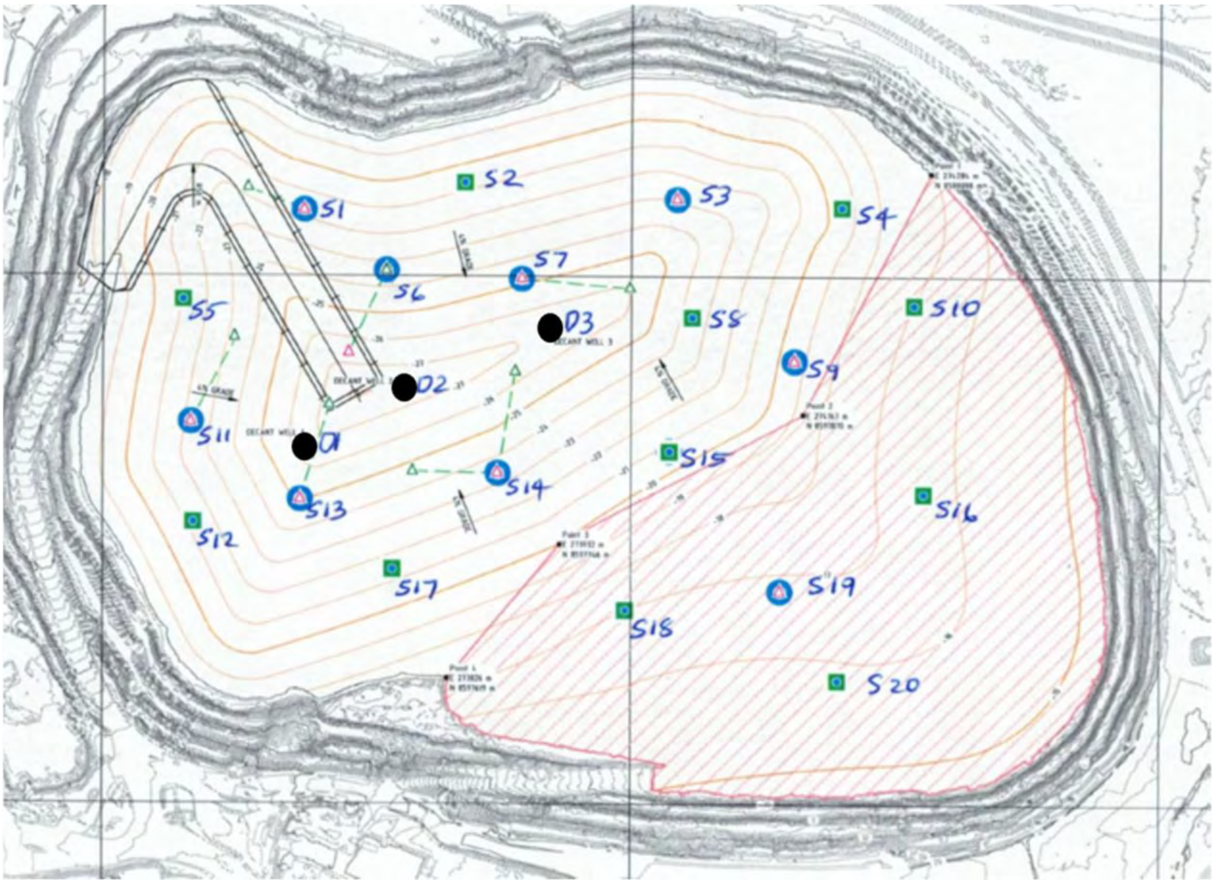

Figure 10-4: Pit 3 Locations of settlement towers

NB: Green squares: water quality configuration;
Blue circles: water extraction configuration; and
Black circles: decant towers.

Monitoring to measure progress towards landform closure criteria will also include final landform topography after completion. It is expected that either airborne and/or terrestrial LiDAR (or equivalent) technology will be used to survey and capture the final landform topography. Specific details on which LiDAR techniques will be utilised have yet to be determined, and new information will be incorporated into future iterations of the MCP. Landform monitoring for closure and the monitoring and maintenance period is presented in Table 10.1 and Table 10.2, respectively (noting that some monitoring presented in Table 10.1 will also carry through into the monitoring and rehabilitation phase – i.e. Table 10.2).

10.1.1.4 Pit 1 landform monitoring (includes Stage 13)

Following the tailings consolidation in Pit 1, the monitoring focus will shift to the surface landform profile, which reveals the final landform behaviours. As discussed in Section 9, Pit 1 is currently undergoing revegetation. *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1) was developed to provide guidance for landform, sediment, and revegetation monitoring on the Pit 1 final landform. Key landform monitoring activities on Pit 1 and Stage 13 include:

- annual survey on the landform and DEM production;
- monthly aerial imagery (UAV orthomosaic) during wet season; and
- visual assessment on landform surface erosion and hydrology.

Updated survey and DEM will provide direct data on waste rock landform settlement and continue to inform Landform Evolution Modelling (LEM) studies. Monthly drone photographs are compared in time sequence to enable a visual assessment of erosion across the entire Pit 1 and Stage 13 surfaces (Figure 10-5). This is complemented by field observations (as required) and weekly ‘photo-point’ monitoring (photos taken at the same location with the same target angle) to characterise micro-topographic changes, local sediment movement and hydrological behaviour within the water management infrastructure.

The monthly stitched-orthomosaic proved to be a helpful monitoring tool to identify the leading indicators for landscape changes, which will inform the preparation works required for the next year’s wet season.

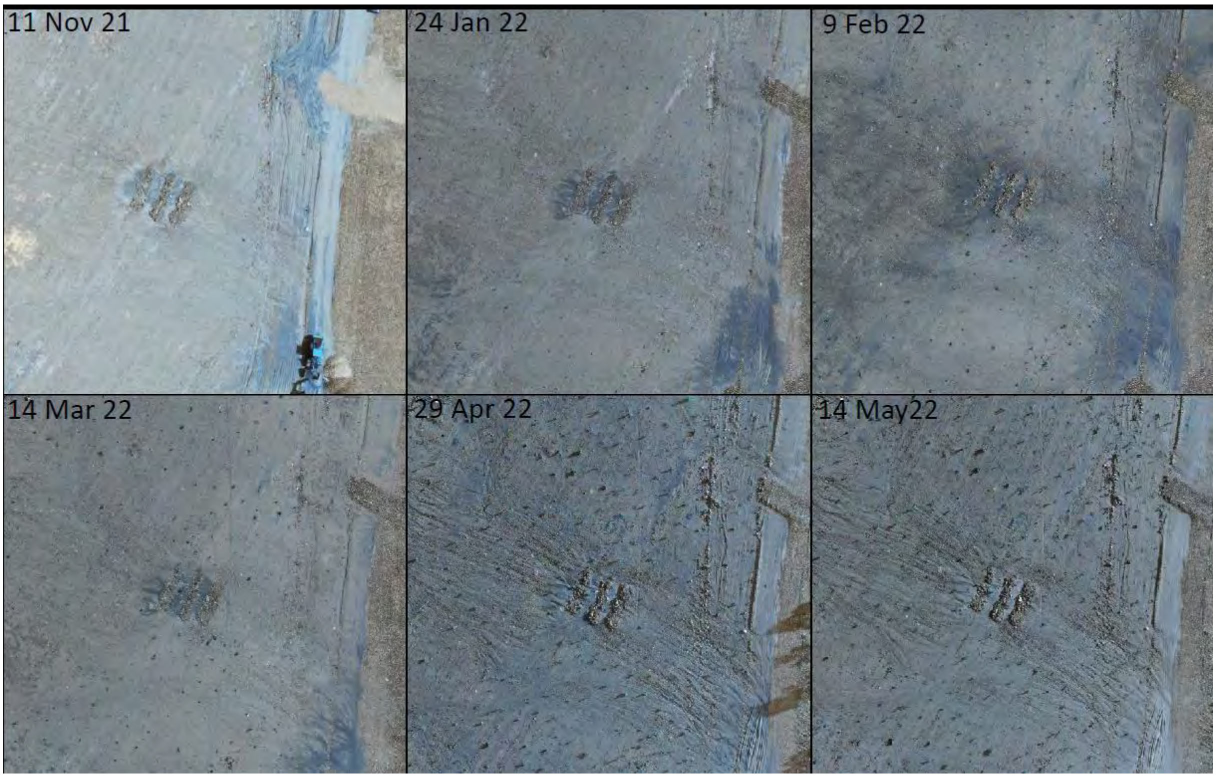

Figure 10-5: Time sequence of first order drainage channel forming on Pit 1 (2rog, 2022)

At the end of each wet season, a review is undertaken of the monitoring activities undertaken to assess appropriateness of each monitor activity and where efficiencies may lie. To date, this has included:

- Monthly aerial imagery (UAV orthomosaic) during wet season was found to be adequate, with observable changes more effective by comparing the last orthomosaic (end of wet season) to the first orthomosaic (start of wet season). There is little additional benefit to the quality and frequency of image capture if also flown after a significant rainfall event (>50 mm), in addition to monthly captures.
- A review of the photo-point monitoring was undertaken to better place weekly photo-point captures, to target the final landform. Previous locations were found to be focused on the Pit 1 perimeter drain rather than the final landform. These have been optimised in advance of the 2022/2023 wet season.

ERA will continue to review the monitoring activities and optimise where possible for better monitoring outcomes.

10.1.2 Completion criteria monitoring

Sediments from erosion of the landform will be measured through both coarse sediment (bedload) and finer sediment (sedimentation). For coarse sediment, bedload is not to be transported from the constructed landform. This parameter will be monitored through post wet season observations after the active post closure management has been completed and the sediment controls structures have been removed. Work completed by the SSB has demonstrated that turbidity can be used as an indicator for suspended sediment. The method developed involves the comparison of annual difference in turbidity between upstream and downstream sites.

Both the monitoring programs and closure criteria are subject to review as the outcomes of studies and/or new information becomes available, and stakeholder feedback is incorporated. As such, some aspects of closure monitoring for landform require further development prior to finalising. Many landform monitoring parameters being measured now are capturing the erosion characteristics of newly constructed final landforms. This data will also be used to determine whether the eroded sediments are in the trajectory towards the background denudation rate. These include water and sediment monitoring within mine area and visual observation undertaken on Pit 1 and Stage 13. If appropriate and feasible, monitoring data on sediment yield in newly constructed landforms can further inform and refine the landform evolution modelling (LEM). Parameters developed to measure the other landform closure criterion under ER 2.2 I, including bedload and turbidity, will be measured where feasible to further inform the trajectory of meeting landform closure criteria.

In addition, high resolution digital elevation model (DEM) and LEM prediction of gully erosion are two parameters developed to measure against the landform closure criterion – ‘tailings will remain isolated under 10,000 years’. The LEM configuration update, based on ongoing monitoring to measure erosion characteristics, tailing consolidation (i.e., tailing storage level post consolidation) and landform settlement, will feed into the ongoing use of a multi-year CAESAR-Lisflood landform evolution model (LEM), which can predict the future landform state and demonstrate that tailings will remain isolated for at least 10,000 years denudation rate.

The description of how other landform monitoring results (e.g., landform material properties) are being used to improve LEM configuration change (i.e. parameter optimisation) are described in Section 5.

Table 10.1: Landform monitoring for 'closure' phase

Aspect	Methodology	Analysis	Location	Frequency	Duration
Material placement*	Material characteristics and volume.	Dynamic mine model with associated tracking methods. Within landform levels during construction.	Whole of final landform via tracking system.	Ongoing	Until landform is built.
Subsidence or slumping, deformation and/or settlement	Geotechnical monitoring	Identify any subsidence or deformation of landform areas.	TSF, pits and landfill walls.	Quarterly	Until final landform is on a stable trajectory to meet final criteria.
Surface topography*	Topography survey	Comparison of DEM and survey to planned landform.	Whole of final landform.	Once. When practical upon completion of final landform.	Not applicable.
	Quantify landform settlement	Year on year DEM change and topographic survey.	Whole of final landform.	Annual	Until final landform is on a stable trajectory to meet final criteria.
Surface micro-topography*	Micro-topography survey	Comparison of DEM and survey to planned landform.	Whole of final landform.	Annual	Until final landform is on a stable trajectory to meet final criteria.
		High resolution DEM and field survey.	Whole of final landform.	After land forming and annual after wet season.	Until final landform is on a stable trajectory to meet final criteria.
Surface ripping*	Map ripped areas	Mapping via GPS tracking, field survey or remote sensing.	Planned ripped areas.	Once, after landform creation.	Not applicable.

Aspect	Methodology	Analysis	Location	Frequency	Duration
Erosion (encapsulated tailings)*	Capture digital elevation model (DEM) of the final constructed landform using either airborne and/or terrestrial LiDAR (or equivalent) technology	Describe the final landform against planned landform. Assess LEM results for critical erosion over tailings areas. Potentially provide updated information to rerun the 10,000 year landscape evolution model (LEM) and confirm LEM predictions for tailings encapsulation.	All disturbed areas.	Once. When practical upon completion of final landform (closure phase).	Not applicable.
Erosion (local scale post-wet season)	Field inspection* of erosion and sedimentation, notes, photographs DEM analysis	Identify significant erosion – rill erosion > 30 cm depth, sheet erosion or prevention of revegetation (>0.1 ha). Identify erosion around drainage channels.	Erosion of drainage channels. Sedimentation of sensitive receptors.	Annually after wet season.	Until final landform is on a stable trajectory to meet final criteria.
Erosion Control Structures*	Confirm erosion control structure function through field inspection.	Ensure erosion structures function effectively.	All erosion control structures.	Annually post-wet season.	Until final landform is on a stable trajectory to meet final criteria.
Bedload (Access Roads and Creeks)	Field inspection* of erosion, notes, photographs	Identify any erosion on roads that may be source of bedload moving offsite.	Access roads. Magela and Gulungul creeks.	Biannually and after each significant rain event.	Until final landform is on a stable trajectory to meet final criteria.
Bedload (sediment traps)*	Quantify sub-catchment bedload sediment movement.	Measurement from sediment traps.	All sediment traps.	Annually post-wet season.	Until final landform is on a stable trajectory to meet final criteria.

Aspect	Methodology	Analysis	Location	Frequency	Duration
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	Turbidity can be used as an indicator of fine suspended sediment. On an annualised basis, the difference between up and downstream can be used as an indicator of site-scale erosion characteristics.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks).	Continuous turbidity monitoring during wet season.	Until suspended sediment loads are approaching background values (note: 5 years in the closure criteria).

*Adapted from *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1)

Table 10.2: Landform monitoring for 'monitoring and maintenance' phase

Aspect	Methodology	Analysis	Location	Frequency	Duration
Erosion (local scale post-wet season)	Field inspection of erosion and sedimentation, notes, photographs	Identify significant erosion – rill erosion > 40 cm depth, sheet erosion or prevention of revegetation (>0.1 ha). Identify erosion around drainage channels.	Erosion of drainage channels. Sedimentation of sensitive receptors.	Annually after wet season.	Until final landform is on a stable trajectory to meet final criteria.
Erosion (general)	Field inspection* of erosion, notes, photographs	General inspection for localised scouring and damage.	All disturbed areas.	Biannually.	First 5 years of phase.
				Annually.	Until final landform is stable and has met final criteria.
Bedload (Access Roads and Creeks)	Field inspection* of erosion, notes, photographs	Identify any erosion on roads that may be source of bedload moving offsite.	Access roads Magela and Gulungul creeks.	Biannually and after each significant rain event.	Until final landform is stable and has met final criteria.
Bedload (Sediment Basins)	Field inspection* of sediment control basins, notes, photographs	Sediment volumes in sediment control basins. Structural integrity of sediment control basins.	All sediment control basins.	Quarterly.	First 3 years of phase.
				Biannually.	Until final landform is stable and has met final criteria.
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	Difference in net annual turbidity between sites located upstream of the mine-site and downstream at the boundary of the Ranger Project Area.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks).	Continuous turbidity monitoring during wet season.	Until suspended sediment loads are approaching background values (note: 5 years in the closure criteria).

*Assuming access to the landform is permitted after 2026

10.2 Water and Sediment theme

10.2.1 Surface water and sediments - Closure research, monitoring, maintenance and adaptive management

Surface water monitoring is currently undertaken at a number of sites within and outside the RPA. Monitoring is undertaken by ERA, the SSB and the Northern Territory Department of Industry, Tourism and Trade (DITT). The ERA surface water monitoring program is reviewed and updated annually in the Ranger Water Management Plan (RWMP) and Ranger Water Monitoring Strategy (RWMS). These documents are subject to a stakeholder review and approval process each year. The program includes monitoring for both compliance and operational purposes (i.e. active water management information).

The surface water compliance monitoring program, interpretation and reporting framework is very mature (Turner *et al.* 2015). The compliance monitoring program consists of continuous monitoring of electrical conductivity (EC) and turbidity, weekly grab samples for a range of key variables, and event-based auto-sampling upstream and mid/downstream of the mine on Magela Creek and Gulungul Creek.

Water quality results are compared to a three-tier system of management and compliance trigger values. This approach aligns with the National Water Quality Management Framework. The upper tier *Limit*, which represents the water quality objective for high-level ecosystem protection, is the compliance value. The framework also includes *Focus*, *Action* and *Guideline* values that prompt management and reporting actions. These lower tier management trigger values also provide criteria to assess the acceptability of, or suitable conditions for, planned active discharges of water from the Ranger Mine site to Magela Creek. This program will continue during the closure phase.

Once the mine enters the monitoring and maintenance phase, discharges of water from the rehabilitated site will be passive, so the three-tiered approach with discharge management responses will not be the most appropriate regime to implement. Monitoring will instead be interpreted against closure criteria at the locations agreed to for each criterion (Section 8).

Monitoring in the monitoring and maintenance phase (currently estimated to be 25 years after the closure phase) will assess rehabilitation success, any unexpected events or concentrations of COPCs (compared to model predicted results), and the protection of ecosystems, human health and environmental values, by comparison of water quality against closure criteria.

Groundwater solute transport modelling with uncertainty analysis has predicted the period of time post closure at which peak solute loads will exfiltrate in the four major RPA surface water catchments (Magela, Gulungul, Coonjimba and Corridor). The periods at which peak loads exfiltrated in the surface water catchments vary as a result of the location of the source, the type of source, and transport pathway/s associated with the source.

Timeframes for the peak loads from the major mine sources (INTERA 2021) are:

- TSF contaminant plume ~6 years;
- Pit 1 tailings flux ~13 years; and
- Pit 3 tailings flux ~22 years.

The Ranger surface water model (Section 5) predicts the concentrations of COPCs that the creeks and billabongs will be exposed to as a result of these loads.

This time lag and its relevance to monitoring, and assessing if closure criteria will be met, is recognised in the SSB rehabilitation standard series[2] which states:

> *Given the potentially long timeframe between the completion of rehabilitation and the peak delivery of contaminants to surface water, this Rehabilitation Standard will most likely be used to assess predicted magnesium[3] concentrations from modelled scenarios. Ongoing surface water and groundwater monitoring will be required after rehabilitation to continue to ensure the environment is being protected, and to validate and assess confidence in the models.*

Thus, the aims of the long-term surface water monitoring program can be described as:

- to assess whether closure criteria are met, or if water quality is transitioning toward meeting criteria;
- to provide assurance that the environment is being protected; and
- to validate and assess confidence in the solute transport predictive models.

Water quality parameters and draft guideline values have been proposed for each of the objectives of the surface water and sediment closure theme (Section 8). These have been developed in consultation with the Water and Sediment Working Group (WASWG). The draft monitoring program to assess if the criteria are being met will be reviewed by the same group.

The locations and monitoring frequencies for current surface water monitoring (Figure 10-6, Figure 10-7 and Figure 10-8) forms the basis of the proposed monitoring strategy. Sub-catchment monitoring exit points will be included as part of surface water monitoring during Pit 1 rehabilitation. Consideration of onsite and sub-catchment exit points will be discussed in future planning meetings with the SSB, with new information included in updates to the MCP. The rationale for monitoring at these locations are:

- Current compliance points MG009 and GCLB, just inside the boundary of the RPA. Comparison of water quality at the current compliance points in Magela and Gulungul creeks against agreed water quality objectives will continue to provide the basis of

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[2] http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards

[3] The same statement is made in the rehabilitation standard for each COPC

assessing protection of the aquatic environment, human health and recreational values in creeks and billabongs downstream of the RPA.

- Upstream and downstream on Magela and Gulungul creeks. Continuous turbidity during the wet season will enable the comparison of suspended sediment with natural distribution (suspended sediment landform criteria and aesthetic values of clarity).
- Onsite billabongs. Comparison of water quality and sedimentation in Coonjimba and Georgetown billabongs with criteria accepted as representing impacts that are as low as reasonably achievable (ALARA) will demonstrate acceptable levels of protection for ecosystems and land use on the RPA.
- Comparison of results against model predictions for all of the above sites will be undertaken for validation purposes.

Table 10.3 provides the proposed monitoring program for the monitoring and maintenance phase, which is also applicable for the closure phase. Monitoring during the closure phase may identify the potential opportunity to decrease the monitoring scope during monitoring and maintenance phase.

ERA is planning to shift to event-based auto-sampling regime for monitoring, with sample collection triggered by changes in continuous EC data. This approach, currently used by the SSB, should be suitable for the monitoring program after closure and will be discussed at the WASWG.

The proposed monitoring program will evolve based on changes in methods and technology, feedback by WASWG, and results collected in the initial years of monitoring. Discussions and improvements to this framework will likely be adapted into the broader site-wide closure monitoring programs. It is anticipated that the post-closure monitoring program could be carried out by a local service provider.

Reporting of the surface water monitoring program during the monitoring and maintenance phase, including frequency, format, and degree of results interpretation, will be discussed by the WASWG. It may be that the results, and any triggered investigations and actions, will be provided to stakeholders with an interpretive report at the end of each wet season. Targeted investigation reports may be provided as completed, rather than at the end of the wet season.

Figure 10-6: GC2 monitoring station in the dry season

Figure 10-7: GC2 monitoring station in the wet season

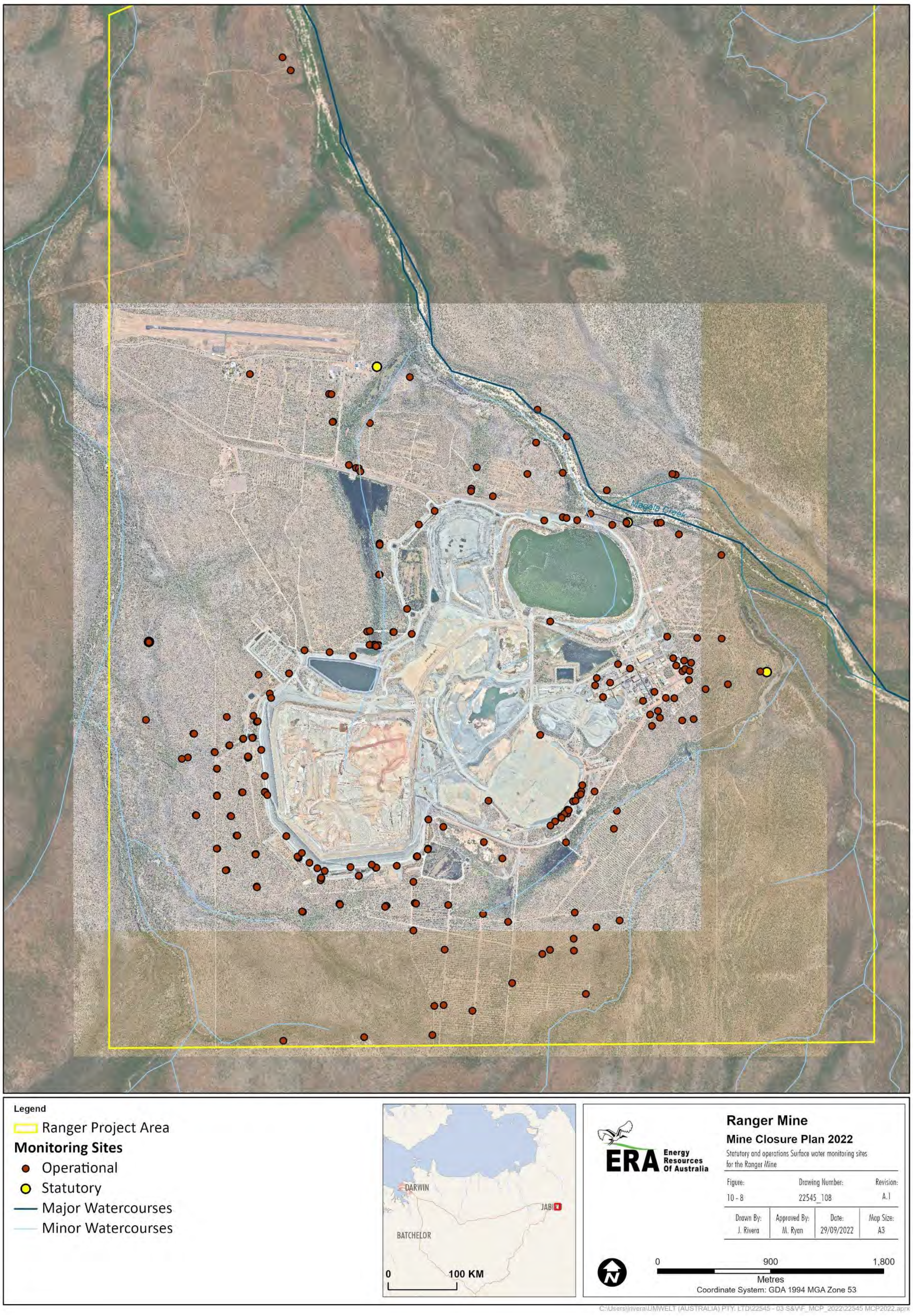

Figure 10-8: Statutory and operations surface water monitoring sites at the Ranger Mine

Table 10.3: Parameters and locations for post-closure surface water monitoring to assess compliance with closure criteria

Location	Parameter	Frequency
MG009, GCLB, MCUS, GCC *The parameter list for MCUS and GCC upstream sites may be reduced in future where criteria does not include comparison against natural distributions*.	Turbidity	Continuous
	EC (proxy for Mg)	
	Mn, U, SO_4	Event-based auto-sampling based on continuous EC during the wet season with frequency reduced over time based on performance and risk review.
	Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N	
	NO_3, NO_2	
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.
Georgetown, Coonjimba and Gulungul Billabongs	Turbidity	Continuous.
	EC	
	U, Mn, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, SO_4	Event-based auto-sampling based on continuous EC during the wet season with frequency reduced over time based on performance and risk review.
	NO_3, NO_2	Monthly (if recreational and drinking water identified as community value for these sites).
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.
	Sediment concentrations and U	Accumulation in sediments limited by U in water criteria. Sediment sampling to demonstrate current compliance via scheduled projects in closure phase.
	Sedimentation	Event-based triggered by results of landform monitoring. TBC in consultation with Landform criteria and Water quality stakeholder groups.

10.2.2 Groundwater – Closure research, monitoring, maintenance and adaptive management

The groundwater monitoring program has been designed to identify changes in groundwater head and solute concentrations for comparison against expected changes in the groundwater system (i.e. changes in groundwater heads and flow direction and changes in concentrations of selected solutes). This monitoring regime will be undertaken at an appropriate temporal and spatial scale to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and achieve the relevant closure criteria.

10.2.2.1 Broader groundwater monitoring program

The primary objective of the groundwater monitoring program is to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and the regional groundwater environment remains protected. The groundwater monitoring program has been modified to provide a greater focus on source terms, site activities, pathways and receptors relevant to the particular monitoring programs and/or site areas.

The groundwater monitoring network on the RPA is described through discrete hydrolithologic units (HLU), divided into seven areas to better identify and report on source-pathway-receptor linkages. These HLUs are delineated based on similar geological and groundwater flow and transport characteristics. The HLUs monitored as part of the Annual Ranger Groundwater Report (ARGWR) are described in detail in *Section 5 KKN Supporting Studies* of this MCP.

The results of solute transport modelling (INTERA 2014a, 2014b, 2018, 2021) indicate that solutes at depth in the backfilled pits will enter low-permeability Hydrolithologic units (non-aquifers) and migrate away from solute sources at very low rates. The modelled flux rates from these units to shallow and deep aquifers and surface water bodies are very low. Ongoing monitoring of groundwater will provide data to validate these solute transport model predictions and assumptions.

Monitoring 'envelopes' in the four sub-catchments; Gulungul, Coonjimba, Djalkmarra and Corridor creeks, will be progressively refined during decommissioning. The ‘envelopes’ will comprise new and/or existing monitoring bores.

The location of piezometers, constructed to specifically monitor standing water level (SWL) at various points around the RPA, are shown in Figure 10-9. Frequency of SWL checks are presented in the annually released Ranger Water Management Strategy.

Figure 10-9: Area 8 – Piezometers

10.2.2.2 Groundwater monitoring across the site

A number of locations have been selected to inform closure studies, collect baseline data to support post closure monitoring, and assess the performance against closure objectives. Timeframes for installing bores are dependent on multiple external factors and therefore cannot have date-specific commitments in this plan.

Groundwater monitoring programs for closure for Pit 3 (Djalkmarra catchment), Pit 1 (Corridor Creek), and R3D are included as components of the annual RWMP and annual RWMS. The programs have been designed to target pathways for transport of solutes into the environment and the various HLUs defined in the groundwater conceptual model. Various new bores have been drilled and developed across the RPA since 2019, in the vicinity of Pit 1, Pit 3 and the processing plant.

Pit 1

The closure specific groundwater monitoring in the Pit 1 area is intended to demonstrate that solute transport velocities and concentrations within each hydrolithologic unit are consistent with modelling predictions, and provide baseline data to support post closure monitoring and the achievement of closure criteria in the receiving environment.

The program monitors changes in groundwater head and solute concentrations, within each hydrogeological unit, for comparison against expected changes in the groundwater system between Pit 1 and Corridor Creek.

Nineteen groundwater bores will be monitored, consisting of thirteen bores drilled specifically for the purpose of closure monitoring, and six existing groundwater monitoring bores (Figure 10-10; ERA, 2022). Monitoring will consist of a water quality laboratory analysis and groundwater level monitoring (Table 10.104; ERA, 2021). The bores monitored for closure purposes are listed in Table 10.10.

Data collected from the Pit 1 groundwater monitoring bores will be reported to stakeholders as part of the existing reporting requirements for the Ranger mine in the ARGWR, together with all other groundwater data collected across the site. Studies undertaken using the data will be shared with stakeholders through the Ranger Closure Consultative Forum (RCCF), ARRTC and the MCP where appropriate.

Data collected from the Pit 1 groundwater monitoring bores during the closure phase will inform development of post-closure monitoring plans, including thresholds and adaptive management outcomes.

Table 10.4: Groundwater monitoring bores for Pit 1 closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
GC2A	Pit 1	274455	8596171	12	7 to 11.7	S-WC	Biannual WQ & SWL
GC2B	Pit 1	274448	8596171	4	0.5 to 3.5	S-WC	Biannual WQ & SWL
MB-A	Pit 1	274092	8596243	50	44 to 50	UMS	Quarterly WQ & SWL
MB-G	Pit 1	273681	8595812	50	44 to 50	UMS	Quarterly WQ & SWL
MB-L	Pit 1	273933	8595935	50	14 to 16	MBL	Quarterly WQ & SWL*
R1C3-1	Pit 1	273977	8595978	22.25	16.25 to 22.25	Pending	Quarterly WQ & SWL
P1_CL_01	Pit 1	273624	8595993	18	10 - 18	WR	Quarterly SWL
P1_CL_02	Pit 1	273965	8595950	8	2 - 8	S-WC	Quarterly WQ & SWL
P1_CL_03	Pit 1	274174	8596230	9	3 - 9	S-WC	Quarterly WQ & SWL
P1_CL_04	Pit 1	274175	8596230	18	12 - 18	D-WC	Quarterly WQ & SWL
P1_CL_05	Pit 1	274176	8596230	35	29 - 35	HWS	Quarterly WQ & SWL
P1_CL_06	Pit 1	274177	8596230	75	63 - 75	MBL	Quarterly WQ & SWL
P1_CL_07	Pit 1	273751	8595738	7	4 - 7	S-WC	Quarterly WQ & SWL
P1_CL_08	Pit 1	273752	8595738	18	15 - 18	D-WC	Quarterly WQ & SWL
P1_CL_09	Pit 1	273753	8595738	35	29 - 35	MBL	Quarterly WQ & SWL
P1_CL_01A	Pit 1	273628	8595996	18	3-18	WR	Quarterly WQ & SWL
P1_CL_10	Pit 1	273521	8596265	18	3-18	WR	Quarterly WQ & SWL
P1_CL_11	Pit 1	274014	8596263	18	3-18	WR	Quarterly WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P1_CL_12	Pit 1	273915	8596019	18	3-18	WR	Quarterly WQ & SWL

Figure 10-10: Pit 1 groundwater monitoring bores

Historic tailings deposition

Several bores surrounding Pit 1 are monitored as part of historic approvals for tailings deposition, which have associated trigger values to ensure protection of the environment during these previous activities. These trigger values are provided in Table 10.5. Proposed control actions to limit the historic migration of seepage is described below.

Table 10.5: Historic trigger values for Pit 1 tailings deposition

Analyte	Stage 1 Trigger Value	Stage 2 Trigger Value
EC (µS/cm)	459	918
Mg (mg/L)	64	128
SO_4 (mg/L)	22	44

Stage 1

If the values of the parameters EC (459 µS/cm), Mg (64 mg/L) and SO_4 (22 mg/L) are exceeded, quarterly monitoring will be increased to monthly monitoring for the SMP, PMP series bores, MB-H, MB-L and OB30.

Stage 2

If the trigger values of the parameters listed in **Table 10.6** for Stage 2 are exceeded, one or a number of actions will be taken. These actions are outlined in the original deposition of tailings application. These actions have already been completed, or are ongoing operational actions, that are already in place irrespective of concentrations of the parameters. These actions include:

- remnant process water is being removed from the historic Pit 1 void via decant abstraction;
- pumping of MB-L bore has ceased, increasing groundwater levels behind the pit wall; and
- the construction of the seepage limiting barrier has been completed.

Pit 3

The closure specific groundwater monitoring for Pit 3 is to monitor groundwater head levels and solute concentrations, within each HLU for comparison against expected changes in the groundwater system between Pit 3 and Magela Creek.

Closure monitoring is via 28 bores detailed in the RWMS. Monitoring of bores proximal to Pit 3 are to address closure related monitoring objectives, including monitoring for any solute transport from Pit 3 associated with the deposition of tailings, to develop a background dataset to support post-closure monitoring, and to inform ongoing closure related studies. The bores monitored for closure purposes are listed in Table 10.6 and shown in Figure 10-11.

Table 10.6: Parameters for groundwater monitoring bores for Pit 3 closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
MS4	Pit 3	274311	8598255	9.25	6 to 9.25	DS	Biannual WQ & SWL
MS4-A	Pit 3	274311	8598255	5.25	1.45 to 5.25	DS	Biannual WQ & SWL
P3-4B	Pit 3	273822	8598301	100	60 to 99.5	D-UMS	Biannual WQ & SWL
P3-8	Pit 3	274292	8598235	81	42 to 69	D-UMS	Biannual WQ & SWL
P3-11	Pit 3	274362	8598122	25.6	11 to 25.6	D-WC	Biannual WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P3-12	Pit 3	273893	8598467	75.6	56 to 71	D-UMS	Biannual WQ & SWL
P3-13	Pit 3	274477	8597921	39	24.6 to 39	S-BC	Biannual WQ & SWL
P3-15A	Pit 3	274651	8598250	57	39 to 54	S-BC	Biannual WQ & SWL
P3-15B	Pit 3	274677	8598252	30	22 to 30	S-BC	Biannual WQ & SWL
P3-16	Pit 3	274117	8598323	57.7	34.7 to 57.7	D-UMS	Biannual WQ & SWL
P3_CL_01	Pit 3	274283	8598187	10	4 - 10	DS	Quarterly WQ & SWL
P3_CL_02	Pit 3	274287	8598183	25	19 - 25	D-WC	Quarterly WQ & SWL
P3_CL_03	Pit 3	274290	8598181	60	48 - 60	D-UMS	Quarterly WQ & SWL
P3_CL_04	Pit 3	273608	8598337	70	46 – 70	S-WC	Quarterly WQ & SWL
P3_CL_05	Pit 3	273820	8598300	20	8 - 20	S-WC	Quarterly WQ & SWL
P3_CL_06	Pit 3	273823	8598299	45	33 - 45	D-WC	Quarterly WQ & SWL
23562	Pit 3	274404	8598253		4.43 to 5.43	DS	Quarterly WQ & SWL
F11	Pit 3	273663	2598557		0.5 to 6	S-WC	Biannual WQ & SWL
F12	Pit 3	273768	8598629		0.5 to 6	S-WC	Biannual WQ & SWL
MC11	Pit 3	274909	8597892		1.5 to 2.5	S-WC	Quarterly WQ & SWL
MC12	Pit 3	274821	8598170		0.3 to 3	S-WC	Quarterly WQ & SWL
MC21	Pit 3	275015	8598001		3 to 4	S-WC	Quarterly WQ & SWL
NWOB003	Pit 3	274012	8598271		3 to 9	DS	Quarterly WQ & SWL
P3-3A	Pit 3	273686	8598892		40 to 52	S-BC	Biannual WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P3-3C	Pit 3	273687	8598898		10.5 to 16.5	D-WC	Biannual WQ & SWL
P3-7	Pit 3	273968	8598296		91.5 to 97.5	D-UMS	Biannual WQ & SWL
P3-9	Pit 3	274240	8598515		18.5 to 36.5	D-UMS	Biannual WQ & SWL

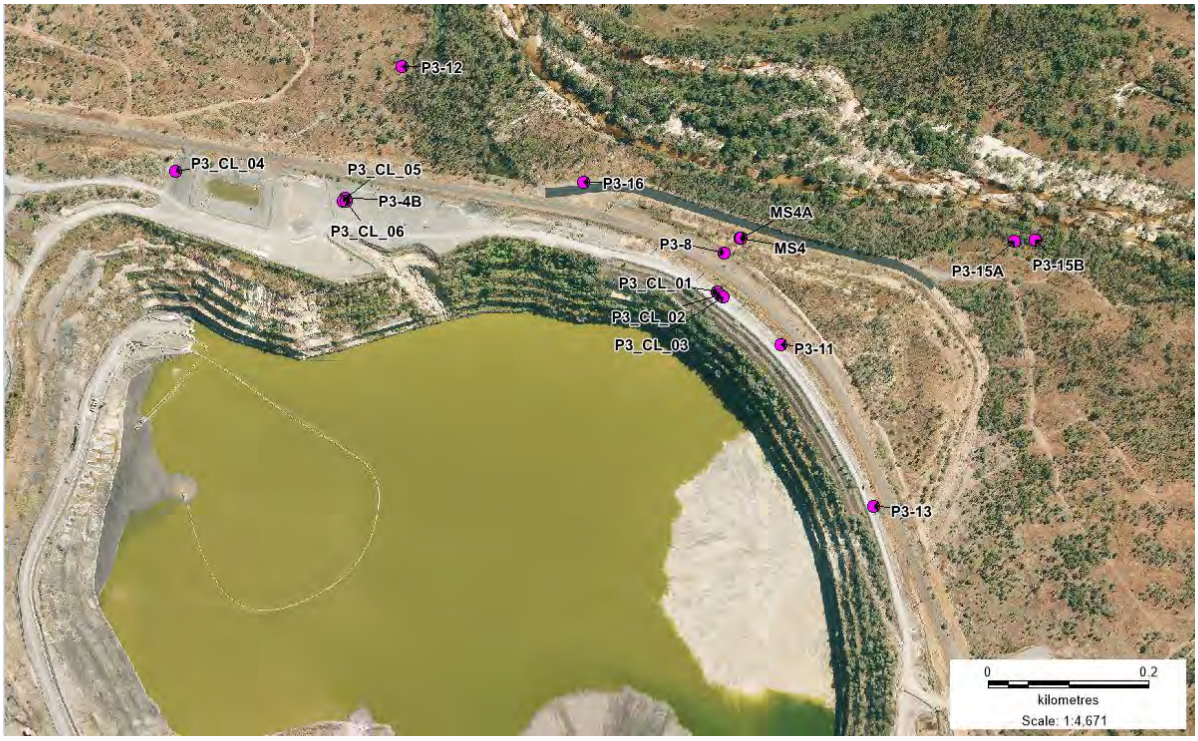

Figure 10-11: Location of Pit 3 monitoring bores

Ranger 3 Deeps

Ranger 3 Deeps (R3D) exploration decline and ventilation shaft rise was backfilled with waste rock in in 2021, however the following section is presented for historical context. This section will be removed from future iterations of the RWMS, and upon the recommendation to remove the associated groundwater monitoring infrastructure once reviewed in the ARGWR.

The overall objective of the groundwater monitoring in this area was to monitor changes in groundwater head and solute concentrations within hydrolithological units adjacent the R3D underground workings.

Adjacent the R3D working, existing bores had been designated for monitoring to capture pre and post-wet season groundwater quality. However, the depth and age of these bores make conventional groundwater sampling impossible, as detailed in the RWMS.

Figure 10-12 shows the location of the groundwater bores used to monitor groundwater levels in the area of the R3D. As per the RWMS (ERA, 2022), all but one bore (R3D56A) has been removed from sampling because of the limited amount of relevant data collected from the bores due to their depth (Table 10.7).

Table 10.7: Groundwater monitoring for Ranger 3 Deeps

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
R3D56A	R3D	274557	8598065	449	0 - 349	DWP-Z	Biannual WQ & SWL

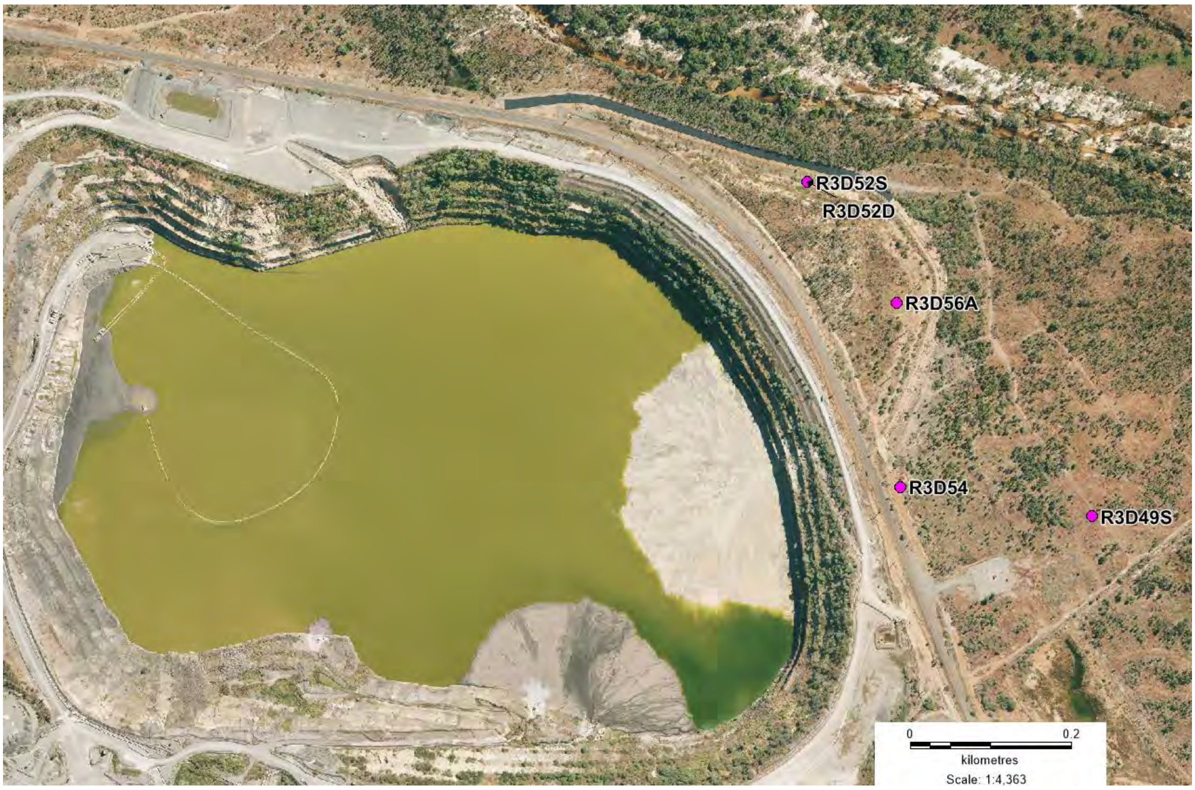

Figure 10-12: Location of R3D closure monitoring bores

Ranger Water Dam

The closure specific groundwater monitoring in this area is to monitor groundwater head levels to support the groundwater to surface water interaction study. The bore monitored for closure purposes is listed in **Table 10.8** and monitored as per the RWMS.

Table 10.8: Groundwater monitoring for the Ranger Water Dam

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
78_5	RWD	270305	8596283	45	5 to 45	D-WC	Biannual WQ & SWL

Stockpile seepage monitoring

This short-term monitoring program aims to collect and characterise stockpile seepage water for source-term use. The monitoring locations, objectives and sampling methodology are outlined the RWMS. The study to quantify the post closure source term for the waste rock has been completed (INTERA, 2020). As a result, water quality monitoring frequency is reducing from monthly to quarterly while the sampling frequency for filterable Radium and Polonium will reduce to annual samples.

Groundwater to surface water interaction

Data loggers recording the static groundwater level are to be installed in various shallow monitoring bores situated within the Magela floodplain to support assessment of groundwater to surface water interaction. The intent of this short-term monitoring program is to collect additional groundwater level data to refine numerical groundwater flow modelling in this vicinity. The monitoring locations are described in the RWMS. Additional monitoring includes bores 78_5 west of the RWD adjacent to Gulungul Creek, and MC12 adjacent to Magela Creek.

Pit 3 North Ramp

Current observed groundwater levels in monitoring bores in proximity to the Pit 3 North Ramp waste disposal location indicate that there is very low likelihood that groundwater adjacent the disposal location will migrate to Magela Creek, particularly whilst Pit 3 is a groundwater sink. Similarly, an investigative drilling program confirmed that there was no contamination of soils adjacent the liquid waste disposal site, with the exception of low hydrocarbon concentrations at the base of the ramp.

To verify this hydraulic response, groundwater monitoring in the vicinity of the disposal location has been increased to a quarterly frequency. Furthermore, the monitoring objectives for monitoring bore P3_CL_05 and NWOB001 have been expanded to include assessment of contaminant migration from the disposal location. The augmentation of the monitoring program will continue for a 12 month period, in order to collect sufficient data to verify the hydraulic response adjacent Pit 3. Monitoring locations, objectives and sampling methodology are outlined in the RWMS.

Background COPC

Following completion of the background COPC study (ERM, 2020), it was identified that some HLU's did not have sufficient data. To support future assessments, eleven existing monitoring bores in the primary transport pathway HLUs that were identified as having insufficient data (Djalkmarra Sands and Depressurised UMS at Pit 3, and MBL Zone at Pit 1) have been identified with an additional data objective in the RWMS.

Baseline Closure Monitoring

The water quality monitoring suite for all closure monitoring bores has been expanded to ensure that at a minimum all 20 COPCs modelled in post closure solute transport studies are monitored. The updated monitoring suite is outlined for each bore in the RWMS.

Drilling of additional Monitoring Bores

Eleven new monitoring bores were drilled in 2021/2022 in order to replace aging infrastructure, reduce spatial data gaps, and inform additional closure monitoring objectives. These new bores have been incorporated into the RWMS.

10.2.3 Completion criteria monitoring

An indication of background groundwater chemistry obtained from current monitoring data is provided in Table 10.9.

Table 10.9: General background groundwater chemistry on the RPA

Parameter	Alluvial HLUs	Shallow Weathered HLUs	Deep Bedrock HLUs
EC	<500 µS/cm		
Sulfate	< 5 mg/L Higher concentrations in the dry may result from evapotranspiration. Fluctuating concentrations may relate to input from surface water or runoff.	<5 mg/L Steadily rising concentrations through time are likely to indicate seepage from the TSF or stockpiles.	<5 mg/L Steadily rising concentrations through time are likely to indicate seepage from the TSF or stockpiles.
Magnesium	< 30 mg/L with no indications or steadily rising concentrations.		
Calcium	< 40 mg/L with no indications or steadily rising concentrations.		
Manganese	< 5 to approximately 2000 µg/L, fluctuating concentrations	< 10 to approximately 2000 µg/L with no indication of steadily rising concentrations	
Radium-226	Variable, < 5 to approximately 100 mBq/L	Variable activities < 5 to approximately 300 mBq/L	
Uranium	< 10 µg/L		

The proposed closure and post-closure monitoring will comprise monthly measurements of standing water level and quarterly or biannual sampling and chemical analysis (Table 10.10).

The objective of the post-closure groundwater monitoring program is to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and that the receiving environment will remain protected from defined COPCs.

COPCs are constituents considered to be a potential concern to the environment, and can be a concern for humans, biota and/or fauna. The Ranger Authorisation stipulates environmental monitoring of groundwater for the solutes magnesium (Mg), sulfate (SO_4), manganese (Mn), uranium (U) and radium-226 (^{226}Ra). Organic contaminates such as total petroleum hydrocarbon (TPH) are potential COPCs for the historical processing plant area.

COPC trigger levels for all parameters must be determined from suitable background collection sites, and these will inform the criteria for ongoing management. A representative sample of bores will remain for the groundwater monitoring program post-closure. The monitoring frequency is expected to decrease as the post-closure groundwater environment stabilises, providing no further risks are identified.

The final groundwater monitoring plan and relevant COPCs for post-closure will be developed with continued stakeholder engagement and advice from INTERA upon completion of the post-closure solute transport modelling. The post-closure groundwater monitoring plan will also incorporate refined background chemistry data as established by KKN studies (Section 5).

Table 10.10 Groundwater closure and post closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Compliance Reference
Standing water level	Manual standing water level measurements	Compare to adopted background levels to confirm groundwater level is behaving according to modelled predictions, within the documented uncertainties. To determine hydraulic gradients and potential movement of COPCs.	Groundwater monitoring locations listed in **Table 10.5. Error! R eference source not found.**	Monthly (during closure and year 1 post-closure). Quarterly (years 2-4 post-closure) if no changes). Annually during wet season (ongoing if no changes).	Until criteria have been achieved.	Ranger Authorisation Annexes D & E, annual Ranger Water Management Plan and Ranger Water Monitoring Strategy.
Chemical analysis	*In situ* parameters (pH, EC) Major ions and cations (Mg, Na, K, Ca, Cl, SO_4, HCO_3, CO_3) Filterable metals (U, Mn, Fe) Total nitrogen (NOx-N (NO_2-N+NO_3-N), NH_3-N) Ra-226	Compare to adopted background levels to confirm groundwater chemistry is not being adversely impacted by COPCs from former RPA activities. Where COPC impacts are already present, to ensure these are not migrating into additional impact areas.	Groundwater monitoring locations listed in **Table 10.5**.	Quarterly (during closure and years 1-3 post-closure if no exceedances). Annually during wet season (ongoing if no exceedances).	Until criteria have been achieved.	Ranger Authorisation Annexes D & E.

Aspect	Methodology	Analysis	Location	Frequency	Duration	Compliance Reference
	Additional trace metals (Cd, Cr, Cu, Hg, Pb, Zn, Fe, Al) Total Petroleum Hydrocarbons (TPH)		Sites (to be determined) in Process Plant Area.			

10.3 Radiation theme

10.3.1 Closure research, monitoring, maintenance and adaptive management

The proposed post-closure monitoring for radiological performance has been structured around the exposure pathways for radiation due to the potential access to, and final land use of, the area. These pathways are:

- inhalation of Long Lived Alpha Activity (LLAA e.g. radioactive dust);
- inhalation of radon progeny (Potential Alpha Energy Concentration; PAEC);
- ingestion of radioactive material in (or with) food or water; and
- external irradiation from gamma rays (and beta particles).

Given the possible post-closure use of the landform, the critical group will be Aboriginal people using the site for traditional activities including transient camping and the gathering of traditional bush foods for consumption.

LLAA and PAEC will be measured towards the end of the dry season for the initial five-year period following construction of the final landform. The details of the monitoring program are provided in Table 10.11. Lower soil moisture during the dry season results in increased Rn exhalation rates and higher dust concentrations in air. Monitoring will be undertaken over a minimum one-week period each dry season using either:

- High volume air samplers (LLAA) or continuous radon decay product monitors (PAEC) targeting areas with increased activity present in the sediments; or
- Passive techniques that integrate over a longer time period, such as track etch detectors (PAEC) or passive dust samplers (LLAA) over a three- to six-month period.

Potentially contaminated waters will be monitored in conjunction with the water and sediment monitoring program with grab samples taken upstream and downstream of Ranger Mine in Magela and Gulungal creeks and at key receptor locations. Samples will initially be taken monthly during creek flow; this will reduce to annually once low levels have been confirmed. Results of this monitoring program will be used to determine ingestion dose from drinking water and eating bush foods.

At the completion of decommissioning activities, an airborne radiometric survey with targeted ground surveys for external gamma dose rate and ^{226}Ra in soils will be undertaken to determine the gamma dose from the final landform.

Radiological research monitoring and studies have been ongoing on the Ranger Trial Landform, the Ranger Land Application Areas and more recently on the Pit 1 landform (ERA, 2020). This includes monitoring to inform human and non-human radiological impact assessments undertaken by both ERA and the Supervising Scientist Branch (Section 5).

10.3.1.1 Surface gamma surveys

ERA is investigating the use of autonomous airborne radiation monitoring equipment for gamma surveying. In the case where autonomous airborne radiation monitoring is not possible, a ground-based gamma survey will be conducted (ERA, 2021).

During 2021, ERA purchased a CZT (Cadmium zinc telluride) based detector unit to undertake drone surveys of the final landform, as different areas become available. A gamma survey will be performed by competent trained personnel using a gamma detector in a regular grid pattern over these areas. Absorbed gamma dose rates are to be measured at a height of 1 m above the ground level and integrated over a 60 second time interval.

In April 2021, SSB undertook a ground-based gamma survey of the Pit 1 landform to verify the grade and U-nat (i.e. U-238 in equilibrium with its decay products) activity concentration of the surface waste rock material (ERA, 2021). This survey was undertaken in a grid pattern and gamma counts over a 60 second time interval was recorded at a height of 1 m above ground level. Measured count rates will be converted into absorbed gamma dose rates and cosmic-ray, Th-232 and K-40 contributions to measured dose rate will be subtracted from the result (ERA, 2021). Dose coefficients for external exposure to radionuclides will then be used to estimate U-nat activity concentrations.

A contour map of U-nat activity concentrations across the entire Pit 1 final landform will be produced to visualize the results.

The distribution (i.e. normal or lognormal) of the U-nat activity concentration data will be determined (ERA, 2021). From the distribution, the percentage (if any) of the Pit 1 final landform with U-nat activity concentration above the cutoff for 1's grade waste rock (i.e. ~2100 Bq/kg) will be estimated (ERA, 2021).

The appropriate mean value (i.e. arithmetic or geometric) for the determined distribution will be calculated and compared with the anticipated average U-nat activity concentration for the entire Ranger final landform of 800 Bq/kg (ERA, 2021).

The results from this survey, and the comparison to historical monitoring data, will be reviewed by ERA and discussed in future iterations of the MCP.

10.3.1.2 Radon 222 exhalation flux density

Radon-222 exhalation measurements on the Ranger trial landform was monitored in 2009, 2014 and 2016 (Bollhöfer & Doering, 2016) to inform the SSB radiation dose assessment for the radon-222 pathway (Doering *et al*., 2018). The SSB radon-222 exhalation measurements on the TLF was re-established in 2019 (Section 5).

ERA aims to undertake radon-222 exhalation monitoring on Pit 1 landform during 2022. Brass canisters containing activated charcoal will be used to collect the exhaled Radon-222 from the surface waste rock and will be estimated using published methodologies with Spehr and Johnston (1983) and Bollhöfer and others (2005) as examples.

To assess seasonal variability, ERA will aim to undertake Radon-222 exhalation flux measurements at the end of dry season in 2022 and end of wet-season in early 2023.

10.3.1.3 Radium 226 substrate sampling

Surface substrate samples of 10cm depth will be collected from directly underneath all the locations where Radon-222 exhalation flux measurements occur. Sufficient volume of substrate to enable analysis is to be collected from each location.

The collected substrate samples are to be homogenised in preparation for radionuclide analysis by gamma spectrometry. Samples will be sent for analysis with an additional storage period of a minimum 24 days after pressing to allow for the ingrowth Radon-222 progeny radionuclides. Radon-222 is used as a proxy measurement of Radium-226 in the sample.

Sampling will be based on a systematic random sampling approach as shown in Figure 10-13 (IAEA, 2019). The systematic random sampling approach will allow radiological monitoring to be deployed without interference with other Pit 1 works (contouring, irrigation, revegetation, etc).

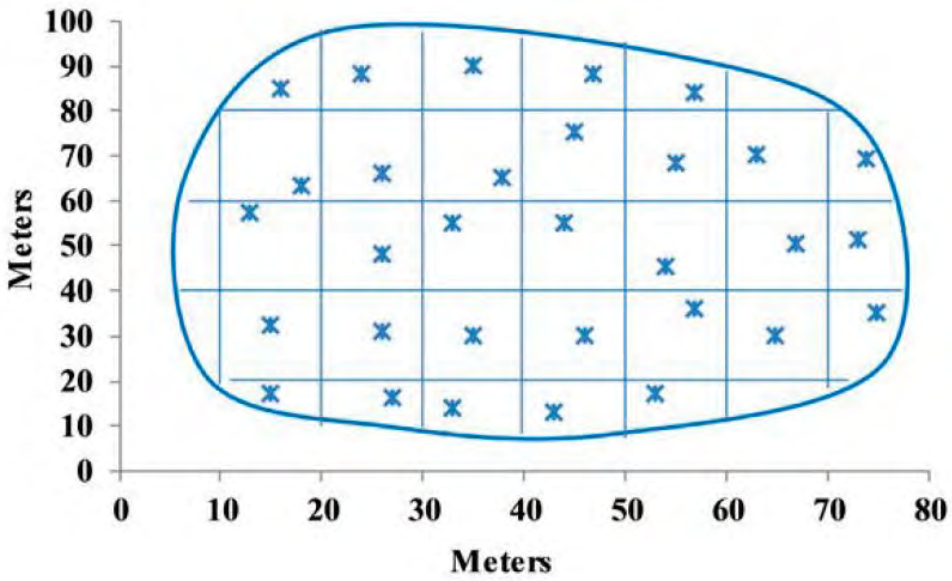

Figure 10-13 Systematic random sampling approach (IAEA 2019)

10.3.1.4 Passive Radon 222 sampling

Passive radon monitors (PRM) will be used for the measurement of radon in air. The monitors will be placed 1 m to 2 m above the ground level for 3 months and then collected to be sent to certified laboratory for Radon-222 analysis. Sampling locations will follow the same grid pattern as Radon-222 exhalation and Radium-226 sampling. The PRM will then be sent to an accredited laboratory for radon gas decay counts.

10.3.2 Completion criteria monitoring

Monitoring and research undertaken will inform the final radiological impact assessment for the Ranger mine closure. The assessment considers potential radiation exposure to members of the public, as well as terrestrial and aquatic biota (Section 5).

Radiation monitoring for the closure phase, and the post-closure phase (i.e. monitoring and maintenance phase), is provided in Table 10.11.

Table 10.11: Radiation closure and post-closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration
Long Lived Alpha Activity (LLAA) – Radionuclides in dust	High volume samplers or deposited dust samplers to monitor.	Confirm radiation doses to members of the public are below limits (as defined in closure criteria).	RPA and key receptor locations off site.	Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3–6 months (for years 1–5)	Five years following completion of rehabilitation works.
Radon Decay Products (RDP)	Continuous radon decay product monitors or more passive techniques such as radon track etch detectors.	Confirm radiation doses to members of the public are below limits (as defined in closure criteria).	RPA and key receptor locations off site.	Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3–6 months (for years 1–5).	Five years following completion of rehabilitation works.
External gamma radiation	Airborne radiometric survey with ground gamma survey and soil sampling.	Confirm radiation doses to members of the public are below limits (as defined in closure criteria).	Final landform.	Once at the completion of rehabilitation activities.	NA.
Radionuclides in bushfood	Alpha spectrometry analysis of samples for Ra-226, Po-210 and Pb-210. ICP-MS for U.	Confirm radiation doses to members of the public are below limits (as defined in closure criteria).	RPA.	To be refined based on fruit and seed production seasons.	Until demonstrated progression towards closure criteria, i.e. low levels have been confirmed.

Aspect	Methodology	Analysis	Location	Frequency	Duration
Bushfood – water	Analysis of samples for Ra-226, U, Po210 and Pb210 *Analysis method to be determined.*	Confirm radiation doses to members of the public are below limits (as defined in closure criteria). Confirm radionuclide concentrations used in concentration ratios for ERICA assessment.	MG009 and GCLB.	Monthly during wet season flow decreasing to annually over time.	Until demonstrated progression towards closure criteria, i.e. low levels have been confirmed. Duration or timeline for ERICA assessment (5 years post completion of rehabilitation works.
Soil radionuclide analysis	Gamma spectometry analysis of samples for Ra-226, U-238.	Confirm radionuclide concentrations used in concentration ratios for tier 2 ERICA assessment.	RPA other than final landform waste rock areas.	Once.	Post completion of rehabilitation works.

10.4 Ecosystem theme

10.4.1 Closure research, monitoring, maintenance and adaptive management

10.4.1.1 Trail Landform (TLF) and Pit 1 monitoring

The Trail Landform (TLF) and Pit 1 are two of ERA's key ecosystem research programs and are critical components of the Species Establishment Research Program (SERP). Each area has its own respective monitoring plan that cover matters including, soil and moisture relations, nutrient cycling, initial revegetation and ecosystem establishment. A summary of the ERA ecosystem monitoring projects is provided below.

The TLF is a twelve-year-old revegetation trial and is considered to be at an intermediate phase of ecosystem development. It produces valuable information regarding ecosystem trajectories, including:

- waste rock as a growing material, including substrate moisture content, nutrient cycling and soil development;
- species-specific performance over time, including their ability to flower, fruit and self-recruit successfully either from seed and/or vegetative means;
- ecosystem community structure development;
- external colonisation of flora species, both native and exotic;
- visitation and/or colonisation of fauna;
- ecosystem resilience against disturbances such as storms, fire, disease and pests; and
- provides the opportunity to trial maintenance and adaptive management actions to ensure the ecosystem develops on a desirable trajectory.

Pit 1 is a newly formed landform and is at the very early stages of ecosystem development. Research monitoring will primarily focus on:

- waste rock as a growing material, including substrate moisture content, nutrient cycling and soil development; and
- species-specific initial establishment of tubestock, considering the different methods used for propagation and the different revegetation seasons.

Each of the soil moisture stations on Pit 1 consists of an array, or ‘vertical nest’, of soil moisture content sensors (CS650, Campbell Sci, USA) and thermal conductivity (TC) sensors (CS229 Soil Moisture Matrix Water Potential Sensor, Campbell Sci, USA) (ERA, 2021). The CS650 sensors monitor temperature, EC, and allow for the monitoring of volumetric water content (VWC). The TC sensors allow for the monitoring of matric suction and temperature. TC sensors also allow for the validation of VWC variations through the material. Data collected will allow for continuous monitoring of gradients and changes in the water storage of the growth medium. Whilst the CS650 sensors provide an indication of the actual water content in the soil, matric suction measured by the TC sensors highlights the relationship between rainfall and movement of moisture within the soil profile (ERA, 2021).

The TLF ecosystem monitoring programs are summarised in Table 10.12, and the Pit 1 ecosystem monitoring programs are summarised in Table 10.13 and Table 10.14. Unless otherwise specified, all data collected from monitoring will be used to inform the Ecosystem Establishment Strategy, the ERA State & Transition Model, and ERA’s Adaptive Management Plan.

The TLF and Pit 1 plans were created prior to ecosystem closure criteria agreement, therefore they will require review and potential updating to ensure monitoring is providing meaningful data that aligns with criteria. Any revisions and changes will be included in future iterations of the MCP.

Table 10.12: Summary of TLF monitoring programs

Monitoring	Timing and Frequency	Location	Parameters	Purpose
Substrate Moisture	Continuous until 2026, or until system failure	1A	Volumetric water content	To determine the changes in soil volumetric water content over time to better understand how plant water uptake dynamics changes over the long term (e.g., at a decadal scale). Data will be used for WAVES modelling.
Nutrient Sampling	April 2024	1A and 1B Permanent Monitoring Plots	Samples will be analysed for: pH, EC and CEC, Total N, NO_3 and NH_3, Total OC, Water Soluble OC, P-Cowell	To understand the nutrient status of the TLF.
Overstorey Monitoring	Biennially at the end of the wet season until 2026	1A and 3	Species and height for all plants > 1.5 m tall. Diameter at breast height (DBH) for all plants with a DBH > 3 cm at 1.3 m.	To gather species survival and growth data from a mature revegetated waste rock ecosystem.
Understorey Monitoring	Annually at the end of the wet season until 2026	1A	Species abundance and ground cover (%)	To capture the structural and compositional development of the TLF’s understorey.
Secondary establishment trials	Annually at the end of the wet season until at least 2022	1A and 1B	Tubestock and direct seeded plots and will be monitored for: Persistence/survival Growth (mm) or cover (%) Health Flowering/fruiting Recruitment	To refine suitable species selection and establishment techniques for introducing understorey species during the secondary phase of revegetation. To better understand understorey establishment, particularly long-term persistence and recruitment.

Sustainability Surveys	Monthly or bi-monthly depending on the season, until at least 2023	Along 2 - 4 *ad hoc* transects in all sections	For every species that was introduced (planted or seeded): Level of flowering and fruiting. Self-recruitment type and approximate amount. General health. The approximate amount of externally colonising flora species (native and exotic) is also recorded. Photos of anything anomalous or interesting.	To opportunistically survey patterns and changes on the TLF that may not be captured during other, less-frequent monitoring. To better understand the TLF's ecosystem development and sustainability, specifically: • Are established plants able to flower and fruit? • Are established plants able to recruit? • Do the plants appear healthy (i.e. any pests and/or diseases present, are there signs of recovery after disturbance)? • Are new plant species able to colonise from external sources? • What weed and exotic species are present? • What animals are observed on the TLF?
Resilience Monitoring	After a disturbance event as soon as the TLF can be safely accessed.	All disturbed sections	Parameters will vary depending on the type and severity of the disturbance. For example, after a significant storm event surveys will focus on canopy defoliation, branch and/or trunk damage, and tree/shrub uprooting. The sustainability surveys will capture signs of long-term recovery. If a prescribed burn is performed, pre- and several post-fire surveys will be conducted to capture the full impact of the burn.	To better understand the revegetated ecosystem's sustainability in terms of resilience to disturbance events.

Table 10.13: Summary of Pit 1 substrate and weather monitoring programs

Monitoring	Timing and Frequency	Parameters	Purpose
Substrate Moisture	End of the wet season 2022 until FLF Application submission	Volumetric water content and soil water potential.	To assess growth medium performance, with specific emphasis on water retention and plant available water (PAW). Data will be used for verification of the WAVES model.
Nutrient Sampling (TBC)	Within the first year of final planting and at five year intervals.	Samples will be collected via stratified sampling transect method, and analysed for: Bulk density, pH and EC, Exchangeable Cations (Ca, K, Mg, Na, CEC), Total N, NO_3 and NH_3, Total OC, Water Soluble OC, P, P-Cowell, PBI, S, Cl, and Exchangeable Al.	To determine the changes in nutrient status in the surface layer of Pit 1 over time, as an indication of nutrient availability and cycling.
Soil Formation (TBC)	Within the first year of final planting and at five/ten year intervals.	Samples will be collected via stratified sampling transect method, and analysed for particle size distribution.	To determine the changes in fines proportions in the surface layer of Pit 1 over time, as an indication of surface particle weathering and soil formation.
Weather Conditions	Continuous until 2026	Key weather conditions including solar radiation, wind speed and direction, rainfall, temperature and relative humidity.	The information will support the substrate moisture assessment and will be input to the WAVES and VADOSE/W modelling. The data will also help characterise the local atmospheric conditions that influence revegetation.

Table 10.14: Summary of Pit 1 revegetation monitoring program

Monitoring	Timing	Frequency	Parameters	Purpose
Ongoing nursery monitoring	Propagation period	Regularly throughout nursery propagation, minimum once a week	Seed lot germination rates (quantitative data recorded). Observations on seedling growth, health and general progress (qualitative data / comments recorded). Any nursery actions / treatments to seedlings are also recorded.	To capture species-specific nursery learnings to incorporate into the SERP database and Seed Management Database (SMD). These learnings will then inform: Future nursery practises (seed treatments, over-sow rates, propagation methods, growing times etc). The seed collection plan (readjusted based on germination rates, propagation methods, seed longevity etc). The revegetation plan / schedule.
Pre-planting survey	Within 2 weeks of planting	Once	Final seedling numbers, health (ranked 1 – 4) and height. A photo record is also taken of each species and treatment.	To record the final number of replicates per species per treatment in the nursery. After which, the planting plan for the area can be finalised and randomisation into planting trays can begin. To record a mean starting height for each species and treatment as a baseline for later growth monitoring. To record the health of species prior to transplanting to contextualise later results (eg. if tubestock were stressed prior to planting, it might explain high initial rates of mortality).
Post-planting survey	As soon as possible after planting	Once	DGPS location of each individual seedling, along with species identification and health ranking.	To more easily track individual seedlings over time, and to capture any early signs of transplant shock.

Monitoring	Timing	Frequency	Parameters	Purpose
Rapid assessment monitoring	First six months after planting	Monthly	A thorough walk-through of the planting area. Record observations on general seedling appearance, colonising weeds, flowering / fruiting, recruitment, substrate surface etc.	Adaptive Management (TARP) Allows ERA to identify any significant weed invasion issues or sections of mass seedling mortality, assess irrigation regime etc. which require follow-up action.
Research Trial Monitoring	First two years after planting	At 3, 6, 12, 18 and 24 months	Every individual seedling will be monitored for: Survival, Growth, Health, Flowering/fruiting, Recruitment. Additional comments will be recorded for seedling appearance and obvious environmental factors that may have impacted seedling performance. Photos of anything anomalous or interesting.	To capture species- and treatment-specific performance to incorporate into the SERP database. These learnings, with consideration of previous trial results and different substrate types, will then inform: Revegetation strategy: eg. if a species has considerably better performance with a particular pot type, or a species appears particularly sensitive to waterlogging etc., then the revegetation strategy may be reconsidered or adjusted for that species. Revegetation plan and scheduling: eg. if a species has considerably better performance at a particular age, or a species has very high mortality if propagated/planted during a particular season, then the revegetation plan / schedule will be reconsidered or adjusted for that species. Seed collection plan: may be adjusted based on species field mortality.

10.4.1.2 Revegetation and native flora monitoring

The scope and frequency of ecosystem monitoring is largely dependent upon the stage of development of the revegetation. Regular monitoring will be needed until the developmental trajectory can be seen to be steadying and the risk of deviation (due to mortality, weeds or fire etc.) and requirements for active management intervention is sufficiently reduced. As the final landform stabilises, the frequency, intensity and scope of the monitoring program can be adjusted to allow more effective use of resources.

Monitoring will be the most intensive during the initial revegetation period, as the highest tubestock mortality is expected within twelve months post-planting. Revegetation areas will be regularly inspected in the period immediately following planting to ensure the irrigation regime is appropriate (based on visible ground conditions), that seedlings are generally healthy, and that there is no weed incursion. This will likely be conducted by ground personnel walking through the revegetation areas, and potentially drones where practical. These regular inspections will be performed during the period when irrigation is operational and in the months leading up to the wet season. If considerable mortality is observed, this will trigger a more quantitative survey of species survival and health in the area. Transects or monitoring plots may be used depending on the nature and severity of mortality (i.e. widespread or localised), and the data collected will inform whether infill planting is required (Table 10.15).

Ongoing annual monitoring of tubestock establishment success will continue until all initial and subsequent infill plantings have developed sufficiently and attrition rates have stabilised, which should occur in the first three to five years.

As the ecosystem develops into the intermediate establishment phase (5–25 years), surveys will be performed every few years to monitor ecosystem development. After secondary introduction planting is performed, likely around the ten-year stage when canopy has matured and developed, additional 'initial' monitoring of these plants will need to occur in addition to the routine vegetation monitoring of the already established vegetation.

If the rehabilitation is impacted by a disturbance event (e.g. extreme weather, wildfire) additional monitoring will be performed to assess any damage to revegetation areas. Depending on the level of damage, remediation such as infill planting will be performed. Areas that receive remediation treatment will require a targeted monitoring program, independent of the surrounding areas, to assess the effectiveness of the remedial action and progress back towards the desired trajectory.

Table 10.15: Maintenance work that may be required for revegetation during the closure and/or post-closure phases

Action	Description
Infill planting	Infill planting will be undertaken during wet season where high mortality of 'initial' tubestock is observed in the first 6-24 months. 'Secondary' introductions of additional species will occur once suitable conditions develop. Infill planting may also be required when an unplanned large-scale event such as fire or cyclone causes significant additional mortality.
Application of fertiliser	To improve optimum growing conditions, tubestock will be planted with fertiliser pellets and, approximately 6-12 months later, a second application of fertiliser will be applied. Plant health and development will be the primary indicator of soil and plant nutrition, however five-yearly soil monitoring will assist with interpretation, and amelioration, of any determined nutrient deficiency, if required (e.g. addition of further fertiliser inputs).

ERA have recently begun investigating opportunities for remote sensing to be used for monitoring during closure. In May 2022, Dendra Systems conducted a trial flight over more than 460 ha of the RPA, including all of the LAAs and revegetated areas (Figure 10-14). The priority for the trial was to individually identify flora to a genus or species level where possible. Other components of interest were vegetation community structure, fauna observations, and identification of erosion and man-made features.

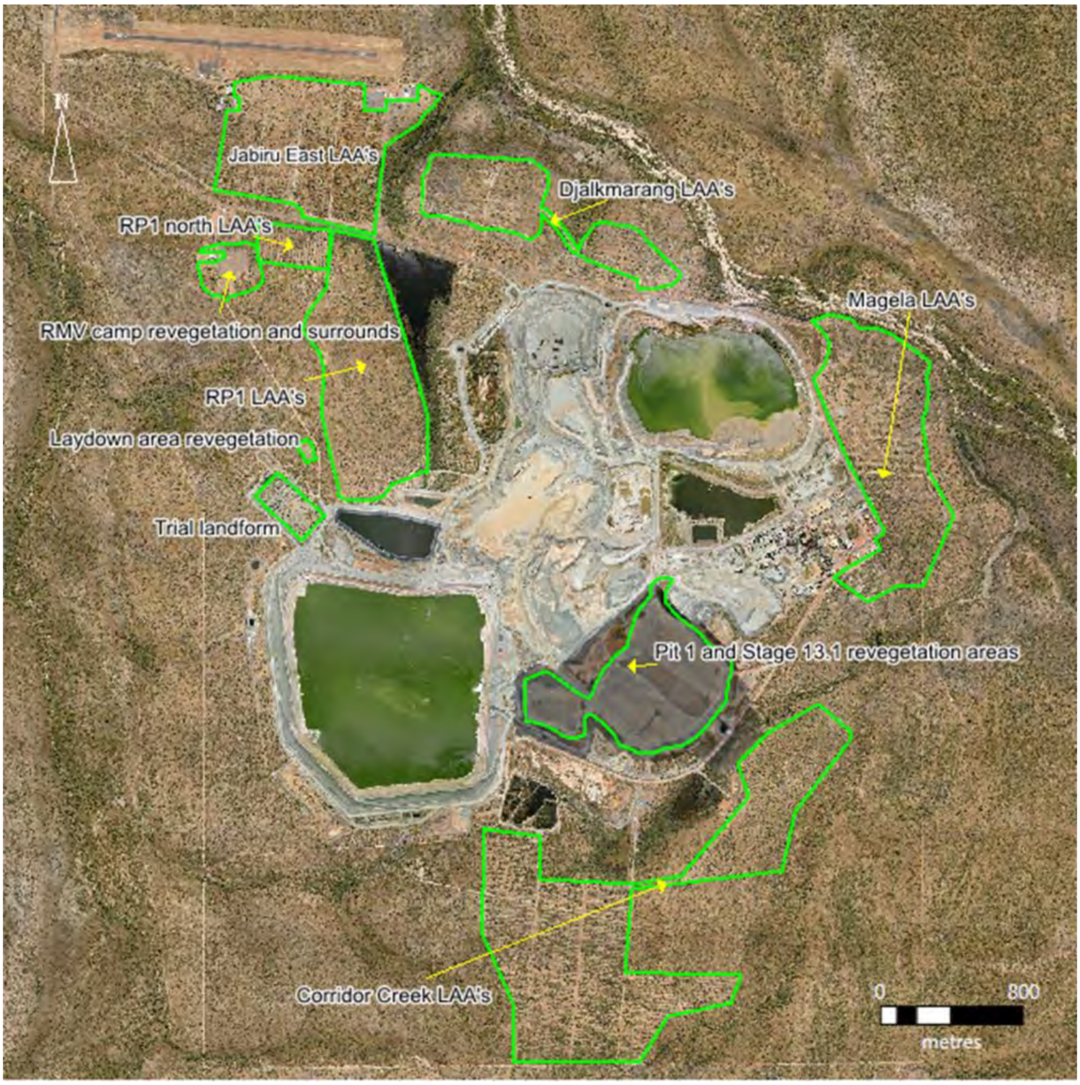

Figure 10-14: Areas surveyed by Dendra in May 2022

Methodology for the Dendra monitoring trials were as follows (pers. comms. Dendra September 2022):

1) Field/ground survey

To support the accurate labelling of features captured by the high-resolution imagery (HR), field ecologists ground-truth features (e.g. plants) in the same areas captured by flight operations. Field ecology operations are carried out at approximately the same time as when the images are captured. Ground-truth data consists of accurate coordinates, captured with a differential GPS unit, photos of features, and other metadata to allow subsequent matching of ground data to HR imagery. Plants are identified in the field when the identity is certain, otherwise specimens are taken, and subsequently identified using relevant literature and resources, and verified against herbarium specimens.

2) My.dendra analysis

Aerial HR and multispectral (MSP) imagery is used for analysis of vegetation cover and height, area classification, digital elevation models (DEMs) and outputs derived from DEMs. DEMs are produced by photogrammetry from the HR imagery. The DEMs that are provided as rasters are digital surface models, that is, they correspond to the ground surface with the shrub and tree layer removed. The vegetation layers are derived from the normalised difference vegetation index (NDVI), which is obtained from the MSP. From the DEM, the slope (gradient) of the terrain is calculated and areas with slopes of specified amounts (e.g. 10-14˚) are provided as output. Bare ground analyses are derived from the NDVI and DEM data.

Each area being analysed is further divided into 1x1 m grid cells, with each cell being classified into the following classes: bare ground, grass, shrub, tree or water. These classifications are assigned based on the dominant feature/class within the grid cell. The classifications are produced from the HR using object-based classification. Several classes of features visible in the HR imagery are labelled. That is, separate layers of either points, lines or polygons are associated with the HR imagery. Each of these feature classes fall into seven main groups: man-made objects or structures; native fauna, including their tracks; exotic/pest fauna, including tracks; erosion features; native plants; exotic/weed species; and ecological assessment or habitat structural features, such as fallen logs.

3) Machine learning

HR imagery, along with labelling of features by experienced data ecologists, is used to train a supervised-learning machine learning (ML) system. Provided that sufficient numbers of training examples have been obtained and input into the system, the accuracy and recall of the associations can be assessed. Accuracy of the identifications (often referred to as precision in ML literature) and recall (the ability to recognise a feature in the imagery) are assessed for each feature type and, once these reach minimum thresholds, those features are included into the ML system used to classify new imagery (i.e. imagery not used to train the system).

Preliminary results include:

- identification of almost 80 different flora groups, majority of which at a species level;
- identification of native birds and macropod tracks, as well as ‘cloven hoof’ tracks;
- identification of various erosion features, including splash, rill, gully, sheet and tunnel erosion, dry and wet pooling, as well as sedimentation; and
- identification of over 7,500 man-made features under 19 categories, such as irrigation infrastructure, poles, pipes, fences and gates, rubbish, scrap metal, drums and machinery.

Initial results from the Dendra monitoring trial are encouraging, and more details will be provided in the 2023 MCP once data analysis and reporting from the trial is completed.

10.4.1.3 Exotic flora

ERA has undertaken fine scale annual weed surveys and mapping across the RPA since 2003 (Figure 10-15) and will continue to do so throughout the closure period. This mapping provides data to assess the effectiveness of weed control measures from the previous season and the current weed loads in management areas (Figure 10-16). This informs the ongoing weed monitoring and subsequent corrective actions required. Weed control methods will be situation and species-specific, with the most effective controls determined from ERA experience and input from specialists. Weeds are likely to be controlled by a combination of chemical and physical methods, including application of residual and/or short acting chemicals, seed head cutting and burning, or fuel-load reduction by fire. Further details on weed management are provided in the *ERA Weed Control Management Plan 2021-2022.*

As the mined footprint is rehabilitated to final landform, new zones will be created and incorporated into the weed management plan. Weed management will be critical on the final landform, particularly during the initial stages whilst revegetation is establishing. Weeds may out-compete and/or smother tubestock, or may increase the risk of fire, and thus potentially increase tubestock mortality. Targeted weed monitoring, and routine revegetation monitoring will record if any weed infestations occur on the final landform.

Figure 10-15: Weed Management Zones Map

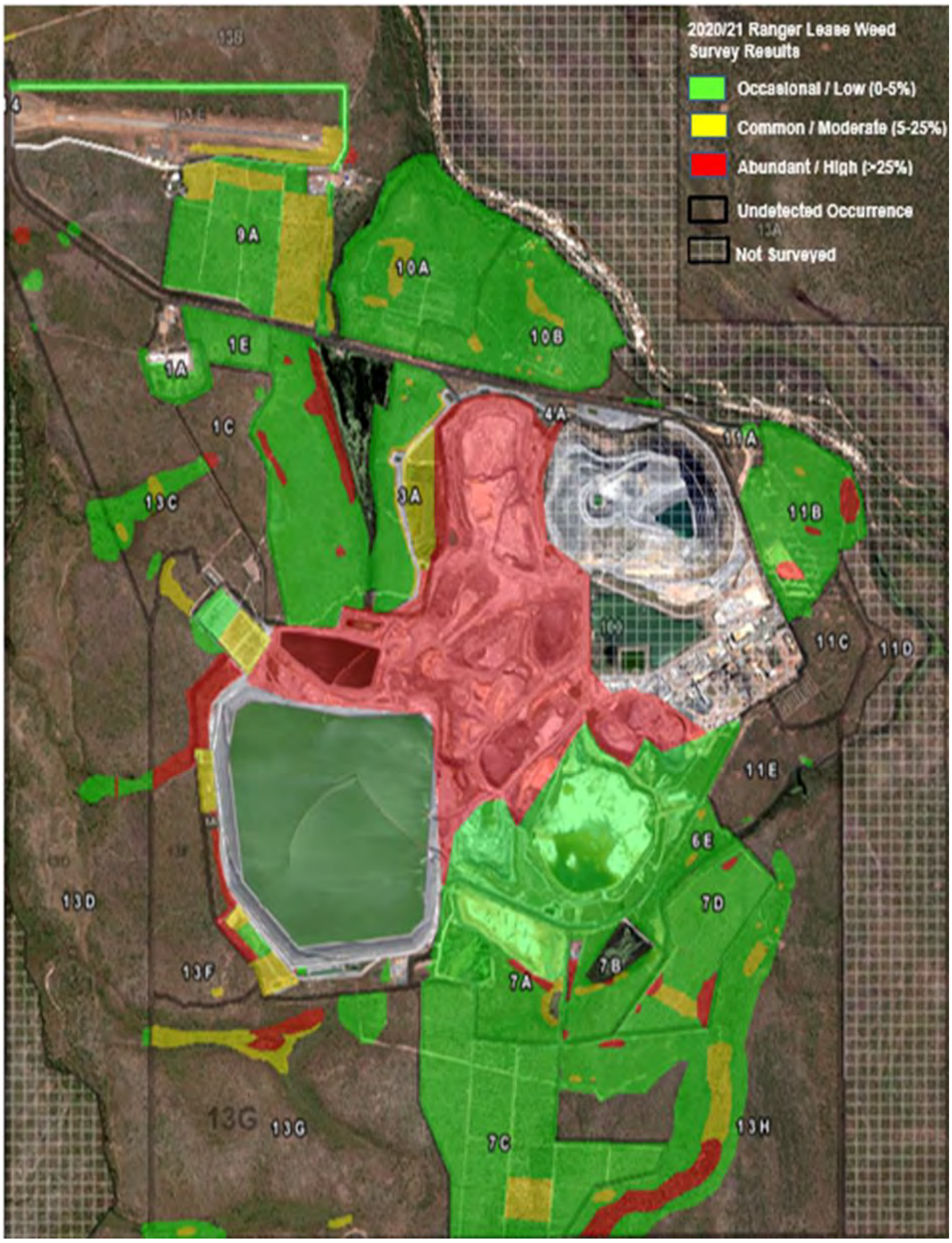

Figure 10-16: Weed loads on the Ranger Project Area 2021

10.4.1.4 Fire management

During operation, ERA's fire management was historically focussed on protecting assets from wildfire by maintaining fire breaks and conducting fuel reduction burns. In the years leading up to closure, the fire strategy shifted to incorporate a greater focus on land management and rehabilitation across the site. With consultation from Kakadu Native Plants Pty Ltd (KNPS), the fire management plan introduced a new aim of conducting wet season burning to deliver a patchwork mosaic of low, medium and high fuel loads across the RPA. These wet season burns not only offered an additional mechanism for the prevention of wildfires, they also improved land accessibility for weed management and helped prepare the landscape for rehabilitation activities. This strategy proved to be very effective and has been continued into closure. Currently, fire teams conduct wet and early dry season burning to manage land and protect the mine footprint and will continue to do so as it is progressively rehabilitated.

Wet season burning (December to March) produces cooler fires that have less impact on the ecosystem; they also allow the fire teams to eliminate fuel loads with minimal risk, as the burn moves more slowly and is less likely to cross containment lines. Carefully timed wet season burning can also be highly effective for reducing highly flammable spear grass loads. Strategically, wet season burns will prevent excessive damage to vegetation, improve groundcover biodiversity by reducing the dominance of annual spear grass, and improve the overall health of the ecosystem. This will also enable natural 'seed and mulch farming' on the RPA, which will assist ERA's seed collection program and ecosystem establishment activities.

Early dry season burning (April to June) is conducted to reduce the intensity of potential fires and ultimately minimise the area burnt by wildfire each year. Weather is closely monitored throughout the burn season to identify favourable burn windows. Burning is not conducted from July to November due to the hotter conditions and more variable wind parameters.

Asset protection, which includes revegetation areas, is still the top priority during closure. However, ERA are also aiming to transition from mostly dry season burning to predominantly wet season burning, with the ultimate goal of reducing the flammability and improving the quality of the surrounding ecosystem. At the time of completion of rehabilitation, the surrounding ecosystem should have transitioned to a state where frequent burning is no longer required; more ecologically-driven, fine-scale fire management can be implemented, with patchy mosaics of small areas burnt at varying intervals, including unburnt areas.

This transition will be achieved through a multi-year fire management campaign during closure, involving comprehensive annual fire plans. Pre-fire season workshops are conducted to review the effectiveness of the previous burn season, share improvement ideas, and strategically plan burns for the following season. The RPA is divided into over forty management areas that are frequently surveyed to inform future fire planning (Figure 10-17). Each area's annual burn plan considers fire history, weed status and accessibility, the type of burn required and the objectives of the burn, and any potential risks. The success of recent fire management plans has been largely due to the collaboration between various ERA site teams, consultation with KNPS, and open communication with stakeholders. Further details on fire management are contained in the *ERA Fire Management Plan 2022.*

Although fire is a part of the current land management of Kakadu NP, it does present a risk to the development of rehabilitation, and therefore needs to be controlled. Fire will be excluded for a minimum of five to eight years until revegetated species have established a certain level of resilience, after which time low intensity 'cool burns' will very gradually be introduced. Any prescribed burns performed will have a specific monitoring plan to help inform future fire implementation and the fire resilience closure criteria.

Figure 10-17: Ranger Fire Management Map

10.4.1.5 Exotic fauna

ERA currently undertakes exotic animal monitoring and culling to manage densities of particular species on the RPA. These management activities have been determined based on risks the species' pose to the environmental, cultural heritage, human health and safety values of the RPA. One invasive invertebrate (Browsing Ant) and the 12 self-sustaining introduced vertebrate species identified in Kakadu National Park (Field *et al*. 2006) have been assigned a broad control management category for the RPA. In order of priority, these categories include (from ERA's *Feral Animal Management Plan 2021*):

- Planned – Feral animal control program planned to be undertaken and/or program established and being undertaken.
- Response to Presence – Feral animal control action may be undertaken where an animal is observed to be present and/or causing actual or potential harm or nuisance.
- Opportunistic – Feral animal control action may be taken if located (for example if animal sighted during the undertaking of animal control program for other target species).
- No known effective control/no planned action – Due to limited knowledge on effective control, ERA will focus investment in the other identified control strategies until effective control measures can be identified.

Management activities for exotic fauna include baiting, trapping and/or ground shooting. These practices will continue during the initial maintenance period after commencement of post-closure monitoring if population densities become too high, if physical works are being adversely impacted (e.g. damaging wetlands or revegetation on the final landform), or if recolonisation by native fauna is significantly compromised. Priority of control for each species may vary over time during closure, subject to population size and risk. As the final landform develops, when appropriate, exotic animal monitoring and management will revert to that which is followed within Kakadu National Park.

Further detail on exotic fauna management is contained in the ERA *Feral Animal Management Plan 2021.*

10.4.2 Completion criteria monitoring

Trajectory monitoring is an integral part of the ecosystem rehabilitation process. It is used to determine the progress of rehabilitation areas and track the development along a trajectory towards longer-term sustainability. Some components of the rehabilitated ecosystem will not be ‘similar’ to the reference ecosystem(s) within a 25-year timeframe. Consequently, there is a need to undertake monitoring to ensure the values that take longer to develop are on a trajectory to demonstrate acceptable performance against criteria and standards.

The methods for monitoring completion criteria are still under development, with ongoing consultation between ERA, SSB and NLC. There should be significant progress on the development of metrics and monitoring methods for ecosystem closure criteria in 2023. The following sections outline high-level considerations for monitoring site selection, as well as some potential methods for monitoring the flora criteria. Updated monitoring plans, including nutrient cycling and fauna criteria, will be provided in future MCP iterations.

10.4.2.1 Monitoring sites

Ecosystem completion criteria monitoring will largely rely on the establishment of permanent plots, quadrats and/or transects, which will enable more consistent recording of species-specific parameters and ecosystem development. The permanent plots will be established in the early phases of rehabilitation when access and establishment is more easily achievable.

The selection of permanent sampling sites will be based on approximately 5 % coverage of representative areas as per industry standard; where site conditions vary (e.g. seasonally moister sites, areas of greater fines or coarser material, depth of waste rock etc.) additional stratified sampling may be undertaken to cover these local variations.

The monitoring plots could include a variety of sampling areas depending on the lifeform and/or attribute being assessed. For example, plots of 50 m x 50 m for overstorey measurements (which could be split into five 50 m x 10 m strips for ease of recording), would provide the flexibility to cover wider areas and would still allow the data to be collated into four 50 m x 50 m plots to compare with the larger 1 hectare sites in the reference areas. It may be valuable to use a mixed sampling design with both fixed permanent and random plots. All permanent plots will be DGPS'd, pegged and tagged for future reference on the corners of the plots and subplots. Fixed photo points will be used to provide a visual representation of rehabilitation progress.

Reference and rehabilitated monitoring sites for fauna are still to be selected, although Einoder and others (2019) recommend that vertebrate monitoring is conducted at a minimum of 20 rehabilitated sites and 30 reference sites. For some criteria, sites will have specific habitat constraints.

Data will be collected with consistent methodologies and standardised data formats to enable comparisons over time and between sites. To assist in determining trends over time it is critical that permanent reference sites are also assessed in the same season as rehabilitation areas.

10.4.2.2 Species specific flora criteria

Species-specific flora indicators include (full details in Section 8):

- Overstorey and understorey species composition, richness and abundance are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s); and
- Weeds are either absent/eradicated from the RPA (Class A and WoNS), or have a presence and abundance no greater than the reference ecosystem, at a landscape-scale (Class B weeds), or than adjacent areas of Kakadu NP (other introduced flora).

ERA are currently investigating potential options for remote sensing and/or machine learning technology to support the monitoring of species-specific criteria. However, at this stage it is expected that the monitoring will likely rely mostly on ground surveys, at least initially. Even as remote sensing species identification technology develops there will likely be limitations with monitoring ground and mid-strata due to visual blockage from the canopy layer.

round surveys in the plots will likely be performed 2 to 3 years in the initial phases of ecosystem development and then every 5 to 7 year intervals (e.g. 5 to 7, 10 to 12 years, etc.). Overstorey data collected in the plots will include each individual shrub and tree species, which will enable assessment of species composition, richness and abundance. Understorey data will be recorded in quadrats (potentially 5 x 5 m quadrats at set intervals along transects within larger overstorey plots) to ensure coverage of local variations in site conditions and enable easier location of smaller understorey species. Understorey data collected will be on an individual species level which will enable assessment of richness; this can then easily be converted to functional group for composition. Abundance of understorey species may use a ranking system such as Braun-Blanquet (Wikum & Shanholtzer, 1978).

As weed presence across Kakadu NP is highly variable, with disturbed areas such as roadsides having higher weed pressures than pristine and/or remote areas, a landscape-scale monitoring approach for weed closure criteria is appropriate for the RPA.

10.4.2.3 Community structure flora criteria

Community structure flora indicators include (full details in Section 8):

- Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s); and
- Percentage cover of overstorey and understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

ERA are currently investigating potential remote sensing options for monitoring community structure development. Some of these options include ground radar/scanner (e.g. Maptek I-site 8200 scanner), drone-mounted LiDAR and/or multispectral drone imagery. If feasible, remote sensing will be used as the main form of monitoring community structure, with some ground truthing.

Ground truthing surveys for community structure will commence after 5 years and then at 5 to 7 year intervals (e.g. 5 to 7, 10 to 12 years, etc.). The community structural data will be collected in plots/transects and quadrats at the same time as the species-specific monitoring. Overstorey data collected in the plots will include tree/shrub height, potentially just within size class ranges rather than directly measured to within centimetres. Canopy cover will be measured using some form of remote sensing and may not require ground truthing. Percentage cover of understorey vegetation can be determined from the data collected during the species abundance monitoring (e.g. Braun-Blanquet method).

10.4.2.4 Ecosystem resilience criteria

All data collected during the monitoring described in previous sections will take into account disturbance event history of the rehabilitation and reference sites such as fire, drought and cyclones. ERA will also be conducting adaptive management fire trials to inform the Fire Implementation Plan; the data from these trials can also be used for assessment against fire resilience criteria.

10.5 Cultural theme

Alongside the development of the cultural closure criteria (Section 8) linguist Murray Garde (Garde, 2015) proposed a number of indicators that could be used to reflect the Traditional Owner attitudes towards rehabilitation progress and by extension the satisfication of the cultural closure criteria during the closure and post-closure phases (Table 10.16). A number of these indicators are largely based on visual and aesthetic values, as viewed through the lens of Mirarr culture. These indicators represent the overall cultural health of the ecosystem, which needs to be assessed by Mirarr Traditional Owners.

Table 10.16: Suggested indicators of cultural health of rehabilitated site (Garde, 2015)

Aspect	Suggested indicators
Landscape surface	Size of rocks; presence/absence of erosion; accessibility; general aesthetic (does it look 'natural')
Vegetation	Growth rate; botanical diversity; correct species for ecological zone; presence/absence of weeds
Riparian zone	Presence or absence of artificial water bodies; visual impressions of water quality, sedimentation, silting of rehabilitated water courses; condition of water course margins, creek banks
Biodiversity	Natural species numbers and diversity; impressions of hunting potential; impressions of vegetable food availability

As noted in Section 8, in the absence of an established best practice methodology in an Australian context, Garde (2015) described a proposed process by which to monitor the success of rehabilitation using a set of cultural health indices. The process described a scalar score, generally out of ten, that allowed impressionistic responses to be quantified. A key aspect of the indices is the bilingual format, including information in both Kundjeyhmi and English (an example is in Table 10.17).

It was suggested that the cultural monitoring assessments could be carried out at specific locations that collectively provide a cross section of rehabilitation and include a number of significant cultural areas. An assessment of cultural health and rehabilitation progress will be conducted at each location on an annual basis. The proposed locations include:

- TSF rehabilitated landform;
- Pit 3 rehabilitated landform;
- Retention Pond 2 (RP2) rehabilitated landform;
- Pit 1 rehabilitated landform;
- Retention Pond 1 (RP1);
- Kundjinba Billabong (Coonjimba Billabong);
- Georgetown Billabong (Madjawulu);

- Brockman irrigation area (i.e. Corridor Creek LAA);
- Karnbowh Djang (Tree Snake Dreaming); and
- Ranger 34 archaeological site (quartz outcrop with grinding holes).

Table 10.17: An example of a bilingual, scalar cultural index score for cultural criteria monitoring

ga-djalbolkwarre yerre	**ga-bolkwarre** **yiga ga-bolkmakmen gun-yahwurd**	**kareh ga-bolkmakmen gare lark**	**ga-bolkmakmen wurd**	**bon, ba-bolkmakminj wanjh**
no improvement yet noticed	some minor improvements	some areas improved, some areas not	noticeable return to healthy state in most areas	satisfactory return to natural state
1 | 2	3 | 4	5 | 6	7 | 8	9 | 10

The Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC) have provided feedback that the MCP is to include a compliance and monitoring process for meeting the cultural closure criteria and that they would propose a process for ERA consideration that included direct involvement of Traditional Owners with technical support.

ERA have been working closely with the GAC and NLC to ensure that closure execution meets the expectations and needs of the Mirarr Traditional Owners. This is being facilitated through a cultural reconnection committee of Bininj. The committee has been facilitated by the NLC with the objective of promoting the achievement of the Cultural Closure Criteria for the mine by giving Bininj an opportunity for input into closure planning and monitoring (Brady *et al* 2021).

10.6 Trigger, action, response plan (TARP)

The monitoring, maintenance and adaptive management programs described in this section have been summarised into a preliminary TARP, which will also be updated in future iterations of the MCP based on agreement of closure criteria and the outcomes of ongoing studies. The TARP is presented in Table 10.18.

Table 10.18: Trigger, action, response plan

Theme	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
Landform					
Final landform surface (topography, erosion and settlement)	Sites: RPA Parameters: Landform terrain Analysis: LiDAR or drone survey Frequency: Annual	To inform landform settling rate and erosion rates.	Change from previous Comparison to modelled.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Erosion (local scale)	Sites: Sensitive receptor areas and drainage channels Parameters: Field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels.	Significant erosion – rill erosion > 40 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha). Erosion around drainage channels.	Site-based plan and action as required. Repairs to area identified.	Site Environmental Officer (or delegate)
Subsidence, slumping, deformation, and/or settlement	Sites: Identified geotechnical sites Parameters: Geotechnical monitoring of pits, landfill walls, TSF Analysis: Identify any changes (subsidence or deformation) of landform Frequency: Quarterly	Identify any subsidence or deformation of landform areas.	Subsidence, deformation, or settlement of final landform are noted.	Site-based plan and action as required. May require additional works including modifying the sediment control basis.	Site Environmental Officer (or delegate)
Bedload	Sites: Water courses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Biannually before and after the wet season	Identify bedload being transferred off site.	Bedload identified moving offsite.	Site-based plan and action as required. May require additional works including modifying the sediment control basis.	Site Environmental Officer (or delegate)
Bedload (sediment basins)	Sites: Temporary sediment basins Parameters: Sediment volume and structural stability Analysis: Design requirements Frequency: Annual	To maintain basins in operational condition.	Outside operational design criteria.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Suspended Sediment	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS)) Analysis: TBC Frequency: Ongoing monitoring, analysis after wet season	Assess site denudation rates.	Turbidity trajectory not transitioning to control environment levels after 5 years.	Site-based plan and action as required. May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin.	Site Environmental Officer (or delegate)
Contamination	Sites: Sites in the Ranger Mine contaminated site register Parameters: Various contaminants Analysis: Contaminated soil assessment based on local background concentrations or published investigation levels Frequency: Prior to decommissioning and as identified by assessment.	To ensure impacted soils are remediated to as low as reasonably achievable to protect the environment.	Impacts not ALARA.	If concentrations of contaminants are not ALARA then a detailed site investigation and/or remediation plan will be developed, requiring further monitoring.	Site Environmental Officer (or delegate)
Nutritional Assessment	Sites: Stratified sampling sites across the rehabilitated landform. Parameters: Macro and micro-nutrients, pH, EC, OC% etc. Analysis: Soil chemical (and physical) parameters compared with known reference sites and vegetation requirements Frequency: Five-yearly surveys (at years 0, 5, 10, 15, etc).	To assess the development of the soil profile and inform follow-up fertiliser application type, quantity and timing.	Conditions required for development of rehabilitation not met.	Develop soil amelioration plan, such as fertiliser application.	Site Environmental Officer (or delegate)

Theme	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
Water and sediment					
Surface water and sediment – turbidity and aesthetic	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Turbidity at both sites and other aesthetic parameters (e.g. surface films, odour) Analysis: Physical and observational analysis of samples Frequency: Continuous monitoring for turbidity	Identify erosion issues and conformance with ecosystem and recreational quality of surface water.	Results exceed specific agreed closure criteria.	Monitor trends and develop site specific action plan as required.	Site Environmental Officer (or delegate)
Surface water and sediment – other parameters	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Various parameters (e.g. EC, major ions, nutrients and metals) Analysis: Chemical analysis of samples and continuous EC Frequency: Ongoing monitoring for EC (Mg), scheduled grab sampling	Assess compliance with closure criteria. Validate surface water model predictions. Identify surface water and sediment quality issues.	Samples exceed specific screening criteria defined in closure criteria.	Monitor trends, identify cause and develop site specific action plan as required. Review model assumptions and outputs.	Site Environmental Officer (or delegate)
Surface water and sediment – U in sediment	Sites: Gulungul, Coonjimba and Georgetown Billabongs Parameters: U in sediment Analysis: Chemical analysis of samples Frequency: Sample prior to and at end of decommissioning	Characterise contaminants in sediments on and off the RPA. Inform decommissioning of onsite billabongs and confirm success of decommissioning activity (if conducted).	Samples exceed specific screening criteria defined in closure criteria.	Identify causes (chemical analyses to identify source) and develop site specific action plan if the mine is the source.	Site Environmental Officer (or delegate)
Groundwater	Sites: Monitoring bores Parameters: Standing water level and *in situ* parameters (pH, EC) Major ions and cations, filterable metals and total nitrogen Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly progressing to quarterly in years 2-4 post closure then annually in no changes, chemical analysis quarterly until year 3 post closure progressing to annually during wet season until criteria have been achieved	To confirm groundwater level and chemistry is behaving according to modelled predictions, within the documented uncertainties.	Analysis indicates that groundwater is not tracking according to model predictions.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Radiation					
LLAA and PAEC inhalation	Sites: RPA Parameters: LLAA and PAEC (mSv per year) Analysis: High volume samplers and continuous radon decay product monitors or more passive techniques such as radon track etch detectors and passive dust samplers Frequency: Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3-6 months (for years 1-5).	To confirm radiation dose constraint to members of the public are below limits.	Exceedance of the baseline radiation dose as defined in the closure criteria.	Action plan to mitigate identified pathway to ALARA. Apply additional restrictions on the use of the land in consultation with Traditional Owners.	Radiation Safety Officer (or delegate)
Food and water contamination	Water Sites: Magela Creek at MG009 and GCLB, also upstream sites Parameters: Ra-226, U-238, Po-210 and Pb-210 (other isotopes if risk identified) (opportunistic bushfoods to be collected from the RPA). Analysis: Gamma spec analysis	As above.	As above.	As above .	Radiation Safety Officer (or delegate)

Theme	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
	Frequency: initially monthly during the wet season, decreasing to annually over time Bushfood collection on and off RPA as per current Kakadu National Park approvals Parameters: Ra-226, U-238, Po-210 and Pb-210 Analysis: Alpha spec analysis and ICP-MS Frequency: Field campaigns with Traditional Owners and park rangers				
External gamma radiation	Sites: RPA Parameters: Radiation dose rate (μGy/h) Analysis: Airborne radiometric survey with ground gamma survey and soil sampling for Ra-226 for ground-truthing Frequency: At the completion of rehabilitation activities	As above.	As above.	As above.	Radiation Safety Officer (or delegate)
Ecosystem					
Flora species composition	Sites: Vegetation plots and transects across the RPA Parameters: Species composition and total species richness (all overstorey, midstorey and understorey species), density of overstorey and midstorey framework species, vegetation structure (e.g. height, DBH), canopy and ground cover indices and overstorey and midstorey species distribution. Analysis: vegetation survey analysis Frequency: three, six and 12 months (year 1); annually (years 2 – 5, inclusive); one-off surveys every five years (e.g. at years 10, 15)	To determine whether species composition and community structure is similar to adjacent areas of Kakadu NP.	Exceedance of final criteria defined in closure criteria (recognising this will be achieved over time).	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Ecosystem maintenance	Sites: vegetation plots and transects across the RPA Parameters: Reproduction (flowering and seeding), recruitment / regeneration, nutrient cycling, fire resilience, resilience to wind and drought, and weed density and composition, species richness of native fauna, density of exotic animals Analysis: vegetation and fauna survey analysis. Frequency: One-off surveys every five years (e.g. at years 5, 10, 15). for all parameters except fire, wind and drought for which it will be event-based. Exotic animal: annual	To determine whether the long term, viable ecosystem requiring maintenance is similar to adjacent areas of Kakadu NP.	As above.	As above.	Site Environmental Officer (or delegate)
Fauna surveying	Sites: Fauna survey plots/transects across the RPA Parameters: Species richness and diversity. Analysis: Fauna survey analysis Frequency: One-off surveys every five years (e.g. at years 5, 10, 15)	To determine the presence of major functional species groups in comparison to surrounding Kakadu NP.	As above.	As above.	Site Environmental Officer (or delegate)
Weed surveying and mapping	Sites: RPA Parameters: Weed density and priority (eg. WoNS) Analysis: Spatial mapping and density scoring Frequency: Annual	To determine the spread of weeds and invasive flora within the revegetation areas.	As above.	As above. No Class A[4] weeds. Class B[2] weeds similar to surrounding Kakadu NP (defined by monitoring). Presence of other	Site Environmental Officer (or delegate)

[4] Class A Weeds are to be eradicated. Class B weeds growth and spread to be controlled

Theme	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
				introduced species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	
Cultural					
Cultural values	To be determined (see **Section 10.6**).	To determine whether Traditional Owners are satisfied that the rehabilitated environment supports cultural land uses.	Conditions identified in closure criteria not met.	Site-based plan and action as required.	Site Environmental Officer (or delegate)

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APPENDIX 10.1: PIT 1 PROGRESSIVE REHABILITATION MONITORING FRAMEWORK

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ERA Energy Resources of Australia Ltd

2rog

Pit 1 Progressive Rehabilitation Monitoring Framework

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Author(s): Dr Paul Frazier (2rog)

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Abbreviations

Abbreviation	Description
AARTC	Alligators Rivers Region Technical Committee
BACIP	Before After Control Impact Paired
DEM	Digital Elevation Model
ERA	Energy Resources of Australia
LEM	Landscape Evolution Model
SSB	Supervising Scientist Branch

1 INTRODUCTION

The Ranger Progressive Rehabilitation Monitoring Workshop was held on 4 September 2018 to 'agree on high-level monitoring, to avoid missing information that is needed to inform the progressive rehabilitation process' (SSB 2018).

This workshop defined the progressive rehabilitation period as being from present to 2026 and identified key monitoring themes that included:

- Landform
- Water (groundwater and surface water)
- Radiation
- Ecosystem restoration.

The workshop also identified that rehabilitation of Pit 1 is planned to proceed in late 2019 and presents an opportunity to develop and refine the Progressive Rehabilitation Monitoring Framework.

Following the initial workshop, a subsequent workshop was held with Energy Resources of Australia (ERA) staff on 27 November 2018, to develop a monitoring and research framework specifically focussing on the Pit 1 area. This team reviewed and incorporated knowledge and advice from the Ranger Progressive Rehabilitation Monitoring Workshop meeting notes, subsequent stakeholder meetings, best practice monitoring procedures and the wealth of knowledge and research available for the site.

Supervising Scientist Branch (SSB) held a Pit 1 monitoring objectives workshop on 23 November 2018. The outcomes of this workshop were shared with ERA on 26 November 2018 (Leggett, Amie. 26 November 2018) and discussed at the internal ERA workshop held on 27 November 2018.

Parallel to these workshops, the 41st Alligator Rivers Region Technical Committee (ARRTC) meeting was held in Darwin on 13-14 November 2018. ARRTC members were actioned to provide input recommendations to the Pit 1 monitoring requirements.

- ***ACTION 41.2****: ARRTC to consider what parameters should be monitored on the Ranger Trial Landform to inform relevant KKNs. While this would include parameters informing plant available water modelling (WAVES), they should also be broadened if necessary to consider parameters informing the design of future research and monitoring for Pit 1 rehabilitation*
- ***ACTION 41-4****: ARRTC to provide input into planning and implementing an adaptive management approach to Pit 1 rehabilitation, including reviewing the detailed plans of ERA/SSB for any additional studies and monitoring that are required to inform the Key Knowledge Needs and the broader rehabilitation project.*

Subsequent communication and feedback via email and meetings was also incorporated into the design of this framework (Dixson, Kingsley. 11 December 2018, Leggett, Amie. 18 December 2018, Leggett, Amie. 20 December 2018, Leggett, Amie. 21 December 2018, Rumpff, Libby. 13 December 2018, Zichy-Woinarski, John. 11 December 2018).

This framework focusses on monitoring and research activities that may be conducted to ensure successful rehabilitation of the Pit 1 area (Figures 2-3) and inform ongoing progressive rehabilitation across the Ranger site.

To ensure clarity throughout this document the terms monitoring and research have been defined as:

> Monitoring – repeated measurement of target indicator parameters that are linked to trigger/threshold values that may invoke a management action.
>
> Research – a defined study with a clear hypothesis and defined objective/s that is designed to inform a specific knowledge gap.

Monitoring data may be incorporated into a research program with properly constructed hypotheses. Likewise, research activities may be incorporated into a monitoring program with suitable action triggers established.

The Pit 1 Rehabilitation Monitoring Framework consists of two distinct monitoring phases: construction; and ecosystem establishment. A separate section on defined research studies associated with Pit 1 is also included.

It is intended that the Pit 1 monitoring framework provides the basis for the progressive rehabilitation monitoring plan for the Ranger site. Lessons learned from the monitoring and research outcomes from Pit 1 will be incorporated into the site monitoring plan as required under an adaptive management framework.

The location and set out of the Ranger Mine and Pit 1 is shown in Figures 1-3.

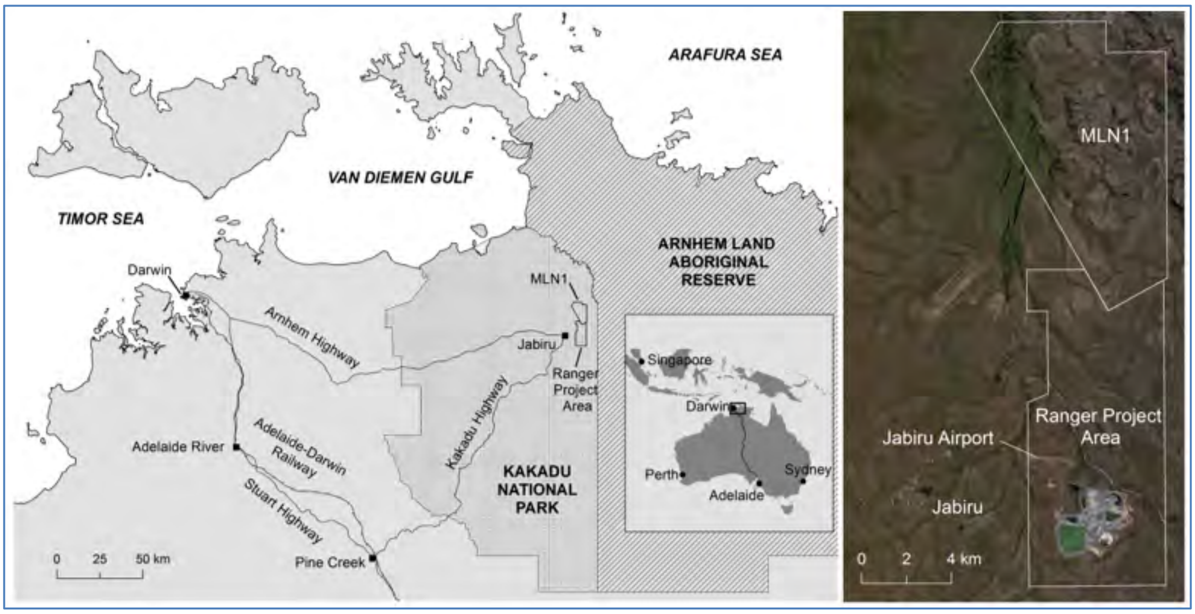

Figure 1 Ranger uranium mine location

Figure 2 Aerial imagery of Ranger Mine layout with Pit 1 identified (Photo capture June 2018)

Figure 3 High-resolution image of Pit 1 area (Photo capture June 2018)

2 PIT 1 REHABILITATION SCHEDULE

The Pit 1 rehabilitation schedule comprises two main phases: construction; and ecosystem establishment (Table 1). The construction phase consists of:

- Backfill with detailed tracking of fill material in regard to material grade (3112-01)
- Construction of the final landform topography (3112-03/04)
- Survey and sign-off of final landform topography (3112-05).

Once the final landform has been created and meets required specifications the ecosystem establishment phase will be undertaken, although some activities such as tube-stock growth and weed spraying will be undertaken between the two phases as required.

At this time the construction phase extends from 01-May-19 through to 25-Aug-20 and the ecosystem establishment phase extends from 15-May-20 to 04-Nov-22 (Table 1).

The Pit 1 rehabilitation monitoring framework will extend from May 2019 to 2026 to provide for a continuous monitoring framework from rehabilitation to closure.

Table 1 Pit 1 rehabilitation schedule (indicative pending appropriate approvals) provides information as provided from Closure Execution schedule.

Project code	Activity	Identifier code	Scheduled Start date	Scheduled End date
Pit 1, backfill and capping and final landform (3110, 3111, 3112)				
3112-01	1s to Pit 1 Backfill	275	01-May-19	01-Feb-20
3112-03	1s to Final Landform Pit 1	120	05-May-20	07-Jul-20
3112-04	Final Landform Details by Dozer Pit 1	34	14-Jul-20	15-Aug-20
3112-05	As-Built Surveying Pit 1	10	15-Aug-20	25-Aug-20
Revegetation – Pit 1 (3113)				
3113-01	Handover of site – Pit 1 Area	0		15-Aug-20
3113-02	Seed Planting and Growing – Pit 1 Area	92	15-May-20	15-Aug-20
3113-03	Initial Weed Spraying – Pit 1 Area	24	15-Aug-20	08-Sep-20
3113-04	Cultivation Period – Pit 1 Area	48	08-Sep-20	24-Oct-20
3113-05	Irrigation Installation – Pit 1 Area	90	24-Oct-20	04-Feb-21
3113-06	Initial Planting – Pit 1 Area	375	04-Feb-21	06-May-22
3113-07	Irrigation Starts (First 3 Months) – Pit 1 Area	90	06-May-22	04-Aug-22
3113-08	Irrigation for 3-6 Months – Pit 1 Area	90	04-Aug-22	04-Nov-22
3113-08	Inspection/Monitoring for Mortality – Pit 1 Area	1	04-Nov-22	04-Nov-22

3 CONSTRUCTION PHASE MONITORING

The construction phase will result in a final landform that complies with the planned landform design. Key elements include:

- Burial of all tailings materials to designed depths
- Staged back fill with higher grade material (grade 2) buried deeper and lower grade material (grade 1) forming the landform surface layer (Table 2).
- Shaping into the planned landform topography
- Installation of water and sediment traps at landscape outflow locations
- Micro-topography construction that may include ripping and placement of surface materials.

Ranger mine is currently operating under the requirements detailed in the Ranger Authorisation to Operate (current version 0108 issued June 2018). The requirements provide a comprehensive set of monitoring and reporting schedules that help to ensure the protection of the surrounding environment and communities. The Ranger Authorisation requirements will continue throughout the construction phase of Pit 1 rehabilitation and they will be enhanced with the additional monitoring and research described in this Framework. As per the requirements in the Ranger Authorisation to Operate, the following reporting and monitoring will continue as normal during the construction of Pit 1:

- Mining Management Plan
- Annual Radiation and Atmospheric Monitoring Interpretative Report
- Tailings Dam Surveillance Reports
- Water Management Plan
- Annual Groundwater Report
- Whole of Site Groundwater Conceptual Model
- Groundwater Monitoring Plan
- Provision of Monitoring Data, including routine Water Quality Reports
- Surface Water Wet Season Report
- Rehabilitation Progress Report

Further detail on Pit 1 construction is provided in the Ranger Mine Closure Plan (MCP 2018).

Table 2 Indicative ore grades and mineral type

Grade	Grade (% U_3O_8)			Material type
	1980-1997	1998-2009	2010-Current	
1	<0.02	<0.02	<0.02	Un-mineralised rock
2	0.02-0.05	0.02-0.08	Low 2 0.02-0.06	Very low grade ore
			High 2 0.06-0.08	Low grade ore
3	0.05-0.10	0.08-0.12	0.08-0.12	ore
4	0.10-0.20	0.12-0.20	0.12-0.20	ore
5	0.20-0.35	0.20-0.35	0.20-0.35	ore
6	0.35-0.50	0.35-0.50	0.35-0.50	ore
7	>0.50	>0.50	>0.50	ore

The Pit 1 Construction Phase monitoring framework focusses on all aspects relevant to Pit 1 rehabilitation (Table 3), thus key elements relating to the physical construction approach and final landscape shape are the focus of this framework. A Trigger, Action, Response, Plan (TARP) is presented in Table 4 and includes management actions should a threshold be exceeded.

Table 3 Pit 1 Construction Phase Monitoring Framework (May 2019-Aug 2020)

Aspect	Objective/s	Method	Variable	Frequency
Tailings consolidation	Confirm tailings consolidation	Settlement monitoring plates	Change in level of settlement	Monthly
Material placement	Confirm 2s material placed at basal levels	Implementation of the dynamic mine model created for ERA, (AMC, 2018)	Material load placement log	Daily
		Survey	Regular surface levels	Weekly
	Confirm 1s material placed as surface layer	Implementation of the dynamic mine model created for ERA, (AMC, 2018)	Material load placement log	Daily
		Survey	Regular surface levels	Weekly
Surface topography	Confirm final surface topography for Landscape Evolution Model (LEM). Confirm built to design requirements	High resolution DEM	Surface Elevation	Annual post wet season LEM rerun if required
		Topographic survey	Cross-sections and/or levels	Once; post construction
	Quantify landscape settlement	Year on year DEM change detection	Surface level change	Annual
		Topographic survey	Cross-sections and/or levels	Annual
	Quantify sediment transport	Year on year DEM change detection	DEM change	Annual
Surface micro-topography	Describe surface micro-topography	High resolution DEM and field survey	Surface DEM and surface complexity	After land forming and annually after wet season
		GPS on ripping machinery, field mapping or remote sensing	Ripped areas	Once, after ripping is complete

Aspect	Objective/s	Method	Variable	Frequency
Landscape denudation and erosion	Quantify site denudation rate (suspended load)	BACIP designed turbidity monitoring (Moliere and Evans 2010)	Stream turbidity	Continuous logged in flowing water
	Quantify gully erosion	High resolution DEM	Surface DEM	Annual post wet season
		Field assessment	Field notes	Annually after wet season
	Quantify sub-catchment bedload sediment movement	Measurements from sediment traps	Transported sediment volume	Annually after wet season
Surface water management	Ensure all surface water runoff is captured and managed	Pumping of water from Pit 1 pond water sump to RP2	Continuous monitoring	During and following rainfall periods

Table 4 Pit 1 Construction Phase: Trigger, Action, Response Plan (TARP)

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Materials placement	Site: Whole of landscape via tracking system. Parameters: Material character and volume. Analysis: Dynamic mine model with associated tracking methods. Within landform levels during construction. Frequency: Ongoing, as per Table 3, as landscape is built.	Describe and verify material strata within final Pit 1 landform	Internal strata vary in a manner that increases risk of higher-grade materials exposure	Stop construction. Remove or reshape current level to conform with design plan	Site Environmental Officer (or delegate)
Surface topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEM and survey to planned landform Frequency: Once off. When practical upon completion of final landform	Describe final landform against planned landform. Confirm LEM predictions for tailings encapsulation Potentially provide updated information for LEM	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface settlement	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify topographic settlement rates	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Sediment transport	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify site scale denudation rates	Site denudation rate is significantly higher than predicted	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface micro-topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and field survey Frequency: Annual	Describe site scale micro-topography	Microtopography does not conform to planned landscape distribution pattern	Alter microtopography through ripping, grading, placement of material or other works	Site Environmental Officer (or delegate)
Surface ripping	Site: Planned ripped areas Parameters: Area Analysis: mapping via GPS tracking, field survey or remote sensing Frequency: Once after landform creation	Map ripped areas	Ripping does not conform to planned ripped area	Undertake works to amend ripping area	Site Environmental Officer (or delegate)
Landscape erosion (gullying)	Sites: Sensitive receptor areas and drainage channels Parameters: DEM analysis and field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels	Significant erosion – rill erosion > 30 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha) Erosion around drainage channels	Site-based plan and action as required. Repairs to area identified	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Bedload	Sites: Watercourses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Biannually before and after the wet season	Identify bedload being transferred to sediment traps	Bedload transport rates significantly beyond those of trial landform	Site-based plan and action as required. May require additional works including modifying the sediment control basins	Site Environmental Officer (or delegate)
Landscape erosion (turbidity)	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS) Analysis: BACIP analysis (Moliere & Evans, 2010) Frequency: Ongoing monitoring, analysis after wet season	Identify site scale erosion rates	Turbidity trajectory not transitioning to control environment levels after 5 years	Site-based plan and action as required May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin	Site Environmental Officer (or delegate)
Surface water management during construction	Site: Whole of landscape Parameters: EC Analysis: Surface water runoff management Frequency: During and after rainfall periods.	Monitor surface water quality	EC trigger; As per section *5.8 Pit 1 Catchment Management* in RWMP 2018/19	Investigation as per section *5.8 Pit 1 Catchment Management* in RWMP 2018/19	Site Environmental Officer (or delegate)

4 ECOSYSTEM ESTABLISHMENT PHASE

This section describes the Pit 1 monitoring framework for the ecosystem establishment phase (15 May 2020 to closure in 2026), noting that it is a part of the planned whole-of-site monitoring for landform, water (ground and surface), radiation and ecosystem processes.

The Pit 1 Ecosystem Establishment monitoring framework focusses on those aspects relevant to this phase of Pit 1 rehabilitation (Table 5). A Trigger, Action, Response, Plan (TARP) is presented in Table 6 and includes management actions should a threshold be exceeded.

During the ecosystem establishment phase of Pit 1, monitoring of radiation will continue to be undertaken as per the Ranger Authorisation to operate and those plans will be in effect. However, specific radiation assessment research tasks will be undertaken (Table 7).

Table 5 Pit 1 Ecosystem establishment phase monitoring (Aug 2020 – Nov 2022)

Theme: Landform				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Surface topography	Quantify landscape settlement	Year on year DEM change	DEM change	Annual
		Topographic survey	Cross-sections and levels	Annual
Surface micro-topography	Describe surface micro-topography	High resolution DEM and field survey	Surface DEM and field notes	After land forming and annual after wet season
Landscape denudation and erosion	Quantify site denudation rate (suspended load)	BACIP designed turbidity monitoring (Moliere and Evans 2010)	Stream turbidity	Continuous logged in flowing water
	Quantify gully erosion	High resolution DEM	Surface DEM	Annual post wet season
		Field assessment	Field notes	Annually after wet season
	Quantify sub-catchment bedload sediment movement	Measurements from sediment traps	Transported sediment volume	Annually after wet season
Erosion control	Confirm erosion control structure function	Field inspection	Field notes and records	Annually after wet season

Theme: Water				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Surface water quality	Confirm water leaving Pit 1conforms to the approved Water Management Plan	Multiple telemetered probes Designed sub-catchment water and sediment traps Grab samples from sumps etc with lab analysis	Solutes, EC, TSS, COPC, Total P, Total N, NH_4, Turbidity, radionuclides	Continuous and grab samples
	Confirm water quality in adjacent/connected water sources	Multiple telemetered probes Grab samples from sumps etc with lab analysis	Solutes, EC, TSS, COPC, Total N, Total P, NH_4, Turbidity, radionuclides	Continuous and grab samples as per WMP
Surface water quantity	Monitoring discharge leaving landform	Designed sub-catchment water and sediment traps	Discharge	Continuous with flow
	Model surface water runoff	DEM based rainfall/runoff model	Discharge	As required to correlate with discharge measurement and provide input to water balance
Groundwater seepage and contaminant transport	Define groundwater movement and quality dynamics	Monitor bore network develop new bores as required Groundwater modelling (INTERA project)	Groundwater flow and quality	Continuous sampling and dynamic model

Theme: Water				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Groundwater heads	Monitor ground water heads	Monitor bore network develop new bores as required Groundwater modelling (INTERA project)	Bore level	Continuous sampling
GW surface water interaction	Better understand GW-SW interaction if any	Bore logging (INTERA project)	Bore level and water quality Grab samples	Continuous sampling and as sampled

Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Plant species distribution and survival	Confirm species distribution conforms to plan Document plant survival	Planting plan and log of species planting location	Plant species, stems per species	During planting
		Survey quadrats, field transects	Plant species and survival	3 month, 6 months, annually
Plant growth rate	Document plant growth rate	Survey quadrats	Height, DBH	3 month, 6 months, annually
Canopy Cover	Document canopy cover	Survey quadrats	Canopy cover %	3 month, 6 months, annually
Plant recruitment	Document plant recruitment	Survey quadrats	Recruitment occurrence and species (flowering, fruiting, emergence)	3 month, 6 months, annually

Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Weather monitoring	Determine site weather conditions	Weather station and observation	Rainfall, temperature, humidity, ET	Ongoing
Irrigation	Confirm irrigation performance	Inspection	Irrigation function	Daily/weekly
Weed management	Control and/or eliminate all priority weeds	Visual inspection	Weed presence and abundance	Daily/weekly with other checks
Flora pests and diseases	Monitor plant pests and diseases	Visual	Presence of pest or disease	Daily/weekly with other checks
Ground cover	Monitor development of groundcover	Survey quadrats	Species, % cover, litter %	3 month, 6 months, annually
Nutrient cycling	Understand edaphic process	Soil/sediment survey and analysis	Soil nutrients, microbes, soil chemistry	Baseline and 5 years
Fauna colonisation	Document fauna on site	Opportunistic observation during other surveys	Species	Opportunistic
Fauna pests	Monitor and control fauna pests	Visual inspection for animals and animal impacts	Fauna pest species	Ongoing

Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Fire exclusion	Confirm fire exclusion	Visual inspection	Presence/absence (location)	As required
Tube-stock quality	Confirm tube-stock quality and viability	Inspection of tube-stock in nursery and upon planting	Root binding, disease	ongoing
Bush foods (aquatic and terrestrial)	Document contaminants levels in bushfoods	Field sampling	Laboratory analysis for contaminants	Baseline and every 2nd year

Table 6 Ecosystem establishment phase TARP

Theme: Landform					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Surface topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify topographic settlement rates	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface micro-topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and field survey Frequency: Annual	Describe site scale micro-topography	Micro-topography does not conform with planned landscape distribution pattern	Alter microtopography through ripping, grading, placement of material or other works	Site Environmental Officer (or delegate)
Bedload	Sites: Water courses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Bi-annually before and after the wet season	Identify bedload being transferred to sediment traps	Bedload transport rates significantly beyond those of trail landform	Site-based plan and action as required. May require additional works including modifying the sediment control basis	Site Environmental Officer (or delegate)

Theme: Landform					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Landscape erosion (gullying)	Sites: Sensitive receptor areas and drainage channels Parameters: DEM analysis and Field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels	Significant erosion – rill erosion > 30 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha) Erosion around drainage channels	Site-based plan and action as required Repairs to area identified	Site Environmental Officer (or delegate)
Landscape erosion (Turbidity)	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS) Analysis: BACIP analysis (Moliere & Evans, 2010) Frequency: Ongoing monitoring, analysis after wet season	Identify site scale erosion rates	Turbidity trajectory not transitioning to control environment levels after 5 years	Site-based plan and action as required May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin	Site Environmental Officer (or delegate)
Erosion control structures	Sites: Site structures and works Parameters: Field inspection, notes and photographs Analysis: Identify problem areas Frequency: Annually after the wet season	Confirm function of erosion control structures	Structures not function or compromised	Site-based plan and action as required. Repairs to area identified	Site Environmental Officer (or delegate)

Theme: Water					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Surface water quality (Pit 1)	Sites: sub-catchment designed exit points Parameters: water quality Analysis: Probe and grab sample Frequency: Continuous and grab sample	Monitor surface water quality	Water quality does not meet release water quality standards	Divert away from release water circuit. Evaluate reason for exceedance and implement remediation and amelioration works	Site Environmental Officer (or delegate)
Surface water quality (offsite receiving environments)	Sites: Defined receiving site Parameters: water quality Analysis: Probe and grab sample Frequency: Regular sampling through year	Monitor surface water quality	Samples exceed Magela Creek trigger values (As per Annex C.1 of the Authorisation "Water Quality Objectives for Magela Creek and Gulungul Creek")	As per Turner et al 2015	Site Environmental Officer (or delegate)
Groundwater seepage and contaminant transport	Sites: Bore network Parameters: Water levels and water quality Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly, chemical analysis quarterly	To confirm groundwater level, movement and chemistry is behaving according to modelled predictions, and to increase model performance and power through additional data input	Analysis indicates that groundwater is exceeding model predictions	Site-based plan and action as required	Site Environmental Officer (or delegate)

Theme: Water					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
GW surface water interaction	Sites: Bore network Parameters: Water level and water quality Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly, chemical analysis quarterly	To confirm groundwater interaction, if any, with key surface water sites	Analysis indicates groundwater ingress into surface water sites	Site-based plan and action as required.	Site Environmental Officer (or delegate)

Theme: Ecosystem					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Flora composition performance and distribution	Sites: Vegetation plots across entire site Parameters: Provenance, species composition (tree and shrubs) and species relative abundance, survival, canopy architecture, canopy cover index, ground cover index, tree distribution, flowering fruiting, seeding, juveniles, overall condition. Analysis: vegetation survey analysis Frequency: three, six and 12 months (year 1); annually	To determine whether species composition and community structure is similar to adjacent areas of KNP	Values do not conform with closure criteria	Site-based plan and action as required	Principal Advisor Rehabilitation and Ecology (or delegate)

Theme: Ecosystem					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Irrigation	Sites: associated with planting Parameter: Functioning irrigation system Analysis: inspection Frequency: ongoing until irrigation removed	Ensure functional irrigation system	Irrigation failure or poor performance	Mend irrigation system	Principal Advisor Rehabilitation and Ecology (or delegate)
Weed management	Sites: Pit 1 site Parameter: Priority weed presence Analysis: Field survey and inspection Frequency: Prior to planting and ongoing associated with vegetation surveys and other site traverses	Assess weed presence, species and abundance	Priority or other weeds present	Weed management (generally spraying) until weeds are no longer present	Site Environmental Officer (or delegate)
Nutrient cycling	Sites: Pit 1 and TLF Parameter: soil edaphic processes Analysis: Soil pit and analysis Frequency: year 1 and 5	Understand soil formation processes and nutrient cycling	Poor soil formation and nutrient processes affecting plant development	Site-based analysis and ameliorant plan and application	Principal Advisor Rehabilitation and Ecology (or delegate)
Fauna pests	Sites: Pit 1 Parameter: Fauna pest present Analysis: Visual survey Frequency: Ongoing, all staff to report signs of fauna pests	Minimise impact of feral pests on rehabilitation	Presence of pests	Implement appropriate pest management	Site Environmental Officer (or delegate)

Theme: Ecosystem					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Bush foods (aquatic and terrestrial)	Sites: Onsite and selected offsite targets Parameter: Food pollutants and toxins Analysis: Field sampling and analysis Frequency: year 1 and 5	Understand potential for contamination of aquatic species	Trigger levels of contaminants found	Remove access to food source and undertake site and source amelioration	Site Environmental Officer (or delegate)

5 PIT 1 RESEARCH PLANNING - PRESENT TO 2026

Ranger mine has developed a list of targeted research projects to inform the creation of a safe and stable final environment. The research tasks listed here are targeted specifically to inform rehabilitation success and are focussed on Pit 1 relevant studies.

Table 7 Pit 1 targeted research tasks

Theme: Landform		
Aspect	**Objective/s**	**Method**
Particle size distribution	Understand Pit 1 surface and top layer particle size distribution	Measures of surface sediment calibre distribution profile appropriate for material type.
Stock pile drilling	To describe the release behaviour and source concentrations of all COPCs over time from each of the waste rock and tailings-derived source materials	INTERA project
Theme: Water		
Aspect	**Objective/s**	**Method**
Water balance	Develop Pit 1 water balance model Identify key parameters that require additional studies (e.g. evaporation and ET, runoff, infiltration, deep drainage and recharge, changes in soil water at key depths related to roots and waste rock dump levels) Undertake targeted studies to complete water balance model	Undertake a specific pit 1 water balance study. Identify key parameters that require additional verification and undertake specific studies to measure these parameters.

Herbicide fate	Understand the fate of glyphosate herbicide in the environment following application and run-off	Develop a trial water quality sampling and analysis program with stakeholders to examine the fate of glyphosate herbicide when it has been applied to an area of weed/grass cover and bare rehabilitation landscape and subjected to watering/rainfall and run off.
Groundwater	Understand Pit 1 groundwater processes	Develop additional bores and undertake site scale monitoring and modelling of groundwater quality, quantify and movement.
Wetland filter process	Understand the water and sediment condition of receiving wetland filter areas	A water and sediment sampling and analysis program to understand the current condition of the Pit 1 wetland filter receiving areas.
Theme: Ecosystem		
Aspect	**Objective/s**	**Method**
Fauna colonisation	Understand fauna colonisation at early stages of rehabilitation	Targeted fauna studies after year 1 and 5 of Pit 1 planting. Surveys developed to specifically early stage fauna such as insects and birds. Field design could follow the pattern established for flora quadrat surveys. Opportunistic records of fauna observations undertaken during regular surveys and inspections.

Fauna translocation	Understand efficacy of translocating critical ecosystem engineer species	In conjunction with fauna studies at other sites develop a study to understand colonisation of critical ecosystem engineering species within rehabilitated areas on site and, if necessary, develop a plan to translocate these species if required. If translocation is required a translocation monitoring study should be developed.
Disturbance	Understand recovery from disturbance	No disturbance is planned during the period covered by this plan. However, should disturbance through fire, disease, wind or other cause occur a disturbance specific assessment and knowledge capture study
Theme: Radiation		
Aspect	**Objective/s**	**Method**
Radon-222 exhalation flux densities	To verify that radon-222 exhalation flux densities	Radon-222 exhalation surveys
Gamma dose rates, waste rock radium-226 activity concentration	To validate predictions on the surface waste rock uranium content	Ground-based gamma dose rate survey

5.1 Whole of site studies

In addition to the studies (research and monitoring) designed specifically considering Pit 1 rehabilitation, several whole of site studies are progressing as parallel programs. These include:

- Nursery establishment and management processes to ensure the quantity and quality of seed and tube-stock
- Trial Landform studies will continue to examine ecosystem establishment processes including:
    - Soil development
    - Plant survival
    - Native species recruitment
    - Fauna establishment and usage
    - Pest and weed treatment
- Trial landform excavation studies
    - Two pits were excavated in March 2019 on the trial landform to collect samples and information to inform further particle size distribution studies and root observation studies.
- ERA is currently undertaking waste rock stockpile oxidation rate studies.

6 REHABILATION FRAMEWORK REVIEW AND STAKEHOLDER COLLABORATION

To ensure the continued refinement of the proposed monitoring framework, the framework will be reviewed by ERA staff in consultation with stakeholders every 12 months and a review outcomes report provided to stakeholders.

A Ranger Rehabilitation – Monitoring Evaluation and Research Review Group will be formed by ERA and include stakeholder group representatives. This review group will be chaired by ERA and will enable collaboration between key stakeholder groups to ensure research programs are developed and refined during the progressive rehabilitation of the Ranger mine. Implementation of additional studies outside of Pit 1 (TLF, nursery etc.) will also be discussed, developed and refined in this review group.

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11 Financial provision for closure

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Cover photograph: Cluster Fig (*Ficus racemosa*) recruit on the trial landform

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Annual Plan of Rehabilitation	High level plan used to determine the securities amount to be held by the Commonwealth Government for Ranger Mine rehabilitation obligations.

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
APR	Annual Plan of Rehabilitation
ASX	Australian Securities Exchange
ERA	Energy Resources of Australia Ltd
TSF	Tailings Storage Facility
RWD	Ranger Water Dam

11 FINANCIAL PROVISION FOR CLOSURE

11.1 Rehabilitation provision

The Energy Resources of Australia Ltd (ERA) rehabilitation provision as at 30 June 2020 was $1,218 million. The calculation of the rehabilitation provision relies on estimates of costs and their timing to rehabilitate and restore disturbed land to establish an environment similar to the adjacent Kakadu National Park in line with the Company's statutory obligations.

The costs are estimated on the basis of a closure plan, taking into account considerations of the technical closure options available to meet ERA's obligations. The provision for rehabilitation represents the net present cost at 30 June 2022 of the preferred plan (subaerial capping) and represents managements best estimate of cost.

In July 2021, ERA commenced a major reforecast of cost and schedule after risks materialised post-completion of the 2019 Feasibility Study. The reforecast continued into early 2022, including an external evaluation by Bechtel of the preliminary findings. The preliminary findings by ERA from its reforecast exercise based on the Ranger rehabilitation project being completed in accordance with the methodology set out in the 2020 Mine Closure Plan indicates that:

i. The revised total cost of completing the Ranger Project Area rehabilitation, including incurred spend from 1 January 2019, is forecast to be approximately between $1.6 billion and $2.2 billion (undiscounted nominal terms). The previously announced closure estimate, which was based on the Ranger Project Area Closure Feasibility Study finalised in 2019 ("Feasibility Study"), was $973 million (undiscounted nominal terms).

ii. The revised date for completing the Ranger Project Area rehabilitation is forecast to be between Quarter 4, 2027 and Quarter 4, 2028.

ERA notes that the above revised estimates, as to both cost and schedule, are based on the Ranger rehabilitation project being completed in accordance with the methodology set out in the 2020 Mine Closure Plan.

In determining the provision, ERA has considered the preliminary findings from the reforecast, recent work in preparation for an interim Entitlement Offer and potential optimisation of the Pit 3 capping strategy. The reforecast estimate is prepared in nominal terms, it has then been adjusted to real terms by removing the impacts of inflation. This has then been discounted at 1.5% to calculate a closure provision. The estimated closure provision at 30 June, excluding unrecognised employee termination benefits and including an allowance of $1 million for Jabiluka rehabilitation is $1,218 million.

Potential short term spend requirements used in preparation for an interim Entitlement Offer indicates expected costs in 2022 and 2023 may be higher than the preliminary reforecast findings, used to determine the rehabilitation provision. The preliminary reforecast findings, used to determine the rehabilitation provision, has adequate available contingency should these additional costs be realised. No adjustment to the closure provision has occurred given the available contingency and the preliminary stages of the Feasibility Study work into the alternate capping method, noting that optimisation activities have not yet commenced.

The rehabilitation project continues to be exposed to challenging conditions, including supply chain constraints and inflationary pressures being experienced across the broader industry. One example is that ERA experienced a 2-month delay in receiving the wicking barge ordered from China.

The ultimate cost of rehabilitation is uncertain and can vary in response to many factors including legal requirements, technological change, weather events and market conditions. The 2022 Feasibility Study is underway and scheduled for completion in 2023, as such it is reasonably possible that outcomes from within the next financial year may be different from the current cost estimate and could require material adjustment to the rehabilitation provision for the Ranger Project Area.

Selected risks on the Ranger rehabilitation provision are detailed below (see *Section 7 Risk Assessment and Management* for all risks).

11.1.1 Tailings consolidation

Following the completion of the transfer of tailings to Pit 3, the wicking of Pit 3 will commence. During the final capping process the tailings in Pit 3 will consolidate and express process water, which will need to be collected and treated. The consolidation process will be aided by installing vertical wicks and the knowledge of the consolidation timeframes is backed up by a detailed model based on in situ testing of site tailings. The consolidation model predictions of rates of process water expression is impacted by many factors, including tailings density and other characteristics, deposition method and free process water volume in the pit during deposition. These impacts have been considered in the reforecast but to the extent tailings consolidation and process water expression extend further could have additional adverse impacts on cost and schedule of completing rehabilitation.

11.1.2 Process water and injection of waste brines

Management of water on the Ranger Project Area is critical to ongoing rehabilitation activities. The 2022 Feasibility Study will review the adequacy of the water infrastructure and the water model. To the extent that any of these closure aspects cost more than expected or ERA is required to implement further initiatives (such as the installation of additional water treatment infrastructure), the rehabilitation cost may increase further.

In addition, as a result of treating processed water, a waste stream of contaminated salt is generated. The salt is ultimately to be stored below tailings in Pit 3 via injecting the brine through bore holes. This technology has been used previously but the long-term performance is yet to be fully confirmed. Should the disposal of salt in this manner not prove viable, an alternate method of salt disposal would be required. This would demand additional capital expenditure which has not been allowed for in the rehabilitation estimate or resulting provision and may not be available to ERA.

11.1.3 Bulk material movement

Once capping of Pit 3 is complete, large scale bulk material backfill and landform shaping will occur. Bulk material movements are sensitive to the volume of material which is to be moved and the schedule of movement. To the extent volumes or costs of movement change, there may be a material impact on the rehabilitation cost or schedule.

11.1.4 Other factors

In addition to the factors identified above there are many additional items that the estimate could be impacted by, including: evaporation rates, stakeholder requirements, higher costs of relinquishing Jabiru township housing, engineering studies, other site contaminants, plant mortality and project support costs.

In estimating the rehabilitation provision a risk-free discount rate is applied to the underlying cash flows. At 30 June 2022, the real discount rate was 1.5 per cent, which remains consistent with 31 December 2021.

11.1.5 Cash flow timing

The company estimates the presentation of its rehabilitation provision between current and non-current liabilities, based on anticipated timing of expenditure from updated cash flow forecasts.

11.2 Closure Feasibility Study Update

In May 2022, ERA commenced a feasibility study update in connection with a lower technical risk rehabilitation methodology (primarily relating to the subaerial capping of Pit 3) and to further refine the Ranger Project Area rehabilitation execution scope, risks, cost and schedule. Subaerial capping, previously adopted for Pit 1, is a more traditional method and it is currently ERA’s preferred methodology. The 2022 Feasibility Study is expected to take approximately 12 months to complete.

11.3 Government Agreement

Separate to this MCP, ERA is required to maintain the Ranger Rehabilitation Special Account (Trust Fund) with the Commonwealth Government. The Trust Fund is intended to provide security against the estimated costs of closing and rehabilitating the Ranger mine immediately. Each year, the Company is required to prepare and submit to the Commonwealth Government an Annual Plan of Rehabilitation (Annual Plan). Once accepted by the Commonwealth Government, the Annual Plan is then independently assessed and costed and the amount to be provided by the Company into the Trust Fund is then determined.

As at 30 June 2022, ERA had $537 million in cash currently held by the Commonwealth Government as part of the Ranger Rehabilitation Special Account (Trust Fund). In addition, bank guarantees procured by ERA totalling $125 million are held by the Commonwealth as additional security for ERA's Ranger rehabilitation obligations (an additional $1 million is held as an allowance for Jabiluka rehabilitation).

These bank guarantees were provided to the Commonwealth Government based on its review in February 2020 of the 44th Annual Plan of Rehabilitation submitted by ERA (i.e. prior to the Reforecast of the cost of Ranger Project Area rehabilitation).

ERA has agreed amendments to its Government Agreement with the Commonwealth to introduce a clearer framework for managing the amount of security held by the Commonwealth and releasing funds from the Trust Fund for completed rehabilitation works. However, drawdown of funds under this framework will first require revaluation of the security following ERA's internal cost review, which is expected to occur after completion of the 2022 Feasibility Study in 2023. Given the expected increase in the cost of rehabilitating the Ranger Project Area, ERA may be required to provide additional security.

Under this new framework, ERA is entitled to submit a one-off interim payment request for the release from the Trust Fund of an amount representing a portion of the cost of rehabilitation works performed at Ranger between 8 January 2021 and 1 June 2022. An application for drawdown of $58 million was submitted on 26 August 2022 and a response from the Commonwealth is anticipated by the end of October.

12 Management of information and data

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Cover photograph: Caterpillar on *Eucalyptus tintinnans* on Trial Landform

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used in this section.

Abbreviation/ Acronym	Description
ANRDR	Australian National Radiation Dose Register
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARRTC	Alligator Rivers Region Technical Committee
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
LIMS	Laboratory Information Management System
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
NT	Northern Territory
OPSIM	Operation Simulation Modelling
RTBS	Rio Tinto Business Solution

12 MANAGEMENT OF INFORMATION AND DATA

This section provides an overview of the information management systems used by Energy Resources of Australia Ltd (ERA) to manage closure related data. The retention and accessibility of multi-disciplinary closure related data is vital for ensuring successful management of mine closure and rehabilitation activities at the Ranger Mine. The monitoring, recording and documentation of closure processes is also key for auditing and the capacity for adaptive management.

To support closure activities and provide confidence in the strategy, ERA has identified three key components for closure knowledge to be retained:

- validation of site conceptual/numerical models;
- landform design and construction; and
- progressive rehabilitation.

Further specifics on post-closure data retention and handover requirements will be determined in close consultation with the relevant government agencies.

The retention and management of this information is important to demonstrate the appropriateness of, and adherence to, the closure strategy, allow for continuous improvement through capture and communication of lessons learnt, and provide a history of information to help inform decision-making and issues management.

12.1 Data collection and management

ERA has maintained accreditation to ISO 14001:2015 and AS4801[2] health, safety and environmental management systems since 2003 and 2005, respectively. The management system provides for consistent performance indicators (including appropriate backup measures for electronic data and document control). The system also provides for compliance self-assessment, which is routinely verified through mechanisms such as periodic inspections and audits by stakeholders including Rio Tinto, regulators and committees.

Records and data are managed according to a range of policies, standards and work instructions to ensure data is secure, maintained, accurate and retrievable. Information is kept in approved data management systems. This reduces the risk of lost information, for example on personal computers, providing stability in relation to retention of knowledge when key personnel leave.

[2] AS4801 has been superseded by ISO 45001. ERA will move to ISO 45001 in November 2022.

To support closure operations a program of ongoing works ensure critical information is available. In accordance with the prescribed legal requirements, the aim of the program is to ensure that the Information Systems can be maintained and, where necessary, relocated efficiently and effectively without disrupting the activities of Business Units, Operations and Projects, and to handover appropriate materials at relinquishment for ongoing monitoring.

The program includes:

- review of the retention schedule to ensure alignment with current legislation and to address specific business needs;
- risk assessment to determine future potential information retrieval scenarios in order to inform current retention procedures;
- identification and classification of data sources against current and future state needs, including the potential for addressing historical datasets on redundant media to ensure they are retrievable, if necessary; and
- development of a handover specification detailing data source and type, nominating handover recipient, reason for handover and indicative timelines.

12.2 Data availability and reporting

Long-term obligations towards data and information management are represented in various legislative requirements. A specific example is Schedule 7.5 of the Authorisation 108 (2018) requiring ERA to

> "… *maintain to the satisfaction of the NT Minister and for examination by a Mining Officer, all records and data associated with the operation and monitoring of the water management system for the life of the mine up to and including rehabilitation and post closure."*

The environmental monitoring requirements provided under Schedule 13 of the Environmental Requirements (ER), determines that the company must ensure data and reports are available to major stakeholders (Schedule 13.2a) and reports, other than commercial-in-confidence matters, are available to members of the Alligator Rivers Region Advisory Committee (ARRAC) established under the *Environment Protection (Alligators Rivers Region) Act 1978* (Schedule 13.2b). In accordance with Annex D of the Ranger Authorisation 0108, provision of monitoring data including routine water quality reports must be submitted weekly during flow events, and monthly at all other times.

Research undertaken, plans and results must be provided to the Alligator Rivers Region Technical Committee (AARTC) established under the *Environment Protection (Alligators Rivers Region) Act 1978,* as per Schedule 15.1 of the Environmental Requirements, to enable the Committee to co-ordinate research in the broader region.

Under the *Work Health and Safety (National Uniform Legislation) Act 2011,* health monitoring records, air monitoring results and hazardous substances exposure records must be available as required by the business or in response to approved stakeholder request, up to and including post closure in accordance with specific retention needs.

The types of data collected by ERA and the internal/external departments and groups responsible for maintenance and reporting of this data is provided in Table 12-1. New/expanded data sets will continue to inform and/or validate the various conceptual and numerical models on which the closure strategy and design criteria are developed, as well as other aspects of the overall design and construction of the final landform. This is an iterative process and ERA maintains these datasets within its various document management systems.

Table 12-1: Data collection types relevant to closure

Type	Storage/software	Reporting	Objective(s)
As built records (drawings)	• Data viewer • ERA server and centralised data storage systems (includes ProjectWise).	• As built report.	• To maintain construction standards • To inform decommissioning and remediation programs.
Closure project	• ProjectWise, ERA server and centralised data storage system.	• Internal • Annual report • Rehabilitation Progress Report.	• To record project decisions • To manage changes in strategy documents.
Ecological surveys (including related Raster, LiDAR and/or drone imagery)	• ERA server and centralised data storage systems • DroneDeploy.	• Periodical reports (developed internally and externally) • Ranger Mine Closure Plan (MCP) • ARRTC.	• To record and demonstrate progressive remediation and rehabilitation • To inform closure criteria • To inform revegetation strategy.
Geochemical QA/QC	• Laboratory Information Management System (LIMS) • ERA server and centralised data storage systems.	• Periodical studies and subsequent reports.	• To inform ore grade control • To inform closure criteria • To validate ground and surface water models.
Geomorpho-logical surveys and data (including related Raster, LiDAR and/or drone imagery)	• Vulcan 3D Geomodelling • ERA server and centralised data storage systems.	• Ranger MCP.	• To record and demonstrate progressive remediation, rehabilitation and erosion control • To inform closure criteria • To input into modelling.

Type	Storage/software	Reporting	Objective(s)
Geotechnical testing	• Datamine Discover Geospatial • ERA server and centralised data storage systems.	• Periodical reports (developed internally and externally).	• To maintain construction standards • To input into modelling.
Hydrological data	• Acquire • CpetIT.	• Periodical reports (developed internally and externally) • Ranger MCP • ARRTC.	• To maintain Water Bore/Hydrology data • To inform closure criteria • To validate groundwater models.
Materials movement tracking	• Hexagon MineEnterprise/Mine Operate.	• Periodical studies and subsequent reports.	• To monitor material tracking.
Medical records	• Cority Medical (RTBS) • HSE BioTronic.	• Internal • Periodical studies and subsequent reports.	• To record and maintain health/medical records.
Radiation dose (including related Raster, LiDAR and/or drone imagery)	• Labware LIMS Radiation • ERA server and centralised data storage systems • GIS Database system.	• Periodical reports (developed internally and externally) • Ranger MCP • Provision of dose records to ARPANSA and ANRDR.	• To validate models • To inform closure criteria • To maintain national dose records.
Revegetation records (including related Raster, LiDAR and/or drone imagery)	• ERA server and centralised data storage systems.	• Ranger MCP • Annual Report • Periodical reports (developed internally and externally) • ARRTC.	• To record and demonstrate progressive remediation and rehabilitation • To inform closure criteria • To inform revegetation strategy and plant growth • To maintain construction standards.
Surface water and groundwater monitoring (including spatial data)	• LIMS Water • Hydstra • LoggerNet Water Telemetry • Operation Simulation Modelling (OPSIM) • ERA server and centralised data storage systems (Map info files).	• Ranger Annual Groundwater Report • Annual Ranger Wet Season Report • Routine water quality reports • Ranger MCP • ARRTC.	• To meet operational monitoring requirements • To validate conceptual and numerical models • To inform closure criteria • To maintain construction standards.

Type	Storage/software	Reporting	Objective(s)
Survey records	• Vulcan • ERA server and centralised data storage systems.	• Ranger MCP • Annual Report • Adherence with Joint Ore Resource Committee guidelines.	• To validate conceptual and numerical models • To maintain construction standards.
Water treatment production (i.e. flows /volumes)	• LIMS.	• Rehabilitation Progress Report.	• To record and demonstrate progressive remediation and rehabilitation • To meet regulatory compliance requirements.
Incident notification	• RTBS.	• Ranger MCP • Annual Report • Periodical reports (developed internally and externally) • ARRTC • Minesite Technical Committee (MTC).	• To maintain and record incident related information.

GLOSSARY

Below are terms used throughout the Ranger Mine Closure Plan

Key term	Definition
Annual Plan of Rehabilitation	High level plan used to determine the securities amount to be held by the Commonwealth Government for Ranger Mine rehabilitation obligations.
As low as reasonably achievable	Abbreviated to ALARA. As low as reasonably achievable, economic and social factors being taken into account.
BC distillate	The product stream produced by BC plant treatment that has very low dissolved solids. Subject to water quality criteria this product may be discharged to the environment.
Becquerels	The Becquerel (Bq) is the SI derived unit of radioactivity. One Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.
Benchmark dose rate	Also referred to as environmental reference level, a chronic radiation dose rate received by the most highly exposed individuals of non-human biota that would be unlikely to have significant effects on terrestrial or aquatic populations
Best Practicable Technology	Technology from time to time relevant to the Ranger Project which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters.
Bininj	Bininj means many things depending on context: 1. Bininj means 'Aboriginal person' as opposed to a non-Aboriginal person. 2. Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent (as opposed to say, a Yolngu person from NE Arnhem Land or 'Mungguy' which is the Jawoyn language equivalent) 3. Bininj means a man as opposed to a daluk (a woman). 4. Bininj means a human being as opposed to a non-human animal. In the context of the mine closure Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent.
Bioregion	An ecologically and geographically defined area that is smaller than a biogeographical realm ,but larger than ecoregion or an ecosystem, in the World Wildlife Fund classification scheme.
Brecciated	Rock that has been mechanically broken by faulting and shearing, resulting in angular fragments
Brine Concentrator (BC)	A treatment facility that treats process water by distillation to produce a clean product stream (distillate) and a waste stream (brine).
Brine	A generic term for the waste stream from the BC, BS or WTP. For each plant, the brine stream contains most of the salt removed from the feed stream to the plant in a concentrated liquid form. The handling of a brine stream depends on the characteristics of that stream.
Bulk material movement	The movement of stockpiled waste rock for the puposes of backfill and the construction of the final landform
Capping (initial and secondary)	The placement of waste rock above the tailings in Pit 3. Capping layers provide drainage and act to dissipate the bearing pressure of construction equipment.

Key term	Definition
Closure criteria	Direct, measurable and quantifiable target values or tiered assessment processes, developed to demonstrate achievement of the closure objectives
Closure domain	Areas with similar features, decommissioning and/or rehabilitation requirements for closure.
Closure phase	Decommissioning, completion of rehabilitation & transition of monitoring requirements
Collection basin	Smaller constructed storage facility built to capture runoff along the western stockpile (Collection Basin 1, CB3, CB4, CB5, and CB6) which requires pond water treatment. Note that CB2 collects clean runoff and WTP permeate which passively drains into RP1.
Contaminated Land Risk Register	Register of all sites where activities have occurred that have the potential to contaminate land on the RPA.
Constituents of potential concern	Chemical elements identified by the Supervising Scientist Division as being of potential concern to the receiving environment
Diameter at breast height	Measurement of tree diameter taken at 1.3 m above ground level (an adult's approximate breast height).
Digital Elevation Model	Digital representation of the land topography
Disposal	The final transfer of release water into the environment. Disposal requires compliance with regulatory water quality criteria and must only be transferred from an approved location.
Direct discharge	The disposal of release water from a control point into an authorised water course location when flowing (i.e. MG001) or enables passive transfer to the environment (i.e. RP1 and GC2).
Electrical conductivity	Abbreviated to EC. Electrical conductivity is a measure of how well a material accommodates the transport of electric charge.
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary 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.
ERICA Assessment	Exposure/dose/effect assessment for radiological risk to terrestrial, freshwater and marine biota.
Gamma Radiation	Ionizing electromagnetic radiation emitted by a radionuclide during radioactive decay
Georgetown Billabong	The statutory surface water monitoring point for Georgetown Billabong, which is located downstream of Corridor Creek and the Corridor Creek wetland filter.
Gray	The Gray (Gy) is a SI derived unit of ionizing radiation dose. One Gray is defined as the adsorption of one joule of radiation energy per kilogram of matter.
Groundwater conceptual model	Calibrated numerical groundwater flow model encompassing all hydrogeologic elements governing groundwater flow and transport at the Ranger Mine to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions.

Key term	Definition
Groundwater solute transport modelling	Prediction of the temporal and spatial mobilisation of constituents of potential concern from the Ranger Project Area to the surrounding environment through groundwater using the Groundwater conceptual model.
Hydrolithologic unit	A grouping of soil or rock units or zones based on common hydraulic properties.
Hydrolithologic zone	Groupings of hydolithologic units based on similar geological and groundwater flow and transport characteristics.
Irrigation	A form of disposal which allows release water to be dispersed via a sprinkler system over an approved land application area (LAA) at an approved rate.
Land Application Area	Abbreviated to LAA. An area on the RPA used as an evapotranspiration disposal method polished and unpolished pond water from the constructed wetlands filters and, more recently, permeates from the water treatment plants. However, irrigation of unpolished pond water ceased at the end of 2009. The concept of land application is to retain metals and radionuclides in the near-surface soil profile.
Land Disturbance Permit	An ERA permit required prior to undertaking any work on the RPA that may lead to surface disturbance, for example ground breaking, surface disturbance, clearing etc.
Landform Evolution Model	Numerical model that simulates the change in landscape over time in response to various parameters.
LiDAR	Remote sensing technique using pulsed laser to measure distances
Long Lived Alpha Activity	Abbreviated to LLAA. The presence, generally in airborne dust, of any of the alpha emitting radionuclides in uranium ore, except for the short lived alpha emitting radon decay products.
MBL Zone	A hydrolithologic zone of relatively higher permeability to the south east of Pit 1 identified through testing and pumping of bore MB_L.
Magela Creek downstream	Abbreviated to MG009. MG009 is Ranger downstream statutory or compliance surface water monitoring point. It is located on the Magela Creek, downstream of Ranger operations.
Magela Creek upstream	Abbreviated to MCUS. MCUS is the upstream statutory surface water monitoring point, location on the RPA.
Maximum Operating Level	Maximum height permitted for process water in the TSF and Pit 3. Maximum operating level also applies to the maximum deposited height of tailings in Pit 3.
Mine Closure Plan	A dynamic plan presenting all past, present and future rehabilitation activities of the Ranger Project Area in order to demonstrate that closure activities will achieve the relevant Environmental Requirements. Submitted annually for approval, the plan provides updates of the preceding year.
Minesite Technical Committee	The Minesite Technical Committee, convened in accordance with Attachment A of the Working Arrangements for the Regulation of Uranium Mining in the Northern Territory dated 30 May 2005, is tasked with: Reviewing proposed and existing approvals and decisions under NT legislation Reviewing technical information in relation to Ranger Mine, including monitoring data and environmental performance Collaboratively developing standards for the protection of the environment

Key term	Definition
	Developing strategies to address emerging issues The MTC consists of the representatives of the Department of Industry, Tourism and Trade, the Supervising Scientist, ERA and the Northern Land Council. Representatives of the Commonwealth Department of Industry, Science, Energy and Resources may also attend MTC meetings.
Mirarr	Mirarr is a patrilineal descent group. Descent groups are often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Monitoring and maintenance phase	Completion criteria monitoring (and maintenance rehabilitation works if required) Site access pending.
Monitoring Evaluation and Research Review Group	Comprised of members of ERA and SSB, as well as subject matter experts as required, the group is tasked with the ongoing development and refinement of research and monitoring programs during the progressive rehabilitation period
Operations phase	Progressive rehabilitation occurring, and operational, closure & research monitoring
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321%.
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Pit 1 Progressive Rehabilitation Monitoring Framework	Overarching framework of environmental monitoring for the rehabilitation of Pit 1
Plant Available Water	Abbreviated to PAW. The amount of water that can be stored in a soil and be available for growing crops.
Pond water	Water of a quality that requires active management. Derived from rainfall that falls on the active Minesite catchments. The main storage facilities for pond water include Retention Pond 2 (RP2), RP3 and RP6.
Potable water	Potable water is sourced from the Brockman Borefield located in the south-east of the RPA. A second production borefield (Magela Borefield) was established to the north of Jabiru East, primarily as a source of supply for Jabiru East and the Ranger Mine village. Grey water (e.g. from showers and toilets) is treated on site and pumped into septic tanks and then to leach drains.
Potential Alpha Energy Concentration	The concentration of the total alpha energy emitted in air during the decay of radon-222 progeny. Usually measured in µJ m-3.

Key term	Definition
Process water	The most impacted water class on site. Currently stored in the TSF and Pit 3. The process water inventory is derived predominantly from water that has passed through or encountered the uranium extraction circuit, and rainfall from designated process water catchments.
Processing	Processing is the mining term to describe all phases of the ore treatment from milling through to the final product packaging of uranium oxide.
Radon decay products or radon progeny	The short-lived radioactive decay products of radon-222. This includes the decay chain up to, but not including lead-210, namely polonium-218 (sometimes called radium A), lead-214 (radium B), bismuth-214 (radium C) an dpolonium-214 (radium C).
Radon exhalation	Amount of radon leaving the surface of the landform
Ranger Project Area	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth Aboriginal Land Rights (Northern Territory) Act 1976.
Reference Level	Reference Level abbreviated to RL. Denotes a specific elevation relative to mean sea level and is regularly used to identify the height or depth of plan or mine infrastructure – e.g. the height of the TSF or depth of Pit 3
Reject streams	Water treatment plant brines: Water that contains the remaining dissolved solids removed from the pond water. Brines are typically discharged to the process water inventory. However, brines may be discharged to the pond water inventory based on operational requirements. BC brines: Residue water after the distillate has been extracted. OBS brines: residue water that contain the remaining dissolved solids removed from the treatment of pond water brines. Typically, discharged to the process water inventory or alternatively to pond water inventory based on operational requirements. High Density Sludge product water: water arising for the lime treatment process of the HDS plant to remove most salts present in process water. HDS product water may be either recycled to the process water inventory, or subject to further approvals, sent directly to the water treatment plants or discharged into the pond water inventory
Release Plan Calculator	Basic mass balance equation model used to assist with the prediction of changes in water quality between upstream (MCUS) and downstream (MG009) monitoring points. The RPC is used to determine when it is appropriate to actively release water from the minesite
Release water	Release water is derived from incident rainfall that falls on catchments within the mine footprint and is of a high enough quality that it is possible to leave on the site as storm water runoff. Specific streams are routed through passive treatment systems or staging points for management and release (**Error! Reference source not found.**).
Relinquishment	Issue of close-out-certificate(s), relinquishment of RPA Successive close-out certificates may be obtained for areas rather than for the entire RPA at a single point in time
Retention Pond	A large constructed storage facility that collects runoff and stores pond water for treatment (RP2 & RP6) or release water post-treatment (RP1).

Key term	Definition
Revegetation domains	Areas of disturbance, to be revegetated, differentiated on their likely physical and chemical constraints that will influence both the initial establishment and the long-term growth, development and functioning of revegetated plant communities.
Risk	The chance of something happening that will have an impact on objectives NOTE 1: A risk is often specified in terms of an event or circumstance and the consequences that may flow from it. NOTE 2: Risk is measured in terms of a combination of the consequences of an event and their likelihood NOTE 3: Risk can be a threat or an opportunity
Risk Analysis	Systematic process to understand the nature of and to deduce the level of risk NOTE 1: Provides the basis for risk evaluation and decisions about risk treatment.
Risk Assessment	The overall process of Risk Identification, Risk Analysis and Risk Evaluation and shall be retained in accordance with procedure.
Risk Control	The process of elimination or minimisation of risks.
Risk Evaluation	The process used to determine risk management priorities by comparing the level of risk against predetermined standards, target risk levels or other criteria
Risk Management Process	The systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analysing, assessing, controlling and monitoring risk
Risk Priority Class	One of four categories where a hazard can be located on the ERA Ranger Risk Matrix – from CRITICAL to HIGH to MODERATE to LOW
Risk Ranking	The level of risk allocated to a non-conformance if a corrective or preventative action is not carried out. The 5 x 5 Consequence/Probability model.
Risk Register	A register of risk information and controls kept at ERA, categorized into functional areas
Sievert	The Sievert is the unit of absorbed radiation dose, taking into account the differing biological effects of different types of radiation.
Subaerial tailings deposition	Deposition of tailings in air, e.g. from spigots or pipes above the surface of the water
Subaqueous tailings deposition	Deposition of tailings below the surface of the water
Tailings dam	Surface dam used to hold tailings and process water at Ranger. Commonly referred to as "tailings storage facility" or "TSF" in other ERA material. The tailings dam is one of currently three tailings storage facilities at Ranger, the others being Pit 1 and Pit 3.
Tailings flux/ Consolidation flux	Process water squeezed from reducing pore spaces during the consolidation of tailings
Transfer	The process of physically distributing water across the water management system using pumps, pipes, valves and other supporting infrastructure to meet operational requirements.
Treated water	Treated water is water that has passed though one of the three water treatment plants, the Osmoflow Brine Squeezer (OBS) or through the BC.

Key term	Definition
	Treated water is divided into the following categories: Water treatment plant permeate: Water that has been treated to remove a significant amount of its dissolved solids to allow it to be released. BC distillate: Purified water that is produced by the BC. Treated distillate is subject to release criteria. Osmoflow Brine Squeezer (OBS) permeate: water derived from further reverse osmosis treatment of water treatment plant brines by the Brine Squeezer. Water quality is equivalent to water treatment plant permeate.
Treatment Facility	Infrastructure that has been installed to undertake water treatment to achieve desired water quality outputs that is suitable for disposal. The main treatment facilities on site include: Brine Concentrator (BC), Water Treatment Plants (WTPs), Brine Squeezer (BS) and High Density Sludge (HDS) plant.
Treatment product	Water that has undergone treatment to remove excess solutes and improve water quality. The product stream from primary treatment may be suitable for disposal (i.e. BC distillate, BS permeate and WTP permeate) or may require secondary treatment prior to disposal (i.e. HDS product).
Treatment waste	The waste stream produced by the water treatment facilities which contains a higher concentration of solutes due to removal from the original feed water. This also includes water that is used during backwashing and cleaning processes. Treatment waste must be retained on site and returned to source storage for further processing.
Trigger, Action, Response Plan	Abbreviated to TARP. Plan of tasks to be undertaken should monitoring detect a change in parameters of a level that requires preventative or remedial action.
Underfill	Initial fill of waste rock placed in the base of Pit 3.
U3O8	The most stable form of uranium oxide and the form most commonly found in nature. Uranium oxide concentrate is sometimes loosely referred to as yellowcake. It is khaki in colour and is usually represented by the empirical formula U3O8. Uranium is normally sold in this form.
Vadose zone	The portion of the sub-surface that lies between ground surface and the water table or saturated zone.
Vulcan	A design, modelling and planning software package that is used in mine processes, mine design, scheduling and rehabilitation.
WA mine closure guidelines	Guidance documentation provided by the Western Australia Department of Mines, Industry Regulation and Safety for the development of mine closure plans.
Waste rock	The mineral waste produced in the mine but is stockpiled due to its low grade i.e. material which does not enter the processing plant. For example, 1s waste rock is typically material that has a grade of less than 0.02% U3O8; 2s waste rock (or low grade ore) is typically material that has between 0.02% and 0.12% U3O8.
Water inventory	The volume of a water class that exists on site at a single point in time. Inventories are inferred from water level measurements or measured by survey across various storages.
Water Management System	The infrastructure, operations and procedures required to manage water at Ranger which includes capturing, storing, transferring, treating and disposing volumes of water.

Key term	Definition
Water storage facility	A designated area or structure where a particular water class will be contained prior to future transfers, treatment or disposal pathways. For example, process water storage facilities include the Tailings Storage Facility (TSF) and Pit 3.
Water Treatment Plants (WTPs)	A series of ultrafiltration/reverse osmosis treatment plants that treat pond water to create a clean product stream (permeate) suitable for disposal and a waste stream (brine).
Wetland filter	A constructed biological filter system that is designed for final treatment of release water and is monitored to ensure water quality meets regulatory criteria for disposal.
Wicks / Prefabricated Vertical Drains	Drains inserted vertically into unconsolidated tailings material in Pit 1 and 3. The drains consist of plastic strips wrapped in geofabric with extruded channels that allow water to drain upwards from the tailings as it consolidates

ABBREVIATIONS & ACRONYMS

Below are abbreviations and acronyms that are used throughout the Mine Closure Plan

Abbreviation/ Acronym	Description
1G project	1 Gigalitre project
1s	Waste rock material that typically has a grade of less than 0.02% U_3O_8
2s	Waste rock (or low grade ore) material that typically has between 0.02% and 0.12% U_3O_8
AALL	Annual Additional Load Limits
AAPA	Aboriginal Areas Protection Authority
ACF	Australian Conservation Foundation
AEP	Annual Exceedance Probability
AHD	Australian height datum
ALARA	As Low As Reasonably Achievable
APR	Annual Plan of Rehabilitation
ANRDR	Australian National Radiation Dose Register
ANZEEC	Australian and New Zealand Environment and Conservation Council
APR	Annual plan of rehabilitation
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
ASIC	Australian Securities and Investment Commission
ASNO	Australian Safeguards and Non-Proliferation Office
ASS	Acid Sulfate Soils
BACIP	Before-After Control-Impact Paired sampling
BC	Brine Concentrator
BMM	Bulk material movement
BOM	Bureau of Meteorology
BPT	Best Practicable Technology
BTV	Background Threshold Value
C&M	Care and maintenance
CCD	Counter Current Decantation
CCWG	Closure Criteria Working Group
CCWLF	Corridor Creek Wetland Filter
CIP	Closure Implementation Plan

CPT	Cone Penetration Test
CLM	Contaminated Land Management
CPT	Cone Penetration Test
CRE	Conceptual Reference Ecosystem
COPC/COPCs	Constituent of Potential Concern / Constituents of Potential Concern
CRF	Cemented rock fill
CRS	Corridor Road Sump
CSM	Conceptual Site Model
DCM	Department of the Chief Minister
DEM	Digital Elevation Model
DIIS	Department of Industry, Innovation and Science
DISER	Commonwealth Department of Industry, Science, Energy and Resources (formally DIIS)
DITT	Department and Industry, Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
DPMC	Department of Prime Minister and Cabinet
DWPZ	Deeps Water Producing Zone
EC	Electrical Conductivity
ECVs	Environmental and Community Values
EDR	Electro Dialysis Reversal
EDZ	Excavation-damaged zone
EIL	Environment Investigation Levels
EIS	Environmental Impact Statement
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EPIP Act	*Environmental Protection (Impact of Proposal) Act 1974*
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
ERICA	Environmental Risk from Ionising Contaminants: Assessment and management
ERISS	Environmental Research Institute of the Supervising Scientist
ET	Evapotranspiration
FIFO	Fly In Fly Out
FLF	Final Landform
FS	Feasibility Study
GAC	Gundjeihmi Aboriginal Corporation
GCBR	Georgetown Creek Brockman Road
GCC	Gulungul Creek Control

GCLB	Gulungal Creek water monitoring site
GCMBL	Georgetown Creek Median Bund Leveline
GCMP	Ground Control Management Plan
GDE	Groundwater Dependent Ecosystem
GIS	Geographic Information System
GPS	Global Positioning System
GTB	Georgetown Billabong
GV	Guideline Value
H&S	Health and Safety
HDPE	High Density Polyethylene
HDS	High Density Sludge
HIL	Health Investigation Level
HLU	Hydrolithologic Unit
HSE	Health, Safety and Environment
HSEC	Health, Safety, Environment and Communities
HSEQ	Health, Safety, Environment and Quality
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMAP	Inventory Multi-tiered Assessment and Prioritisation
ISWWG	Independent Surface Water Working Group
ITWC	Integrated Tailings and Water Closure (Prefeasibility assessment)
JHA	Job hazard analysis
JTDA	Jabiru Town Development Authority
KKN	Key Knowledge Needs
KNPS	Kakadu Native Plants Pty Ltd
LAA	Land Application Area(s)
LAI	Leaf Area Index
LEM	Landform Evolution Model
LLAA	Long Lived Alpha Activity
LiDAR	Light Detection and Ranging
LIMS	Laboratory Information Management System
MCP	Mine Closure Plan
MCUS	Magela Creek Upstream water monitoring site
MERGG	Monitoring Evaluation Research Review Group
MNES	Matters of National Environmental Significance
MOL	Maximum Operating Level

MOU	Memorandum of Understanding
mRL	Metres Reference Level
MTC	Minesite Technical Committee
NAQS	Northern Australia Quarantine Strategy
NGO	Non-government Organisations
NLC	Northern Land Council
NOHSC	National Occupational Health and Safety Commission
NP	National Park
NSMC	Null space Monte Carlo
NT	Northern Territory
NTP	Northern Territory Portion
OBS	Osmoflow Brine Squeezer
O&M	Operations and Maintenance
OPSIM	Operation Simulation Modelling
PAEC	Potential Alpha Energy Concentration
PAW	Plant Available Water
PDF	Probability Distribution Function
PEST	Parameter Estimation Tool
PFS	Prefeasibility Study
PMP	Probable Maximum Precipitation
PSD	Particle Size Distribution
PTF	Pit Tailing Flux
PVD	Prefabricated Vertical Drains
Q1	Quarter 1, as in first quarter of the calendar year. Also Q2, Q3 and Q4.
QA	Quality Assessment
QQ plot	Quantile-quantile Plot
R3D	Ranger 3 Deeps
RBS	Risk Breakdown Structure
RCCF	Ranger Closure Consultative Forum
RCM	Ranger Conceptual Model
RL	Reference Level
RMV	Ranger Mine Village
RO	Reverse osmosis
ROM	Run-of-mine
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6

RP1WLF	Retention Pond 1 Wetland Filter
RPA	Ranger Project Area
RPC	Release Plan Calculator
RSA Archer	Risk Management Tool
RSWM	Ranger Surface Water Model
RTBS	Rio Tinto Business Solution
RWMP	Ranger Mine Water Management Plan
SAQP	Sampling Analysis Quality Plan
SIA	Social Impact Assessment
SSB	Supervising Scientist Branch
SX	Solvent Extraction
TAN	Total Ammoniacal Nitrogen
TARP	Trigger, Action, Response Plan
TDS	Total Dissolved Solids
TLF	Trial Landform
TO	Traditional Owner
TPH	Total Petroleum Hydrocarbon
TPM	Total Particulate Metals
TPWS Act	*Territory Parks and Wildlife Conservation Act 1978 (NT)*
TSF	Tailings Storage Facility
TSS	Total Suspended Solids
UF/MFRO	Ultrafiltration/Microfiltration and Reverse Osmosis
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VAF	Vulnerability Assessment Framework
VSEP	Vibratory Shear Enhanced Processing
WA	Western Australia
WARC	West Arnhem Regional Council
WASWG	Water and Sediment Working Group
WLF	Wetland Filter
WoNS	Weeds of National Significance
WQMF	Water Quality Management Framework
WRD	Water Resources Division
W/SQO	Water or Sediment Quality Objectives
WTP	Water Treatment Plant

CHEMICAL SYMBOLS AND FORMULAE

Symbols/ formulae	Description
Al	Aluminium
Ba	Barium
Ca	Calcium
Cd	Cadmium
Cl	Chloride
Cr	Chromium
Cu	Copper
Fe	Iron
HCO_3	Bicarbonate
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
NH_3-N	Ammoniacal nitrogen
Ni	Nickle
NO_2	Nitrogen dioxide
NO_3	Nitrate ion
NO_3-N	Nitrate-N
NO_x	Total mono-nitrogen oxides (NO and NO_2)
OH	Hydroxide
P	Phosphorus
Pb	Lead
^{210}Po	Polonium
PO_4-P	Phosphate
^{226}Ra / Ra-226	Radium
Si	Silicon
SiO_2	Silica
SO_4^{2-}	Sulfate
TAN	Total ammonia nitrogen
Total-N	Total nitrogen
Total-P	Total phosphorus
U, ^{238}U	Uranium

Symbols/ formulae	Description
U^3O^8	Uranium oxide
V	Vanadium
Zn	Zinc

SYMBOLS / UNITS OF MEASUREMENTS

Unit of measure	Description
θ_{fc}	Water content at field capacity
θ_{pwp}	Permanent wilting point
%	Percentage
µg	Micrograms
Bq	Becquerel(s)
$Bq\ kg^{-1}$	Becquerel per kilogram
$Bq\ m^{-2}\ s^{-1}$	Becquerel per square metre per second
cm	Centimetre
dB	Decibels
GL	Gigalitre
ha	Hectare
kg	Kilogram
km	Kilometre
km/h	Kilometres per hour
km^2	Square kilometres
kt	1,000 metric tonnes
L	Litre
m	Metre
m^2	Square metre
m^3	Cubic metre
$m^3\ s^{-1}$; m^3/s	Cubic metre per second
mBq	Millibecquerel
mg	Milligram
ML	Megalitre
mm	Millimetre
Mm^3	Million cubic metres

Unit of measure	Description
MPa	Megapascal
mRL	Metres relative level
mSv	Milli-sievert
Mt	Metric tonne
t/m^3	Tonne / cubic metre
µm	Micrometre
µS/cm	Micro Siemens per centimetre
µSv/y	Microsieverts per year
st	Stems
wt.%	Weight %
w/w	Weight per weight
Yr	Year

CONTRIBUTORS

ERA acknowledges the contributions of the many past and present ERA employees, and consultants who have contributed to the October 2022 Ranger Mine Closure Plan either directly or indirectly via workshops, studies, consultation and advice.

APPENDIX A: Stakeholder feedback on 2020 MCP cross-referenced to relevant 2022 MCP section

Issued Date: October 2022

Revision #: 0.22.1

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
1	1. Scope and purpose		While the 2020 RMCP includes a list of future planned applications (Table 3-2), it only describes those applications that will require Ministerial approval, as opposed to all planned or potential future standalone applications (e.g. no HDS sludge disposal or RP6 remediation). The list of standalone applications should include all planned applications, noting (as appropriate) any that may be subject to change.	Standalone applications to the Minister are provided in Section 1.7 and other approvals planned for 2022 are provided in Section 3.4 (not all future approvals are included).	Section 1.7 and Section 3.4
2	7. Risk assessment and management		The 2020 RMCP Risk Assessment still doesn't include adequate information to justify assignment and ranking of risks, classes and controls. Further comments are provided in Table 3.	Likelihood and Consequence tables that generate rankings is included, as are existing controls.	Section 7.3 and 7.4
3	7. Risk assessment and management		There is no detail on control effectiveness, either in the Risk Assessment and Management section or contingencies in Closure Implementation section. Further, there are many risks where no control effectiveness has been assigned – specific comments are provided in Table 3.	Control effectiveness is included for all but 3 of the 45 risks.	Appendix 7.1
4	7. Risk assessment and management		Whilst the RMCP has been updated with details of risk assessments that have been undertaken, the minimum frequency of risk reviews (e.g. annual) isn't explicitly stated, or what other factors may trigger an update to the risk assessment.	Timing and triggers included.	Section 7.3.7
5	7. Risk assessment and management/9. Implementation		There are very few additional contingencies, or further detail added since the 2019 RMCP. The Supervising Scientist does not accept ERA's response that details on contingencies are 'not required' and it is particularly concerning that there are still no post-2026 contingencies presented in the 2020 RMCP for ecosystem restoration. Additional comments on contingencies presented in the 2020 RMCP are provided in Table 3.	Some contingencies are included in Appendix 7.1. A material review of risks is planned for 2023.	Appendix 7.1
6	6. Best Practicable Technology (BPT)		The HDS sludge disposal activity has been removed from the list of future BPT assessments since the 2019 RMCP, without explanation. Recommendation: Justify why HDS sludge disposal is no longer considered as a future BPT assessment.	The BPT for the HDS sludge plant was approved in February 2020 and is included in the 2022 MCP.	Section 6.4 and Appendix 6.1
7	10. Closure monitoring and maintenance		Additional specific comments on the TARP presented in the 2020 RMCP are provided in Table 3.	Refer Table A.2.	
8	5. Knowledge base and supporting studies		Information from KKN LAN1B should be incorporated into the RMCP when it is completed.	Noted.	Not included in 2022 MCP
9	5. Knowledge base and supporting studies		Information from KKN LAN2 should be incorporated into the RMCP when it is completed.	Updates included.	Section 5.1.2
10	5. Knowledge base and supporting studies		Results of long-term landform stability modelling being undertaken by both ERA and the Supervising Scientist should be included in the RMCP as they are completed.	LAN2 updates included.	Section 5.1.2 and Section 5.1.3

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
11	8. Post mining land use, closure objectives and closure criteria	**SSB 2019 RMCP Assessment**: Noted that SSB is currently reviewing the Landform Rehabilitation Standard, which will provide ERA updated advice on the approach to assessing suspended sediments.	The assessment approach to closure criterion L7 is being finalised in consultation with ERA and will be reflected in the updated SSB Rehabilitation Standard and the next version of the RMCP should be updated accordingly.	Updates included.	Section 8.3.2
12	8. Post mining land use, closure objectives and closure criteria		Note that the denudation rate has been revised and will be reflected in the updated SSB Rehabilitation Standard. The next version of the RMCP should be updated accordingly.	Updates included.	Section 8.3.1
13	9. Implementation		The Supervising Scientist recently provided landform modelling technical advice to ERA (i.e. after submission of 2020 RMCP), indicating that although gullies may form over Pit 3 under some scenarios wouldn't be deep enough to expose tailings. This information should be summarised in the 2021 RMCP.	Updates included.	Section 5.1.3
14	5. Knowledge base and supporting studies		Section 5.5.1.1 of the 2020 RMCP contains the following text from the 2018 RMCP, which is either incorrect or has been completed: *A number of limitations of the modelling work were identified by the SSB. The following improvements are being implemented to ensure model outputs are both plausible and scientifically defensible. These improvements include:* • *the development of a stochastic synthetic rainfall dataset to generate a series of unique rainfall scenarios which may occur within a period of 10,000 years. This has allowed uncertainty in predictions to be better accounted for and will provide a range or probability of likely outcomes.* • *an enhancement of the effect of vegetation community growth (vegetation has a major effect on the erosion potential of the landform surface) on landscape evolution within the landform model. The vegetation parameter values used in the CAESAR-Lisflood model have been better defined and continue to be reviewed to better account for the effects of developing vegetation cover over the area of the Ranger minesite.* • *consideration of the role of fire, given its role in the northern Australian landscape and potential to disrupt or prevent the development of specific vegetation communities* • *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 and to ensure the models do not prematurely predict sediment exhaustion from the environment*	Updates included.	Section 5.1.2 and Section 5.1.3
15	9. Implementation		Results of work being undertaken by ERA on landform design optimisation should be included in the RMCP as they are completed.	Updates included.	Section 5.1.2 and Section 5.1.3
16	9. Implementation	**SSB 2018 RMCP Assessment:** Provide a detailed backfill plan for Pit 3 including:	This information should be included in the RMCP following approval of the Pit 3 Backfill Application.	Pit 3 Capping, Backfill Application was provided April 2022, feedback has	Section 9.2.2

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		• types and volumes of contaminated material that will require disposal (e.g. hydrocarbons, soil, waste from HDS plant) • plans for material segregation (if required) • disposal methods to be used (e.g. mixing with waste rock, layering, cells, etc.) • schedule for plant demolition and disposal.		been received and the application is being revised.	
17	9. Implementation		Prior to inclusion in the 2021 RMCP, ERA should consult stakeholders via the Minesite Technical Committee on the proposed plan for cleaning of the floor and walls of the Tailings Dam at the completion of dredging.	Completed and updates included.	Section 6.4 and Appendix 6.1
18	9. Implementation	**SSB 2018 RMCP Assessment:** Improve the scheduling for disposal of contaminated material into the pits, including the 4.6 million tonnes of mineralised material from the northern wall of the Tailing Storage Facility that will be placed in Pit 3 in 2025, and the other mineralised material that will be placed in the lower sections of the pits. It should be clarified how this material will be placed below the low-grade 2 rock cap.	This information should be included in the RMCP as it is generated and following approval of the Tailings Storage Facility Deconstruction application.	Noted. Pit 3 application underway and TSF deconstruction application at least 12 months away.	Section 9.2.2 and Section 9.2.3
19	9. Implementation	**SSB 2019 RMCP Assessment:** There is insufficient information on planning / monitoring of material movements and proposed surface structures. Recommendation: Provide more detailed information to demonstrate adequate planning and monitoring of material movements, including a basis on which the progress of landform construction can be assessed over time.	The planning aspect of the recommendation has been adequately addressed in the 2020 RMCP but details of the monitoring to verify the landform during construction still needs to be included.	Updates included.	Section 10.1.1
20	9. Implementation	**SSB 2019 RMCP Assessment:** Further comments are provided in the 2019 RMCP Assessment Report in relation to tailings consolidation vs process water removal.	It remains to be demonstrated by ERA that the removal of process water from Pit 1 is consistent with that used in solute transport modelling.	Updates included.	Section 5.2.4
21	9. Implementation	**SSB 2019 RMCP Assessment:** Recommendation: Present a consistent and justified approach to surface ripping of the final landform that considers requirements for erosion control, infiltration (i.e. ecosystem establishment vs contaminant transport) and the views of Traditional Owners.	Inconsistencies on ripping have been removed from the 2020 RMCP. The RMCP should be updated once the approach for the overall landform has been agreed amongst stakeholders.	Updates included.	Section 9.3.5
22	Monitoring and maintenance	**SSB 2018 RMCP Assessment:** Provide further details on monitoring method to demonstrate how relevant information will be collected to assess landform performance over time, including: • how gully formation will be measured on the revegetated landform • details of monitoring data required for ongoing validation of erosion modelling	Information from relevant monitoring programs should be incorporated into the RMCP as they are developed. Noted that KKN LAN3E is in the process of being removed.	Updates included.	Section 10.1.1

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		• water quality monitoring methods to be used for assessing landform erosion (e.g. turbidity as a surrogate for suspended sediment in surface water).			
23	Monitoring and maintenance		The commitment to include further detail on tailings consolidation monitoring methods in the Pit 3 closure application and subsequent inclusion in the 2021 RMCP is acknowledged.	Updates included.	Section 10.1.1
24	Monitoring and maintenance	**SSB 2019 RMCP Assessment:** There is insufficient information on planning / monitoring of material movements and proposed surface structures. Recommendation: Provide more detailed information to justify the proposed surface structures, including up to date flood modelling, engineering designs and long-term management plans.	Updated flood modelling and engineering designs are included in the 2020 RMCP but long-term management plans for surface structures will still need to be incorporated into the RMCP.	Some updates in Section 10.1.1, further work will occur to inform the Final Landform application	Section 10.1.1
25	Monitoring and maintenance	**SSB 2018 RMCP Assessment:** Provide further detail on time frames that sediment control infrastructure is expected to remain in place (i.e. criteria for removal) and any ongoing maintenance requirements (e.g. sediment removal and disposal locations).	Long-term management plans for sediment control infrastructure will need to be incorporated into the RMCP.	Refer to comment above.	
26	Knowledge base		Information relevant to the nature and extent of contamination associated with the Tailings Storage Facility should be incorporated into the RMCP as it is acquired.	Updates included.	Section 5.2.3
27	Knowledge base		The information presented on source terms has been updated in the 2020 RMCP and once completed and approved in the Pit 3 application, further updated source term information should be incorporated into the 2021 RMCP.	Noted. Some updates included, Pit 3 application being revised.	Section 5.2.3
28	Knowledge base	**SSB 2019 RMCP Assessment:** Further information is required to support the approach to remediating contaminated groundwater and soils across the site. Recommendation: Provide more detailed information on the nature and extent of the existing contaminated groundwater and soil, demonstrating that the: • level of contamination has been adequately measured (i.e. that samples are representative) • volumes of contaminated material have been reliably estimated • environmental risk associated with leaving the contaminated material in place has been assessed, and where necessary, compared against the risk of remediation and disposal of the material in the upper levels of Pit 3 during the late stages of waste rock backfill (which according to the current schedule is when much of the material will be placed in the pit)	Information from the relevant studies should continue to be summarised in the RMCP as they are completed. It is expected that detailed contaminated site assessment reports will be provided for stakeholder review, in support of proposed site remediation plans. Note that additional comments on soil contamination are provided in this table under the 'Soils' closure theme below.	Updates provided throughout chapters 5 and 9, particularly 9.3.1 for contaminated sites	Section 9.3.1

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
29	Knowledge base	**SSB 2019 RMCP Assessment:** Recommendation: Remove inconsistencies in relation to groundwater contamination in the processing area and update to reflect what the latest groundwater monitoring has identified in terms of downgradient groundwater impacts.	It is acknowledged that inconsistencies have been removed in the 2020 RMCP. Completed works to be included in the Pit 3 closure application should also be summarised in the 2021 RMCP.	Noted. Some updates included, Pit 3 application being revised.	Section 5.2.3 and Section 10.2.2
30	Knowledge base		The method for determining infiltration rate has been presented to SSB and ARRTC and assessed as part of the Conceptual model update with no major issues identified. It is also included as a key parameter in the uncertainty analysis. The sulfide material knowledge should be addressed in the source term model update.	Updates included.	Section 5.2.3 and Section 5.2.4
31	Knowledge base		The updated source term modelling takes into account the heterogeneous nature of tailings in the two pits. Results of ongoing tailings consolidation modelling work will need to be considered in further updates (if required) to the source term modelling and summarised in the RMCP.	Updates included.	Section 5.2.3 and Section 5.2.4
32	Knowledge base		Tailings consolidation modelling continues to be revised by ERA and it is expected this will be included in the upcoming Pit 3 application and summarised in the 2021 RMCP.	Updates included. Pit 3 application being revised.	Section 5.2.3 and Section 5.2.4
33	Knowledge base		The updated source term modelling considers the existing groundwater plumes (TSF, processing area, LAAs, RP2 etc). Proposed remediation options should be detailed in the RMCP once all the studies and modelling are completed.	Noted.	-
34	Knowledge base		The acid sulfate soil conceptual model has been completed and reported to stakeholders' satisfaction (ARRTC45) in the 2020 RMCP. The Supervising Scientist has indicated to ERA that an acid sulfate soil risk assessment should be presented in the Pit 3 Application, scheduled for submission in late 2020. Sediment sampling has been planned and the results of ensuing phases of this work should be summarised in the RMCP when completed.	Some updates included. Pit 3 application being revised.	Section 5.2.2 and Section 5.2.6
35	Knowledge base		Once completed in accordance with the recommendations provided by the Supervising Scientist, results of all contaminant transport modelling should be summarised in the RMCP.	Updates included.	Section 5.2.3 and Section 5.2.4
36	Knowledge base	**SSB 2018 RMCP Assessment:** To enable more reliable predictions of contaminant concentrations in surface water, the contaminant transport modelling, particularly the surface water model, needs to be refined using more relevant and appropriate data and assumptions, including: • undertaking contaminant transport modelling at increased temporal and spatial resolution (particularly around the period of peak solute delivery to the surface water system) • developing better understanding of groundwater/surface water interactions that will control the location and timing of delivery of contaminated groundwater to the surface water system	The Supervising Scientist has provided ERA with feedback on the final scope of work for surface water modelling, including the need to address the above recommendations from SSB's assessment of the 2018 RMCP. This information has not been captured in the 2020 RMCP.	Section updated. Updates to the surface water modelling are ongoing following completion of the groundwater solute transport modelling studies.	Section 5.2.5

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		• implications of groundwater recovery as groundwater levels return to a stable state after rehabilitation • improved understanding of the role of groundwater/surface water interactions in solute migration • assessment of confidence in modelled outputs using statistical, sensitivity and uncertainty analyses for each model, as well as analysis of cumulative uncertainty where multiple models are interconnected.			
37	Knowledge base		The scope for groundwater-surface water interactions work has been included in 2020 RMCP. However, further detail on how the groundwater model results are fed into the surface water model should be included in the Pit 3 application and in the 2021 RMCP.	Some updates included. Pit 3 application being revised.	Section 5.2.5
38	Knowledge base		Results of the completed surface water modelling to be included in the Pit 3 closure application should be summarised in the 2021 RMCP.	Some updates included. Pit 3 application being revised.	Section 5.2.5
39	Knowledge base	**SSB 2018 RMCP Assessment:** Reactive transport modelling is required for calcium so that its effect on magnesium toxicity in the receiving surface waters can be understood (calcium has been shown to ameliorate magnesium toxicity). **ERA Response 2019 RMCP:** ERA project 1260-02 - Mg:Ca input into Surface Water Model - is underway to address this. Outcomes will be reported in the next MCP and inform inputs to the surface water model. This project is listed against KKN WS3C. What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?	The ERA study specified above has been completed but not yet summarised in the RMCP. ERA has acknowledged that updates to water and solute transport models (or corrections to previously reported results) may be required, depending on the outcome of updated surface water modelling (with Ca turned off from the mine sources).	Updates included.	Section 5.2, Section 5.2.5
40	Knowledge base	**SSB 2018 RMCP Assessment:** Further work is required to provide reliable predictions of surface water contaminant concentrations post-rehabilitation; including (i) the characterisation of contaminant source terms, (ii) verifying the conceptualisation of key groundwater contaminant pathways, (iii) additional information on the interactions between surface water and groundwater, and (iv) more detailed ground and surface water modelling.	The updated summary of information presented in the 2020 RMCP is acknowledged and current work to update the predicted nature and extent of surface water contamination following rehabilitation should be incorporated into the 2021 RMCP.	Updates included.	Section 5.2
41	Knowledge base		KKN WS7C is currently in the process of being closed out and results of the above SSB project have been provided to ERA. This information should be summarised in the 2021 RMCP.	Noted but not included in 2022 MCP	-
42	Knowledge base		ERA's commitment to include the above information in the RMCP is acknowledged and it is noted that the Supervising Scientist has provided ERA with some of the relevant information via the KKN WS7C.	Noted but not included in 2022 MCP	-

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
43	Knowledge base	**SSB 2018 RMCP Assessment:** Provide additional details on remediation of onsite waterbodies.	There does not appear to be any update provided by ERA in the 2020 RMCP. Outcomes of the above assessments should be incorporated into the RMCP when they are completed.	Some updates included, studies ongoing.	Section 5.2.2, Section 9.2.7 and Section 9.3.1
44	Knowledge base		The following text was included in the 2020 RMCP but not in the ERA response table: *SSB and ERA have agreed that the current AALL are not suitable for closure criteria and that KKN WS6b can be removed. ARRTC45 agreed to this KKN removal.* *ERA is working with SSB to conduct a third tier risk review based on an expanded literature review of biological effects of nutrients and initial results of modelling predicting post closure surface water quality.* SSB notes progress against this item. Outcomes of the above work should be incorporated into the RMCP when they are completed.	Noted. Studies ongoing.	Section 5.2.7
45	Knowledge base	**SSB 2018 RMCP Assessment:** Assess the risk of contaminated groundwater on riparian and aquatic vegetation.	The above-mentioned studies being conducted by NESP (CDU researchers) for the Supervising Scientist are nearing completion and results will be provided to ERA for incorporation into the 2021 RMCP.	Some updates included, studies ongoing.	Section 5.2.6 and Section 5.4.2
46	Knowledge base	**SSB 2018 RMCP Assessment:** Assess the potential risk of contaminant plumes in creek channels forming a barrier that inhibits organism migration and connectivity.	The above-mentioned study being conducted by NESP (CDU researchers) for the Supervising Scientist is nearing completion and results will be provided to ERA for incorporation into the 2021 RMCP.	Some updates included, studies ongoing.	Section 5.2.6 and Section 5.4.2
47	Knowledge base		KKN WS7C is currently in the process of being closed out and results of the above SSB project have been provided to ERA. This information should be summarised in the 2021 RMCP.	Noted but not included in 2022 MCP	-
48	Knowledge base	**SSB 2018 RMCP Assessment:** Determine potential levels of exposure of humans to contaminants from drinking water from onsite waterbodies (i.e. consumption rates, locations, concentrations) and assess the risk to human health.	Relevant information from the above-mentioned studies being conducted by ERA should be incorporated into the 2021 RMCP.	Some updates included, studies ongoing.	Section 5.2.2
49	Post mining land use, closure objectives and closure criteria	**SSB 2019 RMCP Assessment:** Further clarification of this comment was provided in the 2019 RMCP Assessment Report: ERA provides an interpretation of ER 1.2(d) in the second outcome of the Water and Sediment Objectives 2 (RMCP: Table 8-2) that contaminants off the RPA *do not cause detrimental impact to the ecosystem health of the Alligators River Region* which would imply an effect to be regional in nature to be considered detrimental. Rather, ER 1.2(d) states that to be considered detrimental a change must be in excess of that observed naturally in the region, which the Supervising Scientist interprets as outside the range of natural variability, not that changes must be regional in nature.	ERA has not responded to this concern in the 2020 RMCP, and has applied the same interpretation in the 2020 RMCP. The Supervising Scientist remains concerned with ERA's interpretation of the ERs and will actively engage with ERA on this issue, with the objective of reaching a resolution prior to the 2021 RMCP.	Section 8.3.2 notes the second management goal as being: 'mine sourced solutes do not increase contaminants in sediments off the RPA to levels that would be detrimental to ecosystem health off the RPA'.	Section 8.3.2

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
50	Post mining land use, closure objectives and closure criteria		KKN WS7A is currently in the process of being closed out and results of the above SSB project have been provided to ERA. This information should be summarised in the 2021 RMCP.	Noted but not included in 2022 MCP	-
51	Post mining land use, closure objectives and closure criteria		Use of BPT to determine outcomes for the Ranger site that are ALARA is supported by SSB but, and in accordance with ER 12.5, requires consultation with, and having regard to the views of, the major stakeholders (including SSB, NLC and Traditional Owners). Stakeholders have also sought quantitative values as closure criteria associated with ALARA in order to demonstrate the environmental outcomes for on-site have been achieved. Future RMCPs will need to describe the outcomes of these stakeholder consultations, including agreed quantitative closure criteria.	Noted. Closure criteria, and stakeholder engagement in closure criteria, discussed throughout Chapter 8	Chapter 8
52	Post mining land use, closure objectives and closure criteria	**SSB 2018 RMCP Assessment:** Undertake modelling of the potential contaminant accumulation in sediments post-closure, based on the results of surface water contaminant modelling, to demonstrate that sediment closure criteria are likely to be met.	This comment is yet to be addressed, noting that the Supervising Scientist and ERA have recently completed work against KKN WS3G that should be summarised in the 2021 RMCP.	Updates included.	Section 5.2.6
53	Post mining land use, closure objectives and closure criteria		Comments to the separate Supervising Scientist recommendation, "Assess the risk of eutrophication to on and offsite waterbodies when surface water model results predicting nutrient concentrations become available", are directly relevant to this topic. Thus, it is noted that closure criteria for eutrophication are currently being developed (i.e. KKN WS6C). Further, KKN WS6B has been removed, with ARRTC45 agreement, on the basis that AALLs are not applicable as closure criteria.	Updates included, studies ongoing.	Section 5.2.7
54	Post mining land use, closure objectives and closure criteria		The Supervising Scientist's Turbidity and Sedimentation Rehabilitation Standard is close to completion and should be incorporated into the 2021 RMCP.	Turbidity included within relevant criteria.	Section 8.3.1 and Section 10.1
55	Post mining land use, closure objectives and closure criteria		The draft closure criteria for sediments presented in the 2020 RMCP includes uranium but should also include sulfate, in accordance with relevant guidelines: *EPHC & NRMMC 2011. National guidance for the management of acid sulfate soils in inland aquatic ecosystems. Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council, Canberra. It is noted that there also are surface water closure criteria for uranium and sulfate, which aim to protect sediments from accumulating levels of these contaminants that could result in environmental impacts.*	There is currently no agreed sulfate in sediment closure criteria. Sulfate is included in Table 8-5 for water.	Section 8.3.2, Table 8-5
56	Closure implementation		An 'Integrated Water Treatment Strategy' is no longer listed in the 2020 RMCP as a future application but it is understood that ERA may be planning to provide an Integrated Water Strategy as part of the Ranger Water Management Plan. Relevant information from this document should be incorporated into the next RMCP, including a conceptual diagram summarising the various proposed treatment activities.	Updates included, and process water flow diagram included. Ranger Mine Water Management Plan (RWMP) also produced annually.	Section 9.3.3
57	Closure implementation		There is no acknowledgement in the RMCP of the need to demonstrate the suitability of the TSF for process water storage.	Noted.	Section 9.2.3

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
58	Closure implementation		Section 9.3.2.4 of the 2020 RMCP states: *ERA is currently engaging with contractors to complete a broad investigation of alternatives across the industry for current best practice. This work will build on the previous options analysis completed in 2012. Options selected will be subjected to a best practical technology assessment with any viable contingencies included in the 2021 MCP.* Further details on brine injection contingencies should be included in the 2021 RMCP, as stated by ERA above.	Updates included throughout Section 9.2.2. Contingencies included in 9.2.2.4.	Section 9.2.2
59	Closure implementation		An 'Integrated Water Treatment Strategy' is no longer listed in the 2020 RMCP as a future application but it is understood that ERA may be planning to provide this as part of the Ranger Water Management Plan. Relevant information from this document in relation to pond water disposal should be incorporated into the next RMCP.	Updates included. Ranger Mine Water Management Plan (RWMP) also produced annually.	Section 9.3.3
60	Closure implementation	**ERA Response 2020 RMCP:** ERA will be completing OPSIM-based water balance studies to determine the ability to dispose of treated pond and process water, throughout closure and as Land Application Areas are removed from service and rehabilitated. This water balance will also assess the balance between other disposal methods and demand from revegetation irrigation. This work is expected to be completed during 2021 and will be provided in an updated MCP.	ERA's commitment to include the above information in the 2021 RMCP is acknowledged.	Studies ongoing, for OPSIM refer Section 9.6.4.2.	Section 9.6.4
61	Closure implementation		A methodology for monitoring consolidation in Pit 3 should be included in the Pit 3 application and the 2021 RMCP, as committed to above.	Updates included. Pit 3 application being revised.	Section 5.2.3 and Section 5.2.4
62	Closure implementation	**ERA Response 2020 RMCP:** An assessment to inform material management strategy for the TSF sub floor material and the Pit 3 closure application was undertaken in late 2019. The key finding of the study was that removing the subfloor material from below the TSF and placing it in Pit 3 would result in higher solute loadings to the environment. Refer to Section 9.3.3.3.	The ERA response above refers to the contaminated material management but how the contaminated groundwater will be managed still needs to be determined and reported. This will be informed by groundwater modelling, surface water modelling and the TSF deconstruction application.	Noted. Pit 3 application underway and TSF deconstruction application at least 12 months away.	Section 9.2.2 and Section 9.2.3
63	Closure implementation		The 2020 RMCP (Section 5.5.2.5) provides an update on contaminated soil assessments in the processing area, indicating that a contaminated site drilling program and bore installation program was undertaken in late 2019/early 2020 to target areas where there are knowledge gaps. A summary of the results is provided and it is expected that this information will be used to update remediation plans (i.e. volumes of soil/water, recovery methods and placement for disposal) for the processing area in the 2021 RMCP.	Results from the 2019/2020 contaminated sites assessment have been used to inform other studies such as the source terms and the water pathway risk assessments. Results will also be used to inform future remediation plans, when completed.	Section 5.2.3 and 5.2.4
64	Monitoring and maintenance	.	The post-closure monitoring section of the RMCP should include a commitment to periodically review contaminants.	Updates included.	Section 10.2

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
65	Monitoring and maintenance		The groundwater closure monitoring plan remains subject to stakeholder agreement and the RMCP should be updated when agreement is reached.	Noted. Updates included.	Section 10.2.2
66	Monitoring and maintenance		The RMCP should be updated when agreement is reached on the surface water closure monitoring plan. The Supervising Scientist recommends the inclusion of nutrients and pesticides to the water and sediment analysis suite during the early phases of revegetation establishment, when fertiliser is being added to revegetation and large-scale weed spraying is occurring. The monitoring should be periodic, not “opportunistic” (Section 10.3.1) and during the early period following rehabilitation, the surface water monitoring should be continued as event-based sampling, rather than monthly sampling (Table 10-4). The sampling intensity/frequency could be reduced in the long term, once it has been demonstrated that the risk of downstream contamination is acceptably low.	Noted. Updates included.	Section 10.2.1
67	Knowledge base	**ERA Response 2020 RMCP:** Radionuclide concentrations in surface water are predicted within the surface water model (Section 7.8). ERA are in the process of updating the surface water model, the results of which will be available in the 2021 MCP.	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
68	Knowledge base	**ERA Response 2020 RMCP:** Radiological parameters required for the radiation dose assessment will be outlined in future iterations of the MCP and provided in detail within ERA's application for approval to construct the final landform. See Section 7.10.1 for further detail.	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
69	Knowledge base	**ERA Response 2020 RMCP:** Radiological parameters required for the radiation dose assessment will be outlined in future iterations of the MCP and provided in detail within ERA's application for approval to construct the final landform. See Section 7.10.1 for further detail.	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
70	Knowledge base	**ERA Response 2020 RMCP:** Radiological parameters required for the radiation dose assessment will be outlined in future iterations of the MCP and provided in detail within ERA's application for approval to construct the final landform. See Section 7.10.1 for further detail.	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
71	Knowledge base	**ERA Response 2020 RMCP:** Radiological parameters required for the radiation dose assessment within ERA's application for approval to construct the final landform due for submission in 2022. See Section 7.10.1 for further detail.	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
72	Knowledge base	**ERA Response 2020 RMCP:** The radiation dose assessment is contingent upon the completion of current and future closure studies. The completed dose assessment will be included in future	ERA’s commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		iterations of the MCP. See Section 7.10.1 for further detail.			
73	Knowledge base	**ERA Response 2020 RMCP:** The prediction of radiation dose to wildlife forms part of the radiation dose assessment. This study is underway and will be included in future iterations of the MCP. See Section 7.10.1 for further detail.	ERA's commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
74	Knowledge base	**ERA Response 2020 RMCP:** The prediction of radiation dose to wildlife forms part of the radiation dose assessment. This study is underway and will be included in future iterations of the MCP. See Section 7.10.1 for further detail.	ERA's commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
75	Knowledge base	**ERA Response 2020 RMCP:** The prediction of radiation dose to wildlife forms part of the radiation dose assessment. This study is underway and will be included in future iterations of the MCP. See Section 7.10.1 for further detail.	ERA's commitment to include the above information in the RMCP is acknowledged.	Studies ongoing.	Section 5.3.2
76	Monitoring and maintenance		A list of terrestrial bushfood groups to be targeted for post-closure (i.e. beyond 2026) monitoring of radionuclides has not been provided. Also, given that ERA's permits and approvals to collect bushfoods expire in 2025, this does not address the aspect of post-closure monitoring of radionuclides in bush foods nor is it consistent with the intended duration set out in Table 10-9 "Until demonstrated progression towards closure criteria, i.e. low levels have been confirmed".	Studies ongoing (Section 5.3.2), bush diet listed in Section 5.3.1, monitoring is included (Section 10.3)	Section 5.3.2, Section 5.3.1, Section 10.3
77	Monitoring and maintenance		ERA's permits and approvals to collect bushfoods expire in 2025. ERA should seek further approval for the collection of bushfoods to enable post-closure (i.e. beyond 2026) monitoring of radionuclides in aquatic bushfoods in potentially contaminated waterbodies.	Noted.	
78	Knowledge base		The 2020 RMCP (Section 5.5.2.5) provides an update on contaminated soil assessments in the processing area, indicating that a contaminated site drilling program and bore installation program was undertaken in late 2019/early 2020 to target areas where there are knowledge gaps. A summary of the results is provided and it is expected that this information will be used to update remediation plans (i.e. volumes of soil/water, recovery methods and placement for disposal) for the processing area in the 2021 RMCP.	Results from the 2019/2020 contaminated sites assessment have been used to inform other studies such as the source terms and the water pathway risk assessments. Results will also be used to inform future remediation plans, when completed.	Section 5.2.3 and 5.2.4
79	Knowledge base		The 2020 RMCP (Section 5.5.2.4) provides an update on contaminated soil assessments in the land application areas, indicating that the information will inform the approach to remediation of each LAA, if required.	Noted. Studies ongoing. Section 9.3.1 provides some information regarding contaminated sites.	Section 9.3.1
80	Knowledge base	**ERA Response 2020 RMCP:** Details on the contaminated sites assessment completed in the past 12 months are provided in the 2020 MCP	ERA's commitment to include the above information in the RMCP is acknowledged.	Noted. Studies ongoing. Section 9.3.1 provides some information regarding contaminated sites.	Section 9.3.1

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		(Refer to Section 5). As assessments are completed they will continue to be provided in the annual MCP updates.			
81	Post mining land use, closure objectives and closure criteria		The 2020 RMCP indicates that soil contamination sampling has been undertaken, therefore it is expected that this comment should be addressed in the 2021 RMCP.	Noted. Studies ongoing. Section 9.3.1 provides some information regarding contaminated sites.	Section 9.3.1
82	Knowledge base		The inclusion of draft fauna closure criteria in the 2020 RMCP is acknowledged. Some initial comments are provided in Table 3 and Attachment A, noting that further consultation will occur via the Ecosystem Restoration Working Group.	Updates included.	Section 8.3.5
83	Knowledge base		The inclusion of draft fauna closure criteria in the 2020 RMCP is acknowledged. Some initial comments are provided in Table 3 and Attachment A, noting that further consultation will occur via the Ecosystem Restoration Working Group.	Updates included.	Section 8.3.5
84	Knowledge base		It is noted that agreement to a final revegetation species list is subject to ongoing work by ERA and consultation with stakeholders. Additional specific comments on information presented in the 2020 MCP are provided in Table 3.	Noted. Current list provided.	Appendix 5.5
85	Knowledge base	**SSB 2018 RMCP Assessment:** Provide details on which species would be included in the understorey (in consideration of requirements for faunal colonisation), and evidence to support the assumption that direct seeding is the best option for the establishment of such species. **ERA Response 2019 RMCP:** Planned trials on rehabilitation understorey species are described in Section 7.6.3. It is not assumed that these species will be direct seeded, but predominantly introduced via tubestock. Habitat requirements for fauna return will be considered under KKN ESR2B, and will be reported on in the 2020 MCP.	It is noted that the original comment was in relation to understorey establishment, not fauna. As it is generated, the required information should be presented in updates to the RMCP and the Final Landform and Revegetation Application.	Noted. Updates included.	Section 5.4.3
86	Knowledge base		The 2020 RMCP includes brief descriptions of planned fauna habitat trials for the TLF, although there is no indication of when results will be available. As it is generated, the required information should be presented in updates to the RMCP and the Final Landform and Revegetation Application.	Noted. Updates included.	Section 5.4.6
87	Knowledge base	**SSB 2018 RMCP Assessment:** Provide information on nitrogen dynamics in the rehabilitated landform, including an assessment of the potential for nitrogen to be a limiting factor for nutrient cycling, and nutrient availability and presence of soil biota to assist in plant growth.	There do not appear to be any significant updates in the 2020 RMCP to address this recommendation.	Noted. Studies ongoing.	Section 5.4.2
88	Knowledge base	**SSB 2018 RMCP Assessment:** Provide information demonstrating that waste rock can maintain long-term species diversity through recruitment	Limited information is presented in the 2020 RMCP which is based only on observations on the Trial Landform. This indicates that some species have the ability to recruit/regenerate in waste rock. It is recommended that a summary of	Noted. Some updates included. Studies ongoing.	Section 5.4.2

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		and regeneration and whether there are factors that could be manipulated to facilitate this. **SSB 2019 RMCP Assessment:** Further comments on the application of information obtained from revegetation trials are provided in the 2019 RMCP Assessment Report.	all available information be presented in the 2021 RMCP, with a focus on quantitative data where possible (i.e. over the entire Trial Landform).		
89	Knowledge base		While information from the Trial Landform fire study has been incorporated into the 2020 RMCP, this still needs to be put into the context of other relevant information available on plant survivability from fire in the region.	Updates included.	Section 5.4.4
90	Knowledge base		While information from the Trial Landform fire study has been incorporated into the 2020 RMCP, it is noted that ERA has an additional study allocated to KKN ESR8A which will further inform the development of a fire regime.	Updates included.	Section 5.4.4
91	Knowledge base		Updates on weed status have been provided in the 2020 RMCP, although these only appear to include the Trial Landform. While relevant studies may be underway and it is acknowledged that the Supervising Scientist is undertaking work to address KKN ESR4A (introduced species in areas surrounding the RPA), the RMCP should include a commitment by ERA to undertake comprehensive surveys on the RPA to inform the status of weeds and feral animals before and during the rehabilitation process.	Updates included.	Section 5.4.5 and Section 10.4.1
92	Knowledge base		A list of the species present on the RPA has been presented in the 2020 RMCP, which is based on previous work and doesn't include densities or areas adjacent to the RPA. The Supervising Scientist will undertake studies to address KKN ESR4A (introduced species in areas surrounding the RPA) and provide the information to ERA as it becomes available for inclusion in the RMCP.	Noted. Updates included.	Section 5.4.5 and Section 10.4.1
93	Knowledge base	**SSB 2018 RMCP Assessment:** Assess the risk of feral animals impacting on faunal colonisation of the rehabilitated site.	There does not appear to be any updated information from studies (or their status) presented in the 2020 RMCP. It is noted that the 'KKN for fauna outside the RPA' (ESR4A) is not the most relevant KKN to this question. Both ERA and the Supervising Scientist have allocated studies to address the relevant KKN ESR2C ('What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?') and as the results of these studies become available, they should be incorporated into the RMCP.	Noted. Updates included.	Section 5.4.5 and Section 10.4.1
94	Knowledge base	**SSB 2018 RMCP Assessment:** Assess the risk of potential impacts of contaminants leached from waste rock on revegetation and fauna, including details on how this would be avoided or mitigated. **ERA Response 2019 RMCP:** SSB are undertaking KKN ESR6A. What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants? ESR6B will be completed and reported on in updated MCP. **SSB 2019 RMCP Assessment:** Noted that the need for KKN ESR6A (i.e. impact of contaminants on vegetation) is currently subject to discussion between SSB, ERA and ARRTC. Noted that	The Supervising Scientist has agreed that the KKN ESR6A could possibly be removed, if the relevant groundwater modelling (e.g. shallow aquifers) when completed by ERA indicates there is a low risk of exposure of revegetation on the final landform to contaminants. As noted previously, KKN RADA (assigned to ERA) is intended to assess the risk to fauna.	Noted.	

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		the need to assess risk of contaminants to fauna is identified in KKN RAD8.			
95	Knowledge base	**SSB 2018 RMCP Assessment:** Mitigations to address integrated landscape risks, such as weather, should be addressed in the Ecosystem Restoration Strategy. **ERA Response 2019 RMCP:** When further studies are completed, these mitigations will be included within the ecosystem rehabilitation strategy.	The commitment to include further detail on landscape risk mitigation measures in the RMCP is acknowledged.	Noted. Studies ongoing.	Section 5.5
96	Knowledge base	**SSB 2019 RMCP Assessment:** Noted that it is not clear if the results discussed in section 7.5 of the RMCP from the analysis of the FLV5.2 landform are the same as those from the FLV6.2 landform. **ERA Response 2020 RMCP:** During the monitoring and maintenance phase, the landform may settle over time and there is also the potential for subsidence and/or erosion to occur. Revegetation must also progress towards a self-sustaining ecosystem. Potential remedial management practices to ensure continued progress towards a stable landscape and self-sustaining ecosystem in this phase are described in Section 10.	The additional information presented in the 2020 RMCP is acknowledged, noting that the risk will need to be assessed following the completion of all studies allocated to the KKN LAN3B.	Noted. Updates included.	Section 5.1.3
97	Knowledge base	**SSB 2018 RMCP Assessment:** Provide information on soil formation properties for each type of waste rock to be used in landform construction, including: • weathering rates • soil texture information for the entire waste rock substrate (i.e. not just < 2mm fraction).	Soil formation and PSD information have been presented in Appendix 5.1 but this is not consistent with what is presented in the main body of the RMCP. It is also noted that soil formation needs to be determined for other parameters in addition to PSD, such as organic content and nutrients.	Noted. Particle Size Distribution (PSD) updates included.	Section 5.4.2
98	Post mining land use, closure objectives and closure criteria		There are several current and planned studies by both SSB and ERA allocated to KKN ESR5 and the information generated by these studies should be summarised in the RMCP as they are completed. There has not yet been significant progress in studies to address this comment in the 2020 RMCP.	Noted. Updates included.	Section 5.4.7
99	Post mining land use, closure objectives and closure criteria		Draft fauna closure criteria have been included in the 2020 RMCP. These are subject to ongoing consultation with stakeholders and specific comments are provided in Table 3 and Attachment A (Assessment of Closure Criteria) where appropriate.	Noted. Updates included.	Section 8.3.5
100	Post mining land use, closure objectives and closure criteria		Draft fauna closure criteria have been included in the 2020 RMCP. These are subject to ongoing consultation with stakeholders and specific comments are provided in Table 3 and Attachment A (Assessment of Closure Criteria) where appropriate.	Noted. Updates included.	Section 8.3.5

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
101	Post mining land use, closure objectives and closure criteria		Draft fauna criteria have been included in the 2020 RMCP but there is not yet evidence to support the assumption that fauna will colonise the rehabilitated site, once suitable habitat has established. There are several current and planned studies by both SSB and ERA allocated to KKN ESR2B and the information generated by these studies should be summarised in the RMCP as they are completed.	Noted. Updates included.	Section 5.4.6 and Section 8.3.5
102	Closure implementation		The ongoing plant propagation studies being undertaken by ERA to address the KKN ESR3A are acknowledged and the resulting information should be incorporated into the RMCP as it is generated.	Noted. Updates included.	Section 5.4.3 and Section 9.3.6
103	Closure implementation		The contingency plan presented in Section 9.4.6.2 of the 2020 RMCP only considers the nurseries capacity to produce tubestock, not the availability of seed to produce tubestock, or contingencies that may be required during the establishment phase. If the short-lived seeds are not producing well prior to the 24/25 planting season, then a significant lack of tubestock could occur with no potential for collection prior to the large-scale planting following final landform completion. The contingency plan should address the possibility on having low availability/low productivity in short-lived seeds prior to the final rounds of planting. To give confidence that the seed collection practices and contingencies will be able to produce the required number of plants in their ecologically-relevant proportions, more information on the seed collection database needs to be provided. For example, there may be logistical constraints and risks associated with the timely planting of a particular reference ecosystem (compared to another) if species are considered individually in terms of their seed collection requirements and progress against the plan. Information should include: • the number of seeds currently collected per species, including specification of framework/culturally-important species • when the peak seed requirement is for each species • seed proportions collected relating to reference ecosystem/s proposed rankings of species/community types on seed collection and storage difficulty.	Noted. Updates included (also included as a risk in Chapter 7 and Appendix 7.1).	Section 9.3.6
104	Closure implementation	**SSB 2018 RMCP Assessment:** Additional information on the works proposed in the revegetation application should include: • detailed action plans and timelines, including methods (i.e. planting, irrigation) • seed availability and collection plan • nursery details and propagation studies • target and planned planting densities and methods (e.g. final target density for each species) • habitat to be installed (e.g. nesting boxes, rock piles) • ongoing management activities, including weed control and infill planting • any other project specific assumptions or information which would be required to conduct a detailed assessment of the activity.	The information should be summarised in the RMCP as it becomes available and detailed in the Final Landform and Revegetation application, as noted above.	Noted. Updates included in MCP and will be included in Final Landform application	Section 5.4.3 and Section 9.3.6

A.1 SSB feedback on 2020 MCP and cross-reference to relevant section of 2022 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
105	Closure implementation	**SSB 2018 RMCP Assessment:** Refine the vegetation mortality contingencies to consider mortality beyond the first 6 months and the potential for mortality to vary between species and locations.	While ongoing studies may inform specific contingencies, high-level contingencies should be developed for inclusion in the RMCP that can be updated as the relevant information becomes available.	Noted. Some updates included.	Section 9.3.6.7
106	Monitoring and maintenance	**SSB 2018 RMCP Assessment:** The vegetation and fauna monitoring program should include detailed information about: • justification for site selection • survey methods and quantitative metrics being to assess condition and natural variability • how the data from these surveys are being used to derive or update closure criteria.	There does not appear to be any updated information on vegetation/fauna monitoring programs presented in the 2020 RMCP. It is noted that consultation on ecosystem restoration monitoring programs is ongoing.	Updates included.	Section 8.3.5
107	Monitoring and maintenance		The State-and-Transition Model is mentioned in the 2020 RMCP with respect to refining the *'trajectories for key parameters for revegetation, to identify milestones and thresholds to inform the ERA Adaptive Management Plan'*. It is understood this information will be gathered in 2020/21 and it is also noted that both the Supervising Scientist and ERA are undertaking additional studies to address the relevant KKN ESR5B.	Updates included, studies ongoing.	Section 5.4.7

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
108	Section 1.4 Table 1-2 Future applications to be submitted	*Final Landform: Some information will have already been included within the MCP. Thus this application is to include any updates or additional information since July 2021 (MCP 2021).* This could result in a disconnect on approval of final landform with some elements approved through the RMCP and some approved through the final landform 'update' in May 2022.	All information included in the RMCP that is relevant to a given stand-alone application should be included in that application.	Noted.	-
109	Executive Summary	*This Feasibility Study, which developed the technical, costing and scheduling aspects of Ranger Mine closure to a very high level of detail, was subject to scrutiny during multiple internal and external reviews.* This could be interpreted as inferring that Ranger Minesite Technical Committee (MTC) stakeholders (including the Supervising Scientist) have reviewed the feasibility study, which is not the case.	Clarify that the Feasibility Study was not reviewed or endorsed by the MTC, except through the elements provided in the RMCP.	Clarification provided.	Section 6
110	Section 7.4 Current risk profile	Several Class 3 risks identified in the 2019 RMCP appear to have been removed entirely from the 2020 RMCP, including: • *Actual consolidation of tailings (Pit 1 and Pit 3) does not match consolidation modelling and associated closure schedule leading to*	Provide clear justification for changes in levels of risk and/or risks that have been removed as a result of risk reviews.	Subject matter experts review the likelihood and consequence of a risk event, together with existing controls, to determine the risk	Section 7.3 and Section 7.4 and Appendix 7.1

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		longer than planned process water treatment • *No disposal option for high density sludge post tailings deposition (end of 2020)* • *Exposed land surface contributes to increased weed recruitment, decreasing revegetation success and spread into Kakadu NP* Further, the following Class 3 risk identified in the 2019 RMCP has been downgraded to a Class 2 risk in the 2020 RMCP, without any justification provided: *Cannot achieve the desired tailings surface for post-deposition activities in Pit 3*		ranking. This can result in a change to risk rankings, typically where controls reduce the likelihood of an event occurring.	
111	Section 7.3.6 ERA closure risk assessment methodology Risk Evaluation	The probability range for different likelihood classifications has changed from the 2019 RMCP.	Provide an explanation on the changes to the probabilities for likelihood classifications.	Explanation for removal of 10,000 year likelihood criteria included.	Section 7.3.6
112	Section 7.4 Current risk profile	The effectiveness of a large proportion of the identified controls are 'Unrated', which means that it is not possible to assess the potential effectiveness of these controls.	Provide details of, and as previously raised in reviews of both the 2018 and 2019 RMCP, justification for effectiveness for all controls identified to address risks.	Control effectiveness is included for all but 3 of the 45 risks.	Appendix 7.1
113	Section 9.2 Closure Planning		Where contingencies for existing or ongoing approved activities are derived from a BPT described in Section 6, the options that are considered as contingencies should be clearly identified and the risks associated with using any contingencies based on BPT assessment should be discussed.	Noted. Updates included throughout Section 9 with regards to contingencies, and a material update of the risk assessment is planned for 2023.	Section 9
114	Section 9.3.3.4 Tailings Storage Facility Contingency planning	*TSF deconstruction methods are currently being finalised by ERA in preparation for the TSF deconstruction application. This involves a best practical technology assessment of the options. The options not selected for progression, that have not been show stopped for environmental or cultural reasons, will then form the basis of ERA's contingency plan.* This statement suggests that options which are show stopped for other reasons will be used in the contingency plan. It is not clear how ERA will give confidence that ALARA will be achieved via identified contingencies. Alternatively, it may be that ERA foresees that there are only show stopped options remaining in the BPT which can then be used as a contingency. If options selected in the BPT are all show stopped except the one selected, then the options should be reselected/new options should be realised.	Clarify how ALARA will be achieved if options for the contingency planning are those that have been ruled out for implementation during closure (which do not meet BPT assessment criteria as they are show stopped).	ERA does not rule out advances in technology or understanding that may result in a previously ruled-out option becoming considered. Typically, this would not occur for options that have hard-showstoppers. Options with soft-showstoppers may be considered in contingency planning.	Section 6.3
115	Section 9.3.1.4 Pit 1 Contingency planning		Include contingencies for greater settlement than expected for Pit 1 e.g. add additional material to ensure the landform achieves modelled landform expectations, excessive erosion may be remediated with waste rock etc.	Added with regards to erosion.	Section 9.2.1.4
116	Section 9.3.5.4 Process plant, water treatment plants & other infrastructure Contingency planning	*If the demolition of specific infrastructure planned to be deposited into Pit 3 is delayed, then RP2 has the capacity to take extra material than currently planned.* It is unclear what level of capacity RP2 has and therefore how much of the demolished material it may contain to ensure all plant is buried at least 6m	Provide further information on the RP2 burial contingency, including the capacity available vs current planned vs how much contingency this allows.	Not included in the 2022 MCP, studies ongoing. Will be included in the Final Landform application.	-

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		below the final landform surface. It is therefore difficult to assess the effectiveness of this proposed contingency.			
117	Section 9.3.6.4 Stockpiles Contingency planning		Provide further information on contingencies to be implemented if the material mass balance is incorrect and results in a material deficit for the final landform.	Not included in the 2022 MCP, studies ongoing. Will be included in the Final Landform application.	-
118	Section 9.4.3.6 Closure activities Water treatment Contingency plans		Determine whether contingencies are required for pond water treatment.	Not included in the 2022 MCP, studies ongoing. Will be included in the Final Landform application.	-
119	Section 9.4.6.8 Closure activities Revegetation implementation Contingency plans		Provide details of other contingency methods that are being considered for seed collection.	Updates included.	Section 9.3.6.7
120	Section 12 Management of Information and Data		Post-closure data retention and handover requirements need to be determined in close consultation with government.	Noted.	-
121	Section 5.5.1 Supporting Studies Landform	The table at the start of this section suggests that it includes summaries of the completed studies in relation to the KKNs LAN2 and LAN3 (i.e. Pit 1 studies) but it does not appear to include this information.	Provide summaries of relevant studies completed to date to address KKNs LAN2 and LAN3.	Updates included.	Section 5.1.2 and 5.1.3
122	Section 9.4.5.3 Closure activities Final landform / Surface preparation Erosion and sediment controls	*Channels previously reporting to Djalkmarra Creek (flowing over Pit 3) in pre-mining conditions have been diverted to Corridor Creek (flows south of Pit 1) for the final landform. This reduces erosion possibilities over Pit 3.* This appears to be inconsistent with Figure 9-88 (footprint of final landform requiring ripping), which still shows Djalkmara Creek re-establishing across Pit 3.	Ensure there is consistency in planned/predicted drainage pathways from Pit 3.	Updated.	Section 9.3.5.3
123	Section 10.3 Landform Monitoring		Note that the Supervising Scientist is currently revising the Rehabilitation Standard for Landform Stability, which will provide updated advice on the optimal method of monitoring and assessing against the closure criterion for suspended sediment (L6). This should be incorporated into the 2021 RMCP.	Turbidity included within relevant criteria.	Section 8.3.1 and Section 10.1
124	Section 5.2.8 Physical environment Surface water	The concentrations of Cu are high in Table 5-8 and the Supervising Scientist has derived a median background concentration of 0.2 µg/L, which was used as our previous Rehabilitation Standard. The median of 1 µg/L from Klessa (2000) is the same as the national DGV concentration and is double SSB's new effects-based, site-specific GV. The discrepancy between SSB's and the Klessa (2000) background concentratoin is most likely due to the dataset being acquired from an early upstream site affected by Georgetown Billabong outflows (as noted by ERA); inappropriate use of mine-affected "reference" data may affect other concentrations quoted in Table 5-8.	Considering the data may be affected by Georgetown Billabong outflows, include a more accurate analysis of background surface water concentrations.	Updates included.	Section 5.2.6
125	Section 5 Figure 5-55 Control Charts of TPM concentrations in surface sediments	The conceptualisation of the linkages between various models and reports is out of date.	Update the RMCP each year to reflect most recent information/data.	Noted.	-

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
	of Georgetown Billabong				
126	Section 5.5.2.15 Supporting studies Water and Sediment Eutrophication risk study	*The sources of nutrients at Ranger to the water management system are from; waste rock, ammonia and phosphate (in lime) added to the mill process circuit, residual nitrates from blast residue in waste rock, and fertiliser application.* The sources listed in the eutrophication risk study are not consistent with those used in the groundwater modelling.	Ensure consistency between studies and models for contaminant sources.	Noted.	-
127	Section 5.5.2.16 Supporting studies Water and Sediment Aquatic ecosystem assessment & framework development	*Less conservative water quality objectives are required to support the RPA goal of impacts that are ALARA.* This statement negates the possibility of the highest level of protection potentially being achievable.	Revise language to reflect that ALARA should aim to meet the highest level of protection as a first principle.	Updates included.	Section 5.5.1.1
128	Section 8.3.2.3 Closure criteria Water and sediment	*Less likely, though still possible, is the potential that predicted concentrations exceed the draft W/SQO in small areas close to the RPA lease under certain (low) flow conditions* It is not clear what is meant by "small offsite areas".	Until all relevant modelling is completed SSB considers all surface water quality predictions as "interim". The final predictions should be provided in the Pit 3 application and the 2021 RMCP.	Noted. Pit 3 application being revised.	Section 8.3.2
129	Section 8.3.2.3 Closure criteria Water and sediment	*Assessing the need to revise the guideline values or add additional indicators and lines of evidence will be done by the stakeholder working group. The approach would depend on the nature (extent, duration, intensity, location etc.) of any predicted exceedance.* SSBs rehabilitation standards will not be revised for the off-site environment based on predicted exceedances. It is up to ERA to mitigate in the event of predicted exceedances.	Statements suggesting that guideline values off the RPA will be revised based on predicted exceedances should be removed. Predicted exceedances offsite should be managed through mitigation strategies.	Clarified.	Section 8.3.2
130	Section 8.3.2.3 Closure criteria Water and sediment	*Justification for outcome, parameter and criteria, Step 7: Consider additional indicators or refine the water/sediment quality objectives* It is the Supervising Scientist's position the W/SQO for the offsite receiving waters should be considered 'final' and not in 'draft'	Remove references to draft guideline values.	Still included as draft as not yet finalised.	Section 8.3.2
131	Section 8.3.2.3 Closure criteria Water and sediment		Ensure that the wishes of Traditional Owners are considered when undertaking BPT assessment for onsite waterbodies.	This is considered BAU. Traditional Owners now specifically identified as a stakeholder in this section.	Section 8.3.2
132	Section 8.3.2.3 Closure criteria Water and sediment	*Water quality off the RPA meets the national drinking water health guidelines (at times when they would be met in non-mine effected local creeks)*	Clarify what is meant in the statement "(at times when they would be met in non-mine effected local creeks)".	Clarified.	Section 8.3.2, Table 8-5.
133	Section 9.4.1 Closure activities Contaminated sites	Insufficient information is provided on the potential risks associated with disposal of contaminated site infrastructure and other materials in Pit 3.	Assess the potential risks associated with disposal of contaminated site infrastructure and other materials in Pit 3, including the effect(s) this may have: • as potential future contaminant sources on tailings consolidation	Pit 3 application being revised. Pit 3 risks included in risk register.	Chapter 7, Appendix 7.1

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
134	Section 2.2.9.4 Overview of operations Water management Brine Squeezer	*The Brine Squeezer has been approved to treat both pond and process water.* Regulatory approval has been given to conduct process water treatment trials but release of the resulting permeate will require a further approval, demonstrating that the permeate is of suitable quality for release.	Ensure that the process water treatment status (as a trial) is accurately described and more generally, that all activities described in the RMCP accurately reflect their regulatory approval status.	Updated.	Section 2.1, Table 2.1
135	Section 2.2.9.9 Overview of operations Water management Site water model	*The understanding of the site's water systems, as captured in the model, is routinely tested by an annual validation and calibration process* *The most recent validation and calibration was completed in June 2019 by an external contractor and no major changes that pertain to water management were found.* *Figure 2-12 shows the site water model process water inventory.* There have been several significant changes in the site water model since the last validation in June 2019. For example, there has been an increase in the estimated tailings-entrained process water, resulting in less free process water than expected. It is concerning that an "annual validation" has not been undertaken since June 2019.	Clarify/summarise any significant changes in site water systems and knowledge that have occurred since the previous RMCP.	Updated.	Section 2.1.9
136	Section 10 Closure Monitoring and Maintenance	The surface water and groundwater closure monitoring programs outlined in the RMCP remain very high level, with little change from previous years. However, there is acknowledgement that these monitoring programs will need to be refined with stakeholder agreement in the coming years. The described frequency of the monitoring (especially for groundwater) does not yet align with the modelling outputs to target the key periods of risk.	Update the water monitoring program in the RMCP to reflect modelling outputs and as agreement is reached through stakeholder consultation.	Updates included.	Section 10.2
137	Section 10.4.2.1 Table 10-7 General background groundwater chemistry for the RPA		Update the RMCP for whole site groundwater monitoring once the current groundwater modelling is complete, and then periodically as required.	Updates included and studies ongoing.	Section 10.2
138	Section 5.5.3.1 Supporting studies Health impacts of radiation and contaminants Radiological impact assessment		Provide complete details of the methods, data and assumptions used in the radiological impact assessment.	Updates included, studies ongoing.	Section 5.3.2
139	Section 9 Closure Implementation		Provide an updated estimate of the average uranium content of the surface waste rock layer on the final landform and the data and analyses to support the estimate.	Studies ongoing.	Section 9.3.1 (Table 9-4) and Section 9.3.4
140	Section 10 Closure Monitoring and Maintenance Table 10-13 Trigger, action, response plan	The trigger on all radiation exposure pathways is: "*Exceedance of the baseline radiation dose as defined in the closure criteria*" It appears that this should be an exceedance of the <u>dose constraint</u> as defined in the closure criteria.	Provide clarification of the trigger for radiation pathways.	Update included.	Section 10.6
141	Appendix 10.1 Table 7 Pit 1 Targeted Research Tasks	*To verify that radon-222 exhalation flux densities* The objective for the aspect radon-222 exhalation flux densities is unclear.	Provide clarification of what is being verified.	Updates included.	Section 10.3.1.2

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
		It appears that this should be to verify the numerical values of radon-222 exhalation flux densities used in modelling of the radon exposure pathway for the final landform.			
142	Appendix 10.1, Table 7 Pit 1 Targeted Research Tasks	The method for the aspect "Gamma dose rate, waste rock radium-226 activity concentration" does not include any sampling or analysis of waste rock for radium-226.	Update the method to include waste rock sampling and analysis for radium-226.	Updates included.	Section 10.3.1
143	Appendix 5.1 Revegetation knowledge base	A key driver of ERA's Ranger revegetation strategy is ensuring that plant assemblages can be sustained in waste rock in the face of drought, including a greater frequency of drier spells predicted in future climate projections. There is an emphasis on drought-proofing the revegetated site by introducing what are regarded as dry-tolerant species (so-termed "climate change contingency species).	The Supervising Scientist will consult with ERA on these issues via the stakeholder Ecosystem Restoration Working Group, with a view to reaching a resolution prior to the next RMCP.	2020 MCP Appendix 5.1 removed and information provided within relevant section of 2022 MCP. Updates included.	Section 5.4.1, Section 5.4.4, Section 5.6.3, Section 5.6.4
144	Appendix 5.1 Revegetation knowledge base	There is scant information in the RMCP demonstrating evidence-based knowledge of overstorey species suitability for ecosystem establishment.	The Supervising Scientist will consult with ERA on these issues via the stakeholder Ecosystem Restoration Working Group, with a view to reaching a resolution prior to the next RMCP.	Updates included.	Section 5.4.1
145	Appendix 5.1 Revegetation knowledge base		The Supervising Scientist will provide more detailed feedback to ERA on the information presented in the RMCP on conceptual reference ecosystems, via detailed technical review of the referenced reports and consultation via the stakeholder Ecosystem Restoration Working Group.	Updates included.	Section 5.4.1
146	Appendix 5.1 Revegetation knowledge base	*Once construction and land-forming is completed, and inspection of the planting area will enable the final revegetation plan to identify the most suitable target native ecosystem and propagation and planting execution can proceed* It is assumed that this statement is suggesting that final minor 'tweaks' to the planting plan could occur once the final landform is completed, rather than basing the entire revegetation plan on the as-built landform.	Clarify what is meant by the above statement regarding revegetation planning in relation to the completion of the final landform.	Updates for revegetation monitoring on final landform included.	Section 9.3.6 and Section 10.4.1
147	Appendix 5.1 Revegetation knowledge base	Table 2-1 presents the results of a land capability assessment (LCA) of the final landform, in context of the region. The rationale for undertaking a LCA is not clear, as these types of assessments are generally used to assess the potential of land for broad land use (such as agriculture) and determine if there are any development constraints and risks associated with development. However, a LCA could be applicable at Ranger if there was an alternative being considered to the standard for restoration outlined in the ERs.	Clarify the rationale for undertaking a land capability assessment and how this will be used to inform the rehabilitation of Ranger.	No longer included in MCP.	-
148	Section 8 Table 8-3 Closure objectives		Include ER 2.1 as a relevant closure objective for flora and fauna**.**	This is implied throughout ecosystem closure section and specifically included in Table 8-3.	Table 8-3
149	Section 8.3.5.1 Closure criteria Ecosystem	"*Fauna habitat including the provision of hollow bearing tree species and edible fruit species is addressed in the flora closure criteria*"	State explicitly which of the flora closure criteria address fauna habitat requirements or include a specific closure criterion for fauna habitat.	Included in Table 8-9 but also noted as a work in progress (Text box start of Section 8.3.5).	Table 8-9
150	Section 8.3.5.1 Closure criteria Ecosystem	The term 'framework species' is used throughout the closure criteria and is not clearly defined.	Clearly define what a framework species is, including quantitative measures (i.e. abundance, response to fire, life-history strategy, life-form etc.).	Definition included.	Section 5.4.3

A.2 SSB feedback on 2020 MCP

Comment #	2020 SSB Assessment report Section	Correspondence from previous MCP assessments if required to provide context to feedback on 2020 MCP	SSB response in 2020 assessment report	ERA response	2022 MCP Section
151	Section 8.3.5.1 Closure criteria Ecosystem	*Assessment of achievement of* [naturalness] *criteria will be based on surveys conducted according to the Northern Territory vegetation survey guidelines (Brocklehurst et al. 2007).* This assessment approach is not recommended as it would likely not assess 'naturalness' on an ecologically appropriate spatial scale.	Engage with stakeholders in selecting the most appropriate survey method in assessing ‘naturalness’, which should include measures of understorey.	Updates note that ‘naturalness’ not included and captured in agreed criteria.	Section 8.3.5
152	Section 10.7.1 Ecosystem (revegetation) monitoring	*Ongoing annual monitoring of establishment success will continue until all initial establishment and subsequent infill plantings have developed sufficiently and attrition rates have dropped to a recoverable level.*	Clarify what is meant by ‘recoverable level’ in relation to attrition rates in revegetation.	Updated to say that attrition rates should stabilise in the first three to five years following planting.	Section 10.4.1
153	Section 10.7.1 Ecosystem (revegetation) monitoring	It appears that monitoring will only take place after infill planting occurs. However, there needs to be a strategy in place to confirm that the site has been prepared to the conditions expected/specified (i.e. ripped, scarified etc.), before revegetation starts. If this assurance check is already specified, then it should be referred to in this section.	Include monitoring of the final landform prior to large-scale revegetation, to confirm that it has been prepared according to design and will therefore be suitable for revegetation.	Included in landform monitoring.	Section 10.1.1
154	Section 10.7 Ecosystem monitoring		Develop a statistically-rigorous monitoring framework for ecosystem restoration that meets the requirements for adaptive management.	Adaptive management included throughout the sections.	Section 10.4 and 10.6
155	Section 10 Closure Monitoring and Maintenance Table 10-13 Trigger, action, response plan	*Trigger = Exceedance of final criteria defined in closure criteria* A developing ecosystem isn't going to statistically look like a mature "final" ecosystem, so it should be made explicit if the comparison between the reference and the restored ecosystems is done at a successional stage along the restoration trajectory, or when at “maturity”. Criteria should consider both values that are too high (i.e. require thinning of certain species) and too low (i.e. require infill planting), not just “exceedance”.	Clarify what ‘exceedance’ of final criteria means and when this is expected to apply. The TARP should be clearly linked to the risks identified in the Ecosystem Restoration Trajectory Model.	It is recognised that closure criteria for ecosystem restoration will be achieved over time.	Section 10.6, Table 10-18

A.4 2019 MCP feedback from DITT requiring further comment

Comment #	MCP Overarching Section	2019 MCP reference	MCP theme	Correspondence from previous RMCP assessments	ERA Response	MCP Section 2022
1	General	N/A	'How to read this document' Section	**DITT 2019 RMCP Assessment:** Whilst the WA Closure Guidelines have been used, given the scale and size of the MCP, access into the document by stakeholders could be strengthened by a Section on 'How To Read' the document. Elements of this are throughout the Executive Summary.	Executive Summary has been revised to be more reader-friendly. MCP remains technically-focused and Table of Contents provided.	Executive Summary
2	Scope & Purpose	1-7 (1.4 Review and updates)	Section 11 addresses closure implementation and includes outlined schedules for the rehabilitation activities with the agreed assessment process and the draft content proposed for each additional application required for closure activities. The 2018 MCP was subject to stakeholder review and detailed feedback has been considered for the preparation of this document (Appendix A). The 2019 MCP incorporates substantive changes in content compared to the 2018 version, as outlined in the summary of changes table at the front of this document.	**DITT 2019 RMCP Assessment:** This is a repeat of the kinds of information in the Exec Summary. Suggest transferring from the Exec Summary such references to Sections in the MCP to this Section. Or the creation of a dedicated 'How to Read ... " or "What's in this document" Section.	Executive Summary has been revised to be more reader-friendly. MCP remains technically-focused and Table of Contents provided.	Executive Summary
3	Supporting Studies	95 (General use of brackets)		**DITT 2019 RMCP Assessment:** Throughout the MCP (as opposed to the MMP) there is the propensity (albeit with good intentions) to use too many ( ) (which is a sign that the body text (that which is not in the ( )) is insufficiently explanatory. Rule of thumb is to simplify body text to avoid needing ( ) . Over us of ( ) breaks up reading of the document and thus makes understanding it more difficult.	Noted and hopefully improved.	2022 MCP
4	Best Practicable Technology	7 (9.2 Completed BPT)	Completed closure related BPT assessments	**DITT 2019 RMCP Assessment:** Is there a valid reason to have 24 pages of completed closure-related BPT assessments this Section in the MCP? It discusses how ERA applied BPT to various activities and technologies which are now in the MCP. Important is to know that ERA applied BPT to all technologies and techniques in the MCP. And will do for future ones. The MCP should focus on closure planning and activities. Information such as Section 7: supporting studies, and this Section from 9.2 could be appended. It would reduce the size of the actual MCP, yet keep information available for stakeholders.	Completed BPTs summarised and MCP and detail moved to Appendix 6.1	Section 6 and Appendix 6.1
5	Risk Assessment	6 (10.4.4)	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.	**DITT 2019 RMCP Assessment:** 'hazards analysed with mitigation measures in place' A text box informing the reader about why analysing hazards with mitigation measures in place, vs not in place and the difference would be handy.	This section was re-worded for the 2022 MCP and the method explained.	Section 7.3

A.4 2019 MCP feedback from DITT requiring further comment

Comment #	MCP Overarching Section	2019 MCP reference	MCP theme	Correspondence from previous RMCP assessments	ERA Response	MCP Section 2022
6	Implementation	14 (11.2.2 Schedule)	Pit 1 backfill, final landform contouring and ripping is schedule to be completed by mid-2020.	**DITT 2019 RMCP Assessment:** For when information describing schedule like this is presented in text, perhaps place the relevant part of App 11.1 as a visual guide. Also perhaps place a small schematic map of the direct impacted area with the area under discussion highlighted to assist the reader in understanding where they are. Perhaps based on Fig 11.66.	Noted. High-level sequence provided in Executive Summary. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Executive Summary
7	Implementation	16 (11.3 Pit 3)	Closure activities, bullet list	**DITT 2019 RMCP Assessment:** Perhaps this could be shifted to Chap 2_project overview. It's good background info but it's historic. Or as an appendix to this chapter. This Chap is or should be forward looking.	Noted. Section updated. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Section 2
8	Implementation	22 (aa)		**DITT 2019 RMCP Assessment:** Whilst the CSIRO diffuser design is interesting, it is not sure whether this information is needed here. There's a Chapter on BPT where it could be discussed.	Noted. Section updated. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Section 6
9	Implementation	25 (aa)		**DITT 2019 RMCP Assessment:** Useful information that along with a similar description of sub-aerial deposition should be much earlier in the Section. It is how the tailings are to be deposited.	Noted. Section updated. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Section 6 and Section 9
10	Implementation	59 (aa)	The demolition contractor The bulk material movement contractor	**DITT 2019 RMCP Assessment:** This is the first time such contractors are mentioned. Please provide a short description of the competences require in the various contractors who will support ERA during closure including what phase and works each will undertake. This could be in a Section at the beginning of the Implementation Chapter (11.0) describing the EPC/EPCM resources (& perhaps too the financial ones) who shall undertake the works.	Noted. Will be engaging with stakeholders on suggested improvements to readability of MCP.	-
11	Implementation	82 (Table 11.10)	Demolition processes	**DITT 2019 RMCP Assessment:** Table should be at front of Section.	Noted. Section updated. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Section 9.2.5.3
12	Implementation	87 (aa)	Key assumptions of Phase I (&2)	**DITT 2019 RMCP Assessment:** Key data, information, lists, etc, should be presented at the start of the relevant Section.	Noted. Section updated. Will be engaging with stakeholders on suggested improvements to readability of MCP.	Section 9.2.5

A.4 2019 MCP feedback from DITT requiring further comment

Comment #	MCP Overarching Section	2019 MCP reference	MCP theme	Correspondence from previous RMCP assessments	ERA Response	MCP Section 2022
13	Implementation	89 (11.7.1 Ranger deeps closure activities)	First paragraph starting 'The Ranger Deeps … ".	**DITT 2019 RMCP Assessment:** Tabulate. Not particularly relevant for the closure plans and activities.	Paragraph has been tabulated.	
14	Implementation	90 (aa)	Paragraph starting … "ERA has now commenced … "	**DITT 2019 RMCP Assessment:** This paragraph should start the Section. Heavy use of parenthesis breaks up text and makes understanding what the author wants the reader to know more difficult.	Noted. Will be engaging with stakeholders on suggested improvements to readability of MCP.	-
15	Implementation	94 (Figure 11-55)	Perspective of figure	**DITT 2019 RMCP Assessment:** Without the surface included for reference, figure is not informative. Suggest also including a photo with final cutting gradient superimposed.	Noted. Will be engaging with stakeholders on suggested improvements to readability of MCP.	-
16	Implementation	98 (11.7.1.6 Hydro conditions)	The results also suggest that the long-term impact of depressurisation from excavation and dewatering of the exploration decline and shaft on the local groundwater system and Magela Creek will be negligible.	**DITT 2019 RMCP Assessment:** This and other assessments of impacts could be in a dedicated Section.	Noted. Will be engaging with stakeholders on suggested improvements to readability of MCP.	-
17	Implementation	106 (Table 11-18)	Ore grades and material type	**DITT 2019 RMCP Assessment:** This information would be good to have when first mentioned in the text and/or in a Section dedicated to ore-grades and material types to which the reader is referred.	Noted. Will be engaging with stakeholders on suggested improvements to readability of MCP.	-
18	Implementation	121 (Figure 11-67 & 11-21)	Correlation between the figure and table	**DITT 2019 RMCP Assessment:** Is it possible to correlate the figure and the table? They are complementary.	As part of an update to the contaminated sites section, the figure and table have been removed.	-
19	Implementation	140 (Figure 11-76)	Flow direction	**DITT 2019 RMCP Assessment:** Flow direction indicator would be handy	The upstream side of the sediment control structure is marked on the figure.	Figure 9-119

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
1	Closure Obligations and Commitments	3.1.5		At time of writing ERA does not have the right to access the RPA after Jan 2026.How will access post 2026 be assured? How will this monitoring program be developed in consultation and engagement with end land users. Consequently, who will be conducting the monitoring for the estimated 25 years?	Updates included.	Section 3.1.4
2	Closure Obligations and Commitments	3.1.5.1	ERA supports a minor amendment of the Atomic Energy Act, which would enable ERA to apply for a further Section 41 Authority.	Further the comment above (p3-12 s3.1.5), it would be informative for ERA to provide a more detailed discussion on its efforts to secure an amendment to the AEA to allow it to conduct the monitoring it identifies will take 25 years. This discussion should include what is the 'minor amendment' ERA supports. The discussion should also describe what happens if an amendment is not delivered by 2026.	Updates included.	Section 3.1.4
3	Closure Obligations and Commitments	3.4 & Table 3.2		The list of applications requiring Ministerial/MTC approval was agreed between the Cth & NT ministers in May 2018. In addition to those in Table 3.2, the deconstruction of the Processing Plant was also agreed. Please explain why the Processing Plant is not included in the table and other sections of the MCP where future applications are discussed. As Pit 3 Closure does not include the capping the Pit, please describe in which application the capping will be described and approvals sought for. Additionally, what other applications for minor works not requiring Ministerial approval that ERA anticipates may be submitted to the MTC?	Standalone applications to the Minister are provided in Section 1.7 and other approvals planned for 2022 are provided in Section 3.4 (not all future approvals are included).	Section 1.7 and Section 3.4
4	Risk Assessment and Management	7.3.5		The list does not include a dedicated risk related to legislation, in particular to amendments to the AEA. Until the AEA is amended, the risk of ERA not being permitted to conduct long term monitoring after Jan 2026 remains and should be assessed. This includes efforts to secure amendments to the AEA to mitigate the risk.	Risk included for extension beyond 2026.	Section 7.4.2 and Appendix 7.1
5	Risk Assessment and Management	Table 7.4		Not clear if this risk includes not being able to comply with statutory deadlines such as Jan 2026. Please confirm that this risk also includes not being able to comply with statutory deadlines. If not, where is the consequence of such risk defined?	Risk included for extension beyond 2026.	Section 7.4.2 and Appendix 7.1
6	Risk Assessment and Management	7.4.2 Class III risks	- site condition at 8 Jan 2026 does not meet Stakeholder expectations	Where are 'stakeholder expectations' defined & discussed? Unless defined the 'risk' of not meeting stakeholder expectations will or can be very high. And dynamic. Stakeholder expectations are unlikely to be static. Where is how ERA is mitigating this risk described?	As above. Stakeholder expectations more generally are largely tied to agreed closure criteria.	Section 8
7	Risk Assessment and Management	Appendix 7.1 Ranger Closure Risk Assessment Risk ID: 504047		The controls cannot mitigate the risk. 'Engagement', 'public updates', an SIA cannot themselves mitigate 'businesses become unviable'. How 'local employment programs' can 'build a future employable workforce' is unclear. What future work will they perform? If socio-economic impacts of closure and their mitigation are to be a part of the MCP, it will require substantially more work and discussion than is presented in the MCP. If such work is coordinated by parallel initiatives under, perhaps, the Jabiru Steering Committee, the MCP should provide	Further work on SIA planned to occur in 2023.	-

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
				links. If not, then the socio-economic aspects require substantial expansion in the MCP.		
8	Risk Assessment and Management	Appendix 7.1 Ranger Closure Risk Assessment Risk ID: 694650	694650 Contaminants in bush tucker. Consequences: Non-compliance with ER 3.1. Control: Bush food consumption restrictions to particular areas of the RPA may apply post closure. [694655].	This suggests ERA's closure strategy is not suitable for final post-closure land use. Related to comment above regarding 'stakeholder expectations'. Should be Class III risk, as it risks the entire point of the closure process. The controls do not appear to actually mitigate the risk: bioaccumulation of contaminants. Which requires an engineering solution to ensure contaminant mobilisation is reduced to mitigate risk. Suggest ERA provide some context on the probability of this risk being realised. Unless such probability is very low, successfully achieving the objectives of the ERs is going to be questioned, indicating alternative closure strategies will be required.	Elevated levels of contaminants (metals) in bush tucker identified as a Class III risk.	Section 7.4.2
9	Risk Assessment and Management	Appendix 7.1 Ranger Closure Risk Assessment Risk ID: 504069	504069 No mechanism is currently available to allow access to RPA from 9th January 2026. Controls: Acknowledgement by stakeholders that certain monitoring and maintenance activities are required for a number of years post January 2026. [504071]. Evaluation Rationale: Long lead time until 2026 and good working relationship therefore unlikely the ability to access will not be available.	This should be a Class IV risk. A large number of closure activities occur just prior to Jan 2026. The control does not mitigate the risk. Achieving compliance with the ERs requires timeframes extending beyond the completion of such activities and the current mandated deadline. Whilst ERA state that there is a 'long lead time' to 2026, until a mechanism is in place to permit access after 2026 the risk of not having access needs to be appropriately assigned.	Risk included for extension beyond 2026 (Class III).	Section 7.4.2 and Appendix 7.1
10	Risk Assessment and Management	Appendix 7.1 Ranger Closure Risk Assessment Risk ID: 500614		Lacking in the 'controls' is agreement with Stakeholders, specifically TOs as to what to expect. Engagement is not the same as agreement. Suggest ERA provide information on its intentions and efforts to achieve agreement with Traditional Owners on their expectations of 'site condition' at various stages of rehabilitation.	Updates included.	Section 8.3.6 and Section 10.5
11	Post Closure Land use, Closure Objectives and Closure Criteria	8.1 & 8.1.1		As per earlier comments, the degree by which post-closure rehabilitation and land use is contingent on Traditional Owner acceptance suggests (strongly) that an agreement with Traditional Owners on what would 'satisfy' them would be constructive.	Updates included.	Section 8.3.6 and Section 10.5
12	Post Closure Land use, Closure Objectives and Closure Criteria	8.3.5.1	8.3.5.1 Justification for outcome, parameter & criteria. The target revegetated ecosystem/s in the case of Ranger Mine will be a conceptual ecological model synthesised from numerous appropriate reference sites, revegetation trials, cultural values and historical and predictive records.	Please present the cultural values that are agreed with Traditional Owners and how are they integrated into the conceptual ecological model. If this has already been done, please provide the link to where it is in the MCP.	Updates included.	Section 8.3.6 and Section 10.5
13	Post Closure Land use, Closure Objectives and Closure Criteria	8.3.5.1		ERA to present an assessment of the possible changes on fire regimes due to the effects of accelerating climate change and how this may impact successful establishment of an ecosystem.	Updates included.	Section 5.4.4

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
14	Post Closure Land use, Closure Objectives and Closure Criteria	8.3.5.1	Resilience. A resilient ecosystem can be simply thought of as one which can experience the range of reasonably anticipated, 'natural' disturbance events and maintain (or return to) its pre-disturbance condition (given natural degrees of inherent variation).	ERA to present how potential changes to resilience has been assessed in the context of accelerating climate change changing fire regimes.	Updates included.	Section 5.4.4
15	Post Closure Land use, Closure Objectives and Closure Criteria	Table 8-13 cultural closure criteria ER 1.1 (a) & 2.1	Parameter: General aesthetics - does it look 'natural'. Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory.	With respect to this criteria/indicator and others that are 'predicted to occur far beyond the 25 year timeframe for achievement of closure criteria' ERA to explain its mitigation strategy if it doesn't look 'natural'.	'Naturalness' no longer included as a criteria but captured in agreed criteria.	Section 8.3.5
16	Post Closure Land use, Closure Objectives and Closure Criteria	8.3.6.1	Justification for outcome, parameter and criteria. Significant emphasis will be placed on ensuring that culturally important flora and fauna are present on the final landform.	'Emphasis' is not quantifiable. ERA need to present how it shall ensure culturally important flora and fauna are present on the final landform.	Noted. Updates included.	Section 8.3.6
17	Post Closure Land use, Closure Objectives and Closure Criteria	Table 8-14 & supporting text	Proposed indicators … are largely based on visual and aesthetic factors. The design of the program will involve long-term periodic assessment of attitudes and opinions of Traditional Owners and their kin in relation to the dynamics of rehabilitation over time. These assessments will be undertaken annually and will determine whether or not the Traditional Owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.	It would be illustrative for ERA to present indicators reflecting the attitudes of Traditional Owners. When does ERA intend to start the annual assessments in collaboration with Traditional Owners to ensure rehabilitation on the RPA is progressing towards a desirable trajectory in relation to cultural indicators?	Updates included and engagement ongoing.	Section 8.3.6
18	Implementation	9.3.1.3	Direct Seeding Trials However, newly discovered 'finer' waste rock material (such as that present at Pit 1) may provide an opportunity for improved establishment of some species from seed.	'newly discovered 'finer' waste rock material (such as that present at Pit 1)'. Is there a comparison between the waste rock used for the TLF, Stage 13 and Pit 1? What effects the different types of waste rock may or may not have had on revegetation success? If there is a difference in success rates attributable to differences in waste rock, and how that is likely to influence planning for the final landform?	Updates included.	Section 5.4.3
19	Implementation	9.4.1.1	Prior to demolition of some components of the processing plant, ERA will obtain a 'Permit to Decommission Facility' from the Australian Safeguards and Non-Proliferation Office (ASNO).	ERA has received such a permit, which can be referred to in the next MCP.	Included.	Section 9.2.5.1
20	Implementation	9.4.1.1	Decommissioning phase, bullet list: • draining of oil from transformers, gearboxes, hydraulic systems and lubrication systems and steam cleaning of large oil reservoirs • removal of all hazardous materials as per ERA standard	A short discussion on the fate of such oil and hazardous material would be useful. If this is elsewhere in the MCP, a link to where it is discussed would suffice.	Updates included.	Section 9.2.5 and Section 9.3.2

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
21	Implementation	9.3.5.3	Removal and final disposal of the materials and hazardous waste.	How is hazardous waste to be disposed? If elsewhere in the MCP, please provide a link.	Updates included.	Section 9.2.5 and Section 9.3.2
22	Implementation	Table 9.32 & in text	Schedule for closure activities for the stockpile area.	The schedule of these activities: landform, erosion control and revegetation for 2025 is very close to the when ERA must complete rehabilitation. Somewhere in the MCP a discussion on efforts to secure permission to continue beyond Jan 2026 would increase confidence that any delays will not compromise the ERs and that ERA can legitimately perform long term planning.	Updates included.	Section 3.1.4 and Executive Summary
23	Implementation	Table 9.32 & in text	Revegetation. Revegetation of other stockpile areas will be undertaken following the Ranger Mine revegetation strategy (Appendix 5.1).	Admittedly a minor point, but Appendix 5.1 is named Revegetation Knowledge Base, not Revegetation Strategy.	Amended to Revegetation Strategy.	Appendix 5.1
24	Implementation	Table 9.32 & in text	A detailed revegetation plan for the stockpiles will be provided in future updates of this MCP.	Revegetation of stockpiles to be described in future MCP. There are only 4 more iterations of the MCP before rehabilitation must be complete. Which MCP shall describe all revegetation plans? Please provide sufficient detail and surety to understand how 'complete rehabilitation' will be complete by Jan 2026.	Updates included and a standalone Final Landform application is planned for submission Q1 2024	Section 3.1.4 and Executive Summary
25	Implementation	9.4.2	9.4.2 waste and hazardous material management. Reference to other legislative drivers for aspects of closure, such as NT asbestos disposal and general landfill requirements.	Please provide some context on how ERA intend to coordinate between different legislative drivers concerning specific aspects of closure. This may be implicit in other sections (S03 f.eg), but it would be reassuring to know that aspects driven by other legislation (asbestos, landfill, etc) dovetail into actions the cumulative effects of which is achievement of the ERs.	Updates included and a standalone Final Landform application is planned for submission Q1 2024	Chapter 3, Section 9.3.2
26	Implementation	9.4.3.1	Brine Concentrator The BC as described in 9.4.3.1 is the principle process water treatment strategy.	What happens if it is offline for an extended period? Is there a contingency should something serious happen to the functioning of the brine concentrator?	Updates, including contingencies, included.	Section 9.3.3
27	Implementation	9.4.3.2	HDS Plant. Sludge is pumped for co-disposal with mill and dredge tailings in Pit 3 until the cessation of mill operations. After this, the sludge must be disposed of in an alternative manner. The options for disposal after cessation of mill operations are the subject of a BPT assessment and will be subject to a separate application to the MTC.	Cessation of mill operations occurred in Jan 2021. Between then and anticipated approval in May 21 (MTC Oct 20), what happens to the sludge?	Sludge, along with any remnant tailings from the TSF and mill, has continued to be directed to the Pit 3 tailings store through the mill tailings lines.	Section 9.3.3
28	Implementation	9.4.3.4	Pond water treatment. Currently, reject is discharged to the TSF, though it may be recycled back into the pond water inventory if pond water quality permits. If available reject from WTP1 and WTP2 may be diverted to the Brine Squeezer.	It seems that after January 2021 when dredging ceases the reject cannot be discharged to the TSF. If so, what shall happen to the reject after dredging ceases?	Updates included.	Section 9.3.3

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
			Reject from WTP3 will continue to be handled as before.			
29	Implementation	Fig 9-80 & Fig 9-81		The creation of the final landform is scheduled for around May 2025. Rehabilitation is required to be completed by January 2026. Approximately 6 months. Can ERA please include a discussion on how it shall comply with S41 clause 5.2 given that clause 6 requires ERA to 'complete the rehabilitation' of the RPA 'in accordance with Appendix A (ERs)' which, according to clause 5.2, means by 8 January 2026.	Updates included.	Section 3.1.4 and Executive Summary
30	Implementation	9.4.5.6	9.4.5.6 Schedule. The remainder of the final landform construction will not commence until March 2023.	Demonstrate how ERA shall comply with clause 5.2 of S41 given that clause 6 requires ERA to 'complete the rehabilitation' of the RPA 'in accordance with Appendix A (ERs)' by 8 January 2026, given that the final landform construction doesn't start until March 2023.	Updates included.	Section 3.1.4 and Executive Summary
31	Implementation	9.4.5.7	9.4.5.7 Contingency Planning. Following construction of the final landform the post closure monitoring and maintenance phase will commence. Adaptive management processes will be used to manage erosion and ensure long term revegetation success.	The information presented in 9.4.5.7 does not present information on planning for the contingency of issues with the construction of the final landform. Instead, adaptive management processes are the contingency. Can ERA please elaborate more on what contingencies exist for the construction of the final landform?	Updates included.	Section 9.3.5
32	Implementation	9.4.6.2	9.4.6.2 seed collection & propagation. The majority of planting will occur in the 2024-2025 (inclusive) period.	If the majority of planting occurs 2024-25, how can/does ERA intend/expect to comply with S41 Clauses 5.2 & 6? As in, what criteria are ERA proposing to establish S41 clauses 5 & 6 are achieved in such a short time frame?	Updates included.	Section 3.1.4 and Executive Summary
33	Implementation	9.4.6.2	Tubestock propagation. If any particular species is not available exactly on time for propagation … can always be introduced later on during the infill planting program	What is the risk to effective ecosystem establishment if such species are delayed in being introduced into the ecosystem?	Updates included.	Section 9.3.6, Section 7.4.2 and Appendix 7.1
34	Closure Monitoring and Maintenance	10	The closure criteria represent direct, measurable and quantifiable target values or tiered assessment processes, based on industry best practice frameworks to develop suitable monitoring programs.	'Industry best practice' is a nice catch-all but is also not definitive. A footnote elaborating on what ERA sees as 'industry best practice' would help frame the concept for the reader.	Clarification added.	Section 8.3
35	Closure Monitoring and Maintenance	10.4.1.2	ERA is planning to shift to event-based auto-sampling regime for monitoring, with sample collection triggered by changes in continuous EC data. This approach, currently used by the SSB, should be suitable for the monitoring program after closure and will be considered by WASWG.	Does WASWG 'approve' this? Or how will this be formally identified and agreed as suitable? Considering the MCP is a public document care should be exercised regarding such statements. Is, for example, WASWG a statutory body which can approve actions? And, in this case, what means 'will be considered by WASWG'.	Noted. Wording amended.	Section 10.2.1

A.5 DITT feedback on 2020 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2022
36	Closure Monitoring and Maintenance	10.7	10.7 Ecosystem monitoring. Monitoring provides feedback to identify problems and inform adaptive management or intervention and is also needed to demonstrate acceptable performance against criteria and standards, ultimately leading into stakeholder acceptance of the ecosystem restoration	Stakeholder acceptance likely to occur, if at all, well into the future. It will influence close-out and issuance of a closure certificate. Has there been an agreement on what, provisionally, 'stakeholder acceptance' looks like? Assume this would be closely related to closure and completion criteria. But what is the process by which to agree?	Agree that Stakeholder acceptance largely tied to agreed closure criteria.	Section 8
37	Closure Monitoring and Maintenance	10.7.1	10.7.1 Ecosystem (revegetation) monitoring. Long-term ecosystem monitoring will need to continue on an annual basis, until the developmental trajectory can be seen to be steadying and the risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention is sufficiently reduced.	This reinforces that 'stakeholder acceptance' is likely to be a long-term consideration. Stakeholder expectations, including regulatory, may change during this period. Has ERA (and project Stakeholders) considered how to manage changing expectations based on lessons learned during the closure period?	Agree. Focus is on reaching agreed closure criteria.	Section 8