Summary of Changes to the Ranger MCP since the 2019 submission

No.	Adapted from the Western Australian Mine Closure Plan checklist (DMIRS 2020)	Y/N/NA	Section No.	Changes from previous version	Comments
Cover Pages, incl approvals, contact details, version control and table of contents					
1	Do the MCP cover pages include: • Project Title • Company Name • Contact Details • Document ID and version number • Date of submission	Y	N/A	Updated for 2020 Ranger Mine Closure Plan (MCP)	
S1 Scope and purpose *Comparative section in 2019 MCP: Section 1*					
2	State why the MCP is submitted (i.e. to fulfil approval, regulatory or other legal requirements)	Y	1	The structure of the MCP has been revised to align with the Western Australian *Mine Closure Plan Guidance – How to prepare in accordance with Part 1 of the Statutory Guidelines for Mine Closure Plans* (Department of Mines, Industry Regulation and Safety, 2020) and to improve the narrative flow of the document.	The Ranger MCP is submitted to meet condition B3 of Annex B, Authorisation 0108-18, issued under the *Mining Management Act 2001 (NT)*
S2 Project overview *Comparative section in 2019 MCP: Section 2*					
3	The project summary includes: • Location of the project; • Comprehensive site plan(s) • Background information on the history and status of the project	Y	2	Updated, where required. Figures have been updated.	
S3 Closure obligations and commitments *Comparative section in 2019 MCP: Section 3*					
4	Land ownership details (include any land management agency responsible for the land/reserve and the purpose for which the land/reserve [including surrounding land] is being managed)	Y	3	Section 3 includes updates to the list of applicable legislation and standards as well as revised figures to improve image clarity. The obligations register has been updated with new conditions from	

No.	Adapted from the Western Australian Mine Closure Plan checklist (DMIRS 2020)	Y/N/NA	Section No.	Changes from previous version	Comments
				approved applications over the past 12 months.	
5	The MCP includes a consolidated summary or register of closure obligations and commitments	Y	3		Section 3 includes Appendix 3.1 Overview of primary legislation, agreements and authorisations and Appendix 3.2 Closure legal obligations register
S4 Stakeholder engagement *Comparative section in 2019 MCP: Section 5*					
6	All stakeholders involved in closure have been identified	Y	4	Section 4 was previously Environmental and social setting (2019 MCP). The sections have been realigned to better reflect the structure required by the WA Statutory Guidelines for Mine Closure Plans.	The environmental and social settings are now both included in Section 5.
7	The MCP includes a summary or register of historic stakeholder engagement with details on who has been consulted and the outcomes	Y	4		
8	The MCP includes a stakeholder consultation strategy to be implemented in the future	Y	4	Section 4 is now Stakeholder Engagement and includes an updated figure depicting the stakeholder linkages and a new table to outline the ERA principles for stakeholder engagement. Appendix 4.1, Ranger Mine closure stakeholder consultation register, has been updated to include all stakeholder engagement on closure matters undertaken between July 2019 and June 2020.	
S5 Baseline and closure data, and analysis *Comparative sections in 2019 MCP: Sections 4 & 7*					
9	The MCP includes baseline data (including pre-mining studies and environmental data)	Y	5	Baseline environmental and social data is now presented as a preface to the results and proposals of all current and planned ERA research. The intent of this restructure is to aid in narrative flow. Summaries for each closure study have been	

No.	Adapted from the Western Australian Mine Closure Plan checklist (DMIRS 2020)	Y/N/NA	Section No.	Changes from previous version	Comments
				updated with where new data is available. Studies are now organised by Key Knowledge Need (KKN) theme where practical.	
10	The MCP identifies all key issues impacting mine closure objectives and outcomes (including potential contamination impacts)	Y	5 / 7 / 8	Section 5 now describes the environmental setting including the current and future research to refine this information and identify the likely environmental impacts of the proposed rehabilitation approaches. Section 7 details all major environmental risks identified during and after rehabilitation. Section 8 now describes the closure objectives, developed to ensure the agreed upon post mining landuse can be realised.	
S6 Best practicable technology *Comparative section in 2019 MCP: Section 9*					
11	The MCP identifies applicable closure learning from benchmarking against other comparable mine sites	Y	6	Section 6 is now Best practicable technology. The section has been updated to include all summaries of all best practicable technology assessments undertaken by ERA prior to June 2020.	Benchmarking is integral to all BPTs (Section 9), and other site studies are referred to within Section 7.

S7 Risk assessment and management

Comparative section in 2019 MCP: Section 10

12	The MCP includes a gap analysis/risk assessment to determine if further information is required a relation to closure of each domain or feature	Y	7	Section 7 is now Risk assessment and management. This revision of the MCP includes an updated risk assessment, to take into account all amendments made to closure risks since July 2019.	
13	The MCP includes the process, methodology and has the rationale been provided, to justify identification and management of the issues	Y	7		

S8 Post-mining landuse, closure objectives and closure criteria

Comparative sections in 2019 MCP: Sections 6 & 8

14	The MCP includes agreed post-mining land use(s), closure objectives and conceptual landform design diagram	Y	8	Sections 6 and 8 of the 2019 MCP have now merged to form Section 8 Post-mining landuse, closure objectives and closure criteria.	Closure objectives are aligned to the Environmental Requirements (ERs) as appended to the section 41 Authority, issued under the *Atomic Energy Act* and now annexed to the Ranger Authorisation issued under the *Mining Management Act*. There were no pre-existing environmental legacy sites at the RPA.
15	The MCP identifies all potential (or pre-existing) environmental legacies, which may restrict the post mining land use (including contaminated sites)	Y	5 / 8	No changes	
16	Soil or groundwater contamination that occurred, or is suspected to have occurred, during the operation of the mine, has been managed / reported in accordance with the Authorisation	Y	5 / 8 / 9	Closure criteria for contaminated soils are included in Section 8.	Refer to Sections 5 and 9 for additional discussion on studies and management pertaining to contaminated land.
17	The MCP includes an appropriate set of specific completion criteria and closure performance indicators	Y	8	Closure criteria have been revised to reflect ongoing consultation with stakeholders to develop appropriate criteria.	The closure criteria for each key environmental theme are now presented in two categories; proposed criteria for minister approval and draft criteria for review

S9 Implementation

Comparative section in 2019 MCP: Section 11

18	Materials characterisation has been carried out consistent with applicable standards and guidelines.	Y	9	Implementation is now addressed in Section 9.	Materials characterisation is provided in Section 9
19	The MCP includes information relevant to mine closure for each domain or feature	Y	9 / 5	Closure implementation strategies for each closure domain within Section 9 is now presented as completed rehabilitation, current rehabilitation, planned rehabilitation and contingency planning. Closure activities, that fall outside of, or across multiple domains, are also discussed. The schedule of activities for closure has been updated to reflect the progress and planning of rehabilitation as of 30 June 2020.	Section 9 describes the closure implementation strategies by domain/activities. Section 5 summarises projects aligned to the Key Knowledge Needs which will be undertaken to inform closure.
20	The MCP includes a summary of closure implementation strategies and activities for the proposed operation or for the whole site	Y	9		
21	The MCP includes a closure work program for each domain or feature	Y	9		Section 9 includes a section on closure activities for each domain/activity where relevant.
22	The MCP contains a schedule of research and trial activities	Y	9 / 5		Section 5 discusses future studies. Trial activities are included in Section 9.
23	The MCP contains a schedule of progressive rehabilitation activities	Y	9		Section 9 includes a schedule of progressive rehabilitation tasks for domains/activities where relevant.
24	The MCP includes details of how unexpected closure and care and maintenance will be handled	Y	9		Section 9 includes a section on contingency plans for each domain/activity, where relevant.
25	The MCP contains a schedule of decommissioning activities	Y	9		Section 9 includes a section on decontamination and decommissioning for each domain/activity, where relevant.
26	The MCP contains a schedule of closure performance monitoring and maintenance activities	Y	10		Section 10 provides information on closure performance monitoring methods and frequency

S10 Closure monitoring and maintenance

Comparative section in 2019 MCP: Section 12

27	The MCP contains a framework, including methodology, quality control and remedial strategy for closure performance monitoring including post-closure monitoring and maintenance	Y	12	Section 10 is now Closure monitoring and maintenance. This section has been updated to reflect progress in the development of closure and post-closure monitoring programs.	

S11 Financial provision for closure *Comparative section in 2019 MCP: Section 13*					
28	The MCP includes costing methodology, assumptions and financial provision to resource closure implementation and monitoring	Y	11	Financial provision for closure is addressed in Section 11. There are no substantive changes to this section.	
29	The MCP includes a process for regular review of the financial provision	Y	11		
S12 Management of information and data *Comparative section in 2019 MCP: Section 14*					
30	The MCP contains a description of management strategies including system and processes for the retention of mine records	Y	12	Management of Information and data is now Section 12. There are no substantive changes.	

ERA Energy Resources of Australia Ltd

Ranger Mine Closure Plan

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Document Details (ERA)

Department	Closure		
Status	Final	Project Reference	Closure
Unique Reference	PLN007		

Approvals Table

	Name	Position	Signed	Date
Originator	Elmarie Fagan	Superintendent Studies and Approvals	Elmarie Fagan	1/10/20
Checked	Sharon Paulka	Manager Closure	Sharon Paulka	1/10/20
Checked	Lesley Bryce	General Manager	Lesley Bryce	1/10/2020
Approved	Paul Arnold	Chief Executive Officer	Paul Arnold	1/10/20

Revision History

Revision	Issued date	Description	By (initials)	Checked (initials)	Approved
1.20.0	1/10/20	2020 Ranger Mine Closure Plan	SP	LB	PA
1.19.0	1/10/19	2019 Ranger Mine Closure Plan	GL	SP	PA
0.18.0	1/05/18	Revisions to draft mine closure plan issued December 2016 Issue of final mine closure plan	LP, SI	SP, JO'C	PA
0.16.0	21/12/16	Review and update of 2013 Plan	LP	SP	TE
Rev C	23/08/13	61808 ITWC PFS Report – Draft Closure Plan for Internal Distribution only	JC	-	GS
0.10.0	1/03/10	2-016 Ranger Model	PP, LP	SS, RM, MC	AP
0.09.0	2009	2-016 Draft Ranger Closure Model	PP, LP, AP	RF, MF, JS, PL, MD, JC	TM

Revision History					
Revision	**Issued date**	**Description**	**By (initials)**	**Checked (initials)**	**Approved**
0.07.0	1/11/07	2-185 Ranger Closure Model	LP, AP	DB, JD, LF, MG, IH, DK, PL, PQ, CS	TM
0.06.0	1/03/06	806 Revised Ranger Mine Draft Closure Model – First Pass	EM	AB, JD, MG, DG, MH, IH, DK, KM	TM
0.05.0	1/06/05	677 Ranger Mine Draft Closure Model – First Pass	DJ, CS, EM	AB, LC, CD, DK, DK, PR	TM
0.03.0	1/02/03	296 Closure Plan for Ranger Mine	EM	AP, DS	TM

Cover photograph: Magpie Goose (*Anseranas semipalmata*)

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5.3: Consolidation model B

5.4: Key Knowledge Needs

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9.2: Flood modelling

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Contributors

ERA Energy Resources of Australia Ltd

Executive summary

Issued date: October 2020

Revision number: 1.20.0

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EXECUTIVE SUMMARY

The following Executive Summary is a brief overview of the content of the main body of the 2020 Ranger Mine Closure Plan. For further detail, please refer to the appropriate sections of the main document.

1 SCOPE AND PURPOSE

This Mine Closure Plan (MCP) is prepared by Energy Resources of Australia Ltd (ERA) to meet its Northern Territory (NT) and Commonwealth regulatory obligations and conditions, as described below. The MCP is prepared for the Commonwealth Minister for Resources, Water and Northern Australia and the Northern Territory Minister for Mining and Industry to meet Annex B.2 of the Ranger Authority. This MCP is an update to the 2019 MCP, issued on 1 October 2019.

The MCP represents the updated Ranger Mine closure strategy following further studies and on-the-ground experience in the past 12 months. The 2019 MCP was prepared after the finalisation of the closure Feasibility Study for the rehabilitation of the Ranger Project Area (RPA) (Feasibility Study) in 2018. ERA, supported by an experienced engineering service provider, undertook the Feasibility Study to further refine scheduled rehabilitation activities and plans. 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.

The 2020 MCP is an update of the studies and closure planning from the 12 month period from 1 July 2019 to 30 June 2020. As well as providing a concise description of the closure strategy, this MCP includes an overview of the rationale and knowledge base used for the development of the document. It must be acknowledged that further studies and works are ongoing, and that these will be utilised to further develop the annual updates of the plan.

A result of a variation to the Authorisation (0108), issued on 22 June 2018, is the requirement for the MCP to be reviewed and updated annually with submission to the Commonwealth Minister and the NT Minister due on or before 1 October each year. The variation details the process for submission and assessment of the MCP (also referred to as a 'rehabilitation plan') in accordance with section 34 of the *Mining Management Act*.

The 2019 MCP was subject to stakeholder review and the detailed feedback has been considered for the preparation of this document. ERA has prepared a detailed response to stakeholder feedback on the 2019 Ranger MCP (Appendix A). In reviewing this 2020 MCP submission, stakeholders are requested to use the form provided in Appendix 1.1 for feedback for consideration in the next annual review process.

This MCP has been prepared with reference to the Western Australian Guidelines for Preparing Mine Closure Plans (the WA Guidelines) (DMIRS 2020)[2]. The WA Guidelines outline a general mine closure planning process and document structure for the MCP. ERA has followed this mine closure planning process throughout its operation and addresses each component of this process in detail throughout this MCP. The structure of the 2020 MCP was modified to align with the updated WA Guidelines and improve narrative flow.

The changes of content that have occurred in the 2020 MCP, compared to the 2019 version, are outlined in the table at the front of this document. The changes are either due to:

- provision of new information obtained through findings over the past 12 months (1 July 2019 to 30 June 2020)
- improvement in narrative flow of the document
- updated figures
- alignment with the 2020 WA Guidelines

It is intended that the 2021 update will follow the same format as 2020, but with updates to sections where new information has been obtained.

Figure ES- 1: Ranger Mine site (August 2020)

[2] Clause B6 of the Ranger Authorisation 0108-18 requires that the MCP must be prepared in accordance with mine closure guidelines accepted by the Commonwealth Minister. The currently adopted guidelines are the Western Australian (WA) mine closure guidelines.

2 PROJECT OVERVIEW

The Ranger uranium mine (Ranger Mine) is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 km east of Darwin in the Alligator Rivers Region of the NT (Figure ES- 2). The RPA is surrounded by Kakadu National Park (NP) 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 ES- 3).

ERA has operated the Ranger Mine since the commencement of operations in 1980. ERA has provided international customers with reliable supply of uranium oxide in the 38 years since production at Ranger Mine began. Ranger Mine has produced in excess of 130,000 tonnes of uranium (ERA 2020) to meet the world uranium demand for fuelling nuclear power plants. ERA production is supplied to power utilities in Asia, Europe and North America in accordance with strict international and Australian safeguards. The ERA shares are publicly held and traded on the Australian Securities Exchange, with Rio Tinto, a diversified resources group, currently holding 86.3 per cent of ERA shares.

The initial discovery of the Ranger Mine deposits was made in October 1969 by an exploration joint venture between Peko-Wallsend Operations Limited (Peko) and Electrolytic Zinc Company of Australasia Ltd through aerial radiometric survey. ERA was established in February 1980 as the operator of the Ranger Mine.

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 January 1979 and the mine came into full production in October 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 Kakadu NP management. The Commonwealth Government introduced laws covering the Alligator Rivers Region (*Commonwealth Environment Protection (Alligator Rivers Region) Act 1978*) and established several research bodies and committees to overview the environmental regulation of mining in the region. These included the Supervising Scientist and the Environmental Research Institute of the Supervising Scientist (ERISS), the Alligator Rivers Region Advisory Committee (ARRAC) and the Alligator Rivers Region Technical Committee (ARRTC).[3] 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 to permit mining to proceed.

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3 The functions of these committees and research bodies are described further in Section 4.

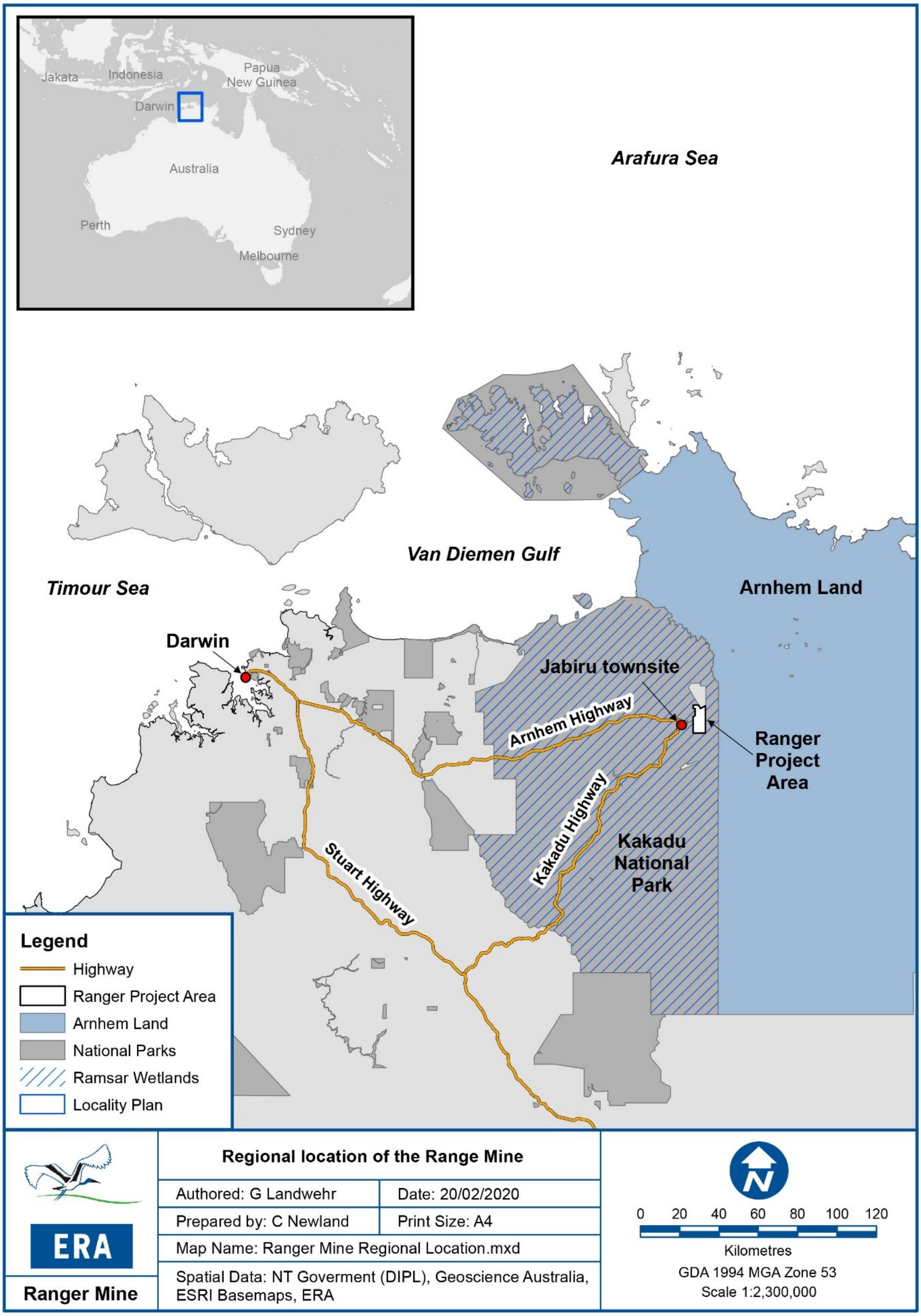
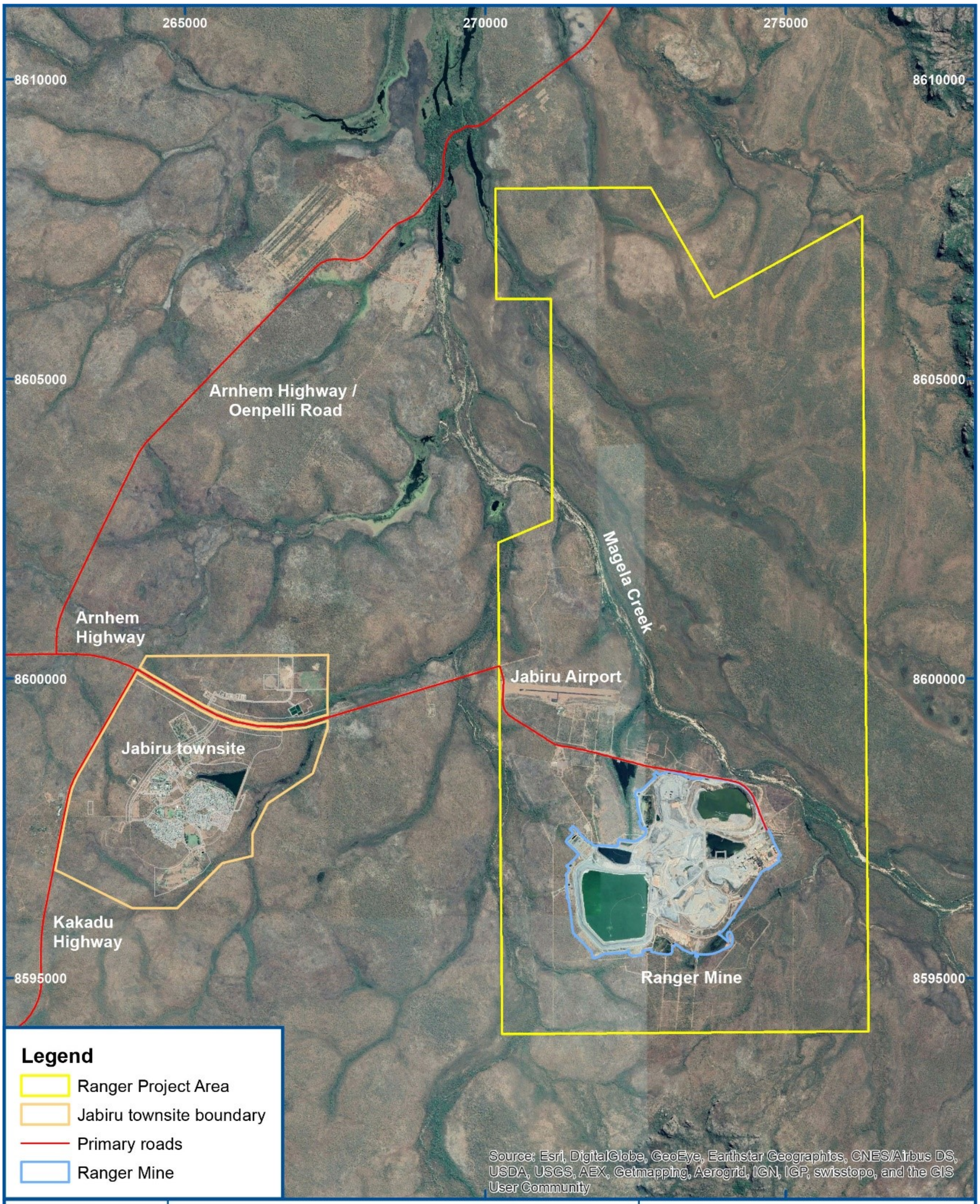


Figure ES- 2: Regional location of Ranger Project Area



Ranger Mine	Ranger Mine Project Area		
	Authored: G Landwehr	Date: 24/02/2020	0 1 2 3 4 Kilometres
	Prepared by: C Newland	Print Size: A4	GDA 1994 MGA Zone 53
	Map Name: Ranger Mine Project Area.mxd		Scale 1:80,000
	Spatial Data: ESRI Basemap, NT Government (DIPL), ERA, Geoscience Australia		

Figure ES- 3: Ranger Mine Project Area

Mining of Pit 1 finished in December 1994. During that time, 19.78 million tonnes of uranium ore was mined. Mining from Pit 3 commenced in July 1997 and concluded in November 2012. Since mining finished in Pit 3, ERA has produced uranium oxide from stockpiled ore.

The processing of stockpiled ore will continue during the operations phase through the Ranger Mine processing plant, where uranium is leached from the ore using sulfuric acid. The uranium is then purified, concentrated, precipitated, calcined (dried), placed into drums and exported. Components of the mining and processing operations include:

- processing area including a power station (which also provides power to the town of Jabiru), administration and maintenance facilities
- Ranger 3 Deeps (R3D) exploration decline
- a tailings storage facility (TSF) (historically referred to as the 'tailings dam')
- two mined-out pits – Pit 1 and Pit 3
- ore and waste rock stockpiles
- several water retention ponds, water storage structures and constructed wetland filters
- water treatment plants (WTPs)
- irrigation areas for the disposal of managed release water
- an access road and service tracks
- Jabiru Airport, Jabiru East and associated infrastructure.

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. It encompasses all aspects of water capture, storage, supply, distribution, use and disposal. The water management facilities within the RPA include:

- retention ponds
- water treatment ponds
- wetland filters
- Land Application Areas
- High Density Sludge plant
- Brine Concentrator (BC)
- Brine Squeezer.

Water is managed according to the Ranger Water Management Plan (RWMP), which describes the method used to control water on site. The RWMP fulfils the requirements of the Ranger Authorisation (0108-18) and is approved annually by regulators.

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 2026.

3 CLOSURE OBLIGATIONS AND COMMITMENTS

Closure of the Ranger Mine is governed by both Commonwealth and NT legislation and regulations. The key instrument that governs operations at the Ranger Mine on a day-to-day basis is the Ranger Authorisation, issued under the NT *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 operations (the section 41 Authority).

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 the section 44 Agreement with the NLC under the *Aboriginal Land Rights Act*. The section 41 Authority (described above) was granted on 9 January 1979.

The Ranger Environmental Requirements (ERs) are appended to the section 41 Authority and set out 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. The *Mining Management Act* also requires the Ranger Authorisation to incorporate, by reference, the ERs. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation.

It is implicit that ERA will comply with all necessary legal obligations and uphold internal standards during closure to ensure the ongoing protection of the environmental values surrounding Kakadu NP; the health and safety of the community and preservation of cultural values. ERA is committed to protecting these values by implementing the required management controls.

The transition into closure will involve applying for regulatory approvals to authorise new requests or to modify the currently authorised activities that have the potential to result in an environmental impact to either intact or undisturbed areas of the RPA; or downstream and/or offsite. It is planned that no areas outside of the existing footprint will be disturbed during closure and, as such, no additional permits or approvals relating to land disturbance will be required. Permits for decommissioning works, post-closure and access approvals will be submitted to the relevant authority, as needed.

4 STAKEHOLDER ENGAGEMENT

ERA has a diverse and complex range of stakeholders. (The generic term "stakeholder" is used in this MCP to cover all interested and affected external parties, including Traditional Owners and regulatory agencies. It is noted that in other contexts Traditional Owners and regulators may be differentiated from the broader stakeholder groups). These stakeholders have interests in specific areas of the closure process or outcomes and/or in the more general closure objectives and successful achievement of the planned post-mining land use. The ERA approach to stakeholder engagement is focused on building enduring relationships based on mutual respect, active partnership, transparency and long-term commitment.

ERA representatives are in frequent, regular contact with the Gundjeihmi Aboriginal Corporation (GAC), NLC, Northern Territory Department of Industry, Tourism and Trade (DITT), Commonwealth Department of Industry, Science, Energy and Resources (DISER) and the Supervising Scientist Branch (SSB), both informally and formally through various stakeholder committees, including the Minesite Technical Committee (MTC). There are documented communications via forums including the Alligator River Regions Technical Committee (ARRTC) and the Alligator River Regions Advisory Committee (ARRAC), which date back to 2001. Public communication on aspects of mine rehabilitation and closure can be traced back to the first ERA annual report in 1981.

Throughout the life of the Ranger Mine, ERA has engaged, communicated and consulted with multiple stakeholder groups through various engagement activities and range from formal, often regulatory based, processes to informal consultative processes. This stakeholder consultation aims to both provide information and to seek feedback on closure plans.

5 KNOWLEDGE BASE AND SUPPORTING STUDIES

The baseline information provides an overview of the physical, environmental and social setting of the Ranger Mine, and provides the context to planning mine closure. The substantial dataset has been accumulated by ERA and regulators over more than 30 years of environmental, safety and health monitoring and research investigations of the site and surrounding environment.

The RPA is surrounded by Kakadu NP (Figure ES- 2). The Kakadu region has had at least 65,000 years of indigenous occupation, with increasing contact between the region's Aboriginal people and other cultures from around the 17th century and a more permanent non-indigenous presence evident from the late 1800s. Historical land use within the Alligator Rivers Region has included indigenous occupation, buffalo hunting, missions, pastoral grazing, agriculture, mining exploration, uranium mining and tourism. The RPA is within the Magela catchment, within the Alligator Rivers Region, and currently contains several land use types, including Kakadu NP, mining and native title lands. Kakadu NP is a World Heritage listed area and within a Ramsar wetland site (Figure ES- 2). Section 5.1 describes the social setting.

The description of the physical environment (Section 5.2) includes an overview of the RPA climate, land systems, surface water resources, groundwater and radiation. The description of the biological environment (Section 5.3) includes an overview of the bioregions, NPs and protected areas, terrestrial ecology and aquatic ecosystems which the RPA is sited within.

The climate of the Alligator Rivers Region, within which the Ranger Mine is located, is dominated by a seasonal wet-dry monsoon cycle with the large inter-annual and intra-seasonal variability largely associated with the effects of the El Niño Southern Oscillation, the Madden-Julian Oscillation and tropical cyclone activity. The wet season generally extends from late October to early April with predominantly westerly winds, whilst the dry season is dominated by easterly to south-easterly winds and extends from May to September.

Surface water management will be a key focus of rehabilitation and closure, as it is one of the pathways for constituents of potential concern (COPC) to enter the environment. The Ranger Mine is located within the 1,600 km^2 of the Magela catchment and adjacent to Magela Creek (Figure E- 4). 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 tropical, monsoon climate of the NT creates seasonal changes that drive groundwater flow into and out of the Ranger Mine area (Section 5.2.7). 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[4]. Groundwater also occurs in intermediate layers of weathered bedrock between the shallow and deeper groundwater flow systems. The natural background hydrochemistry of groundwater of the RPA typically exhibits relatively low concentrations of total dissolved constituents.

There has been a substantial survey and monitoring of the terrestrial flora across the RPA over the past 15 years. In a 2013 survey of lowland riparian and woodland areas within the RPA, 292 flora species from 30 families were identified. These species are common in surrounding Kakadu NP and did not include any threatened or rare species. Approximately 1,600 terrestrial and aquatic flora species have been recorded in Kakadu, including 15 species considered rare or threatened. These conservation significant species have not been recorded within the RPA.

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 *EPBC Act.* Gamba Grass (*Andropogon gayanus*) is the only WoNS previously recorded in the RPA with the recorded presence restricted to isolated plants on roadsides or in the vicinity of the Jabiru Airport. With successful weed control, there has been no plants or viable seeds of this species detected for a number of years. A new weed to Australia, Indian Pinkroot (*Spigelia anthelmia*) was discovered onsite in April 2019 and an eradication program has been implemented.

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

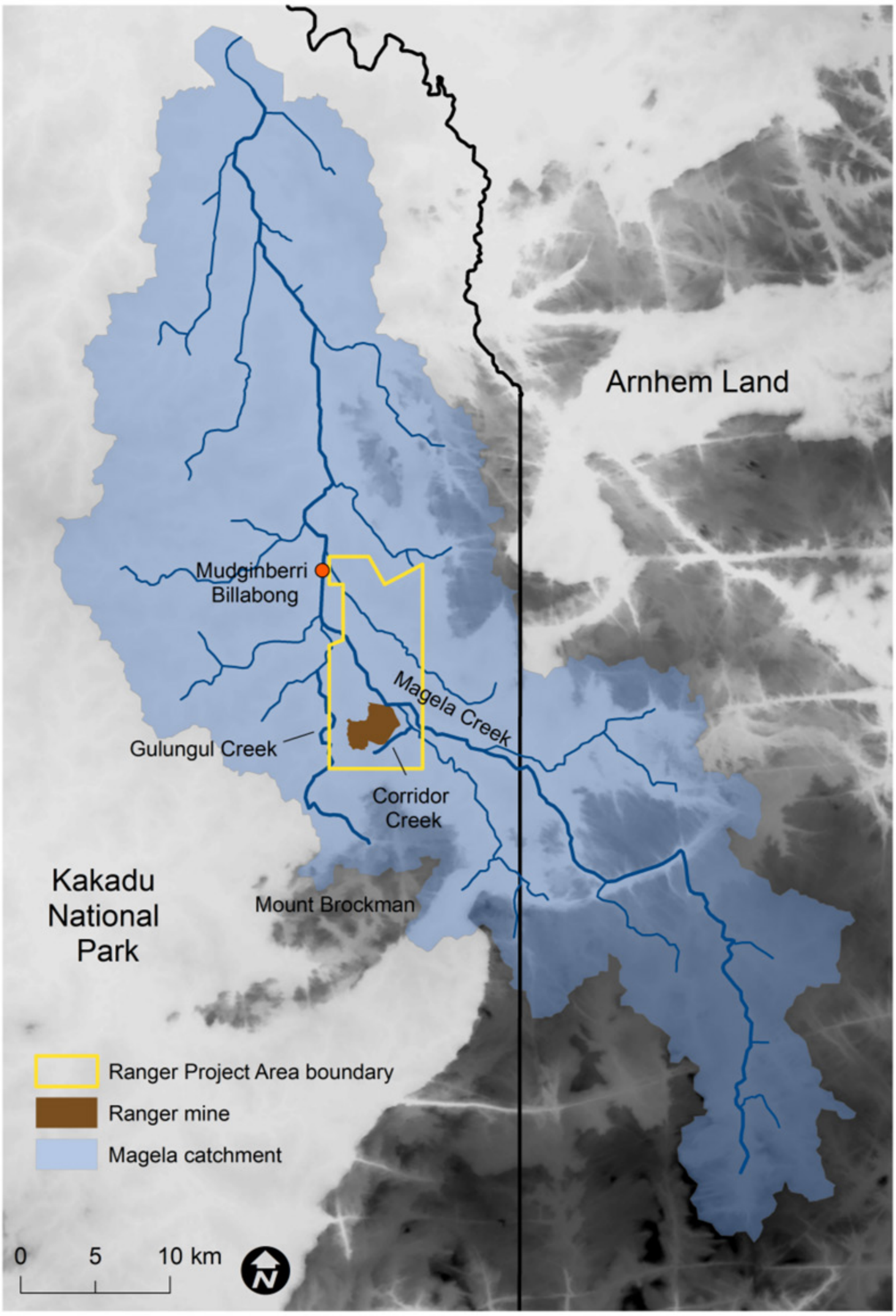

Figure E- 1 Regional extent of Magela catchment

A number of conservation significant fauna species (including a large number of mostly bird species listed under various migratory agreements) have been recorded on the RPA during previous surveys 4.3. The identified species include the conservation listed Northern Quoll *Dasyurus hallucatus* (Endangered; Critically Endangered) and the Partridge Pigeon *Geophaps* *smithii smithii* (Vulnerable; Vulnerable) (the *EPBC Act* and *Territory Parks and Wildlife Conservation Act)*.

Fire within the RPA is managed by ERA for asset protection and weed control, and includes fuel reduction burns, excluding fire from certain areas and maintaining a network of graded firebreaks.

Studies and monitoring programs within the RPA have been conducted since before mining commenced. The outcomes of this substantive body of work have:

- informed the overarching closure strategy and approach
- informed the development of closure criteria
- informed strategies for closure implementation aligned to best environmental practice and the ERs
- informed identification and rank of closure risks to ensure the ongoing management of potentially high risks and an iterative approach to mine closure risk assessment
- informed the construction of a final landform
- provided baseline data against which to measure closure performance
- highlighted knowledge gaps and/or alternative options to previous elements of the closure strategy.

It is recognised that some projects have been finalised whilst others are ongoing. Further updates of the ongoing studies are provided in Section 5.5, Appendix 5.1 and in subsequent MCPs. The Key Knowledge Needs (KKNs) have been identified, by stakeholders and ERA, as the information gaps that are required to be addressed for the effective closure of the Ranger Mine. Both ERA and the SSB will implement KKN projects, either independently or cooperatively, depending upon the project.

A summary of the ERA closure-related technical and scientific studies are provided below (Table ES- 1).

Table ES- 1: Summary of supporting studies

Area of study	Summary of studies
Tailings	Comprehensive test work and characterisation of tailings has been undertaken on the Ranger Mine tailings, including *in situ* testing in both Pit 1 and Pit 3 since 2003. This large body of work has underpinned the development of a tailings consolidation model for Pit 1 and Pit 3. The Pit 1 model has been continually validated throughout the backfill of Pit 1 through a series of settlement plates installed at the commencement of backfill activities and provided a high level of confidence in the model. The consolidation model enables the prediction of final tailings elevations and expected process water volumes in Pit 1 and Pit 3. The model output includes density, permeability, void ratio and effective stress profiles at user defined times and cumulative consolidation flows to the surface and base.

Area of study	Summary of studies
	Validation and verification of the consolidation model using monthly tailings settlement readings in Pit 1 and *in situ* test data in Pit 3 demonstrates that the model is still valid. The validated model suggests that the target process water removal from the tailings in Pit 1 and Pit 3 will occur by January 2026. Another geotechnical investigation will be conducted in Pit 3 from September to November 2020, to verify the consolidation model and provide tailings parameters for the capping design. The investigation will comprise cone penetration tests with pore pressure measurements, pore pressure dissipation test, vane shear test, and ailings sampling and laboratory testing. After completion of tailings deposition into Pit 3, the tailings consolidation model will be updated then utilised for the settlement monitoring during the Pit 3 capping and bulk backfill period.
Groundwater	The 2016 Ranger Mine conceptual and numerical models for groundwater were updated in 2018 for use in assessment of potential impacts from post-closure conditions. The updated conceptual model describes the most important hydrogeologic elements governing groundwater flow and transport at the Ranger Mine. The calibrated groundwater flow model incorporates the major stresses applied to the Ranger groundwater flow system at Pit 1, Pit 3 and the TSF. All available spatial and temporal data was used to build and calibrate the flow model constrains the values of the model parameters and provides confidence gained through the calibration process. 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 groundwater calibrated model will meet all indicators for a high confidence level after the planned peer review by an independent hydrogeologist with modelling experience is completed. The Ranger Mine conceptual modelling has been undertaken in part to support Key Knowledge Needs projects for groundwater and surface water. Updates to the post-closure solute transport modelling have commenced and include a number of supporting studies including an updated to the site source term model and the groundwater surface water interaction model. Updates to predictions of post-closure solute transport modelling will be provided in subsequent submissions of the MCP. *The Ranger Conceptual Model and solute transport areas of interest/concern* The Ranger Conceptual Model is an important tool for understanding groundwater and surface water flow and solute migration within and out from the Ranger Mine. Conceptual models were developed for the regional scale, sitewide scale, and the scale of individual areas of interest where the COPC sources are located. The Ranger Mine Conceptual Model provides an evidence based framework by which ERA can measure and implement decommissioning and closure activities to meet its environmental rehabilitation obligations. There are specific areas that are of interest/concern for COPC sources and migration within and from the Ranger Mine site, and smaller-scale conceptual models have been developed for each of these areas: • Pit 3 • Pit 1 • TSF • Processing plant area • LAAs • Ranger 3 Deeps • Landform waste rock.

Area of study	Summary of studies
	<u>Pit 1 Solute Egress Modelling</u> The Pit 1 solute egress model, updated in 2014, demonstrates that no detrimental impact to the surrounding environment will occur for at least 10,000 years due to tailings storage within the pit, as required under the Ranger Authorisation. <u>Pit 3 Solute Transport Modelling</u> Pit 3 solute transport modelling, both conceptual and numerical, was developed to assess the ability of the proposed Pit 3 backfill options to meet the ERs outlined in the Ranger Authorisation. Much of the data has been incorporated into the Ranger Mine Conceptual Model. The overall objective was to quantify the amounts and rates of groundwater COPCs transported from Pit 3 to Magela Creek over a 10,000-year period for closure scenarios, with and without mitigation features. The mitigation features evaluated include a low-permeability cap at the top of the shallow waste rock backfill, a low-permeability cap over the tailings, and a cut-off wall between Pit 3 and Magela Creek. The modelling identified that mitigation through the use of low-permeability caps was preferred over a cut-off wall. When reviewing the effectiveness of these caps in reducing solute loads to Magela Creek in the context of the overall site, the modelling predicted the caps only have a marginal impact on loads. The conceptual model demonstrates that these low-permeability caps will not be required. Other closure-related groundwater studies that have informed the Ranger Mine Conceptual Model include: • magnesium loading to Magela Creek from Pit 3 tailings – post-closure • extent and hydraulic properties of the MBL hydrolithologic zone near Pit 1 • effect of tailings deposition on flow from Pit 3 • hydrological conditions after halt of pumping in the Ranger 3 Deeps decline • predicting post-closure groundwater solute loading to creeks using uncertainty analysis • assessment of groundwater levels and quality in Sed2B bores • groundwater assessment in waste rock stockpiles • background COPCs in groundwater • aquatic ecosystem assessment & framework development
Surface water	The purpose of the surface water modelling is to refine the closure strategy and support the approvals required to rehabilitate the minesite by providing estimates of the concentrations of nominated COPCs in receiving surface waters over a period of 10,000 years following the rehabilitation of the mine. The area of interest is the Magela Creek catchment, from the rehabilitated minesite down to Mudginberri Billabong. An updated surface water model was developed in 2020 and included the following elements: • flow configuration and calibration • water quality configuration and calibration • derivation of site loadings and time series • preliminary simulations Five scenarios were simulated using the configured and calibrated model. The first modelled scenario is the case used for model calibration, referred to as the ‘No Mine’

Area of study	Summary of studies
	case as it represents just the loads from natural catchment sources, that is, no loads are included from the minesite. (This scenario has been included in the results to assist in understanding the results for the other four scenarios.) The other four scenarios are the selected four time horizons Year 1, 20, 270 and 10000. The groundwater loads input into this model were derived from the initial groundwater modelling described above. The results of these preliminary simulations are provided in Section 5.4.4. The model is currently undergoing further updates to address key stakeholder feedback, improvements identified through development of the model, and included updated post closure solute transport loadings predictions and the surface water to groundwater interaction model outcomes. Following completion of the update in late 2020, multiple projects, including assessments of sediment accumulation, human diet and health, ecosystem vulnerability, release water pathways and cumulative aquatic risks can be conducted to assess if water quality closure criteria/objectives will be met. This will include additional studies such as assessing the traditional diet, risks associated with the predicted water quality, and predictions of accumulation of uranium into sediments. This will also inform decisions on what is as low as reasonably achievable (ALARA) on the RPA.
Landform	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 current or the predicted climate/rainfall regime that will result from climate change. Initial landform development was based on landform design criteria developed by ERA through studies of a nearby natural analogue area. Topography of the final landform is similar to the pre-mining landform; maximum elevation after consolidation increases from 38 m pre-mining to a final landform maximum of 44 m Australian height datum (AHD). Slopes of the landform range in grade from approximately 2 percent to 5 percent. Analysis showed slopes vary from about 1 in 30 (3 %) to 1 in 200 (0.5 %), with the larger catchments tending to have lower slopes, although this is not always the case. The current version of the final landform is version 6 (FLv6). Each version of the landform has been subjected to landform evolution modelling by the SSB to assess the performance of the landform. The SSB uses a modified version of the CAESAR-Lisflood landform evaluation model to assess the stability of the final RPA landform over time frames ranging from decades to millennia. The model predicts both the locations of gully formation and the broad scale erosion and deposition across the landform with long-term denudation rates being calculated. 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. Modelled denudation rates after 10,000 years provided by the SSB on FLv5 are: • Coonjimba: 0.05 mm per year • Corridor Creek: 0.03 mm per year • Djalkmara Creek: 0.02 mm per year, and • natural background: 0.01 – 0.04 mm per year. Modelling of FLv6 is ongoing, to date the SSB landform model simulations for extreme wet and extreme dry rainfall scenarios over the Corridor Creek catchment predict that gullies, which could potentially expose tailings, will not form across the surface of Pit 1 within a simulated period of up to 1,000 years. In mid-2019 ERA engaged a Rio Tinto hydrologist to build capacity in the assessment of closure landforms using the CAESER-Lisflood landform evolution

Area of study	Summary of studies
	modelling software. ERA is currently evaluating closure landforms and completing sensitivity testing of key model parameters including climate sequences, rainfall losses, particle size distribution and vegetation cover. This project has allowed for faster evaluation of landforms, and a better understanding of the modelling process and the implications for erosion outcomes dependent upon both landform design and parameter choice. Landform design is an iterative process; design of drainage channels and other erosion mitigations is ongoing to minimise the potential impact on landform stability and revegetation success. ERA's ongoing engagement with a Rio Tinto hydrologist will assist ERA in understanding whether incremental changes in landform design are achievable and/or beneficial, and to better provide input into the final evaluation of landform stability at closure (denudation and the formation of gullies).
Water & Sediment	*Background and operational surface water quality* Surface water and sediment quality monitoring at the Ranger Mine and surrounding environment has occurred for several decades, providing significant information on surface water and sediment quality within the creeks and billabongs. Several studies describe the background conditions in billabongs and creeks in the Magela Creek catchment. Surface water monitoring over 30 years indicates that at the end of the wet season, upstream of Ranger Mine, waters have elevated magnesium and EC levels which are not related to mining. Downstream of the Ranger Mine there is a general trend of relatively constant magnesium concentration and salinity. The SSB's integrated monitoring programs have been developed over nearly 30 years and are leading practice. The 30 years of multiple lines of evidence show that during the operational phase, the mine derived COPCs (including magnesium, uranium, manganese and radium-226) have not adversely affected the abundance or diversity of aquatic organisms downstream of Ranger Mine. Background COPCs in groundwater require characterisation in order to identify the natural range in concentrations in different HLUs across the site. The background COPCs in groundwater project was completed in June 2020. This included the development of interactive html dashboards allowing for full interrogation of the dataset and statistical analysis undertaken to develop the background threshold values. This data will inform the modelling of post-closure solute transport, solute source Area / Concentration conceptual model and the modelling of surface water. *Aquatic sediments* Aquatic sediment sampling is required to understand any potential ecological impacts related to mine contaminated sediments. This will inform ALARA-BPT assessments which in turn inform the decommissioning requirements for onsite waterbodies. A sampling and analyses program based on leading practice and a review of historical data from earlier investigations of billabong sediments was trialled in 2015 and implemented and refined in 2016. These results demonstrated that there has been no sediment contamination in off-site billabongs as a result of mining. Given the improved water quality leaving the minesite in recent years the risk of sediment contamination off the RPA occurring now is negligible. Metal contamination of onsite billabongs has not increased in recent years and the formation of acid sulfate soils (ASS) is now the recognised priority hazard to sediments in water bodies on the RPA. Therefore, the focus has now shifted away from routine monitoring of on and off-site sediments to a targeted program to understand the ASS issues. A preliminary site wide ASS conceptual model has been developed, based on a collation and review of historical topography, groundwater and surface water data,

Area of study	Summary of studies
	and existing soil and sediment sampling result. The objective of the model is to further understand: • source dynamics of ASS formation at the site • mechanisms of potential ASS exposure and oxidation to form AASS • potential pathways for acidification products (dissolved metals, acid and sulfate) from ASS sources areas • surface water and groundwater receptors that may receive such acidification products • potentially complete source-pathway-receptor linkages ERA has now commenced investigating the risk associated with each conceptualised potential ASS source location. Targeted sediment sampling during the next 12-18 months, along with the development of a location specific risk-ranking, are proposed to evaluate potential ASS formation in the sources areas identified. The risk-ranking for each identified sources area will be based on location specific concentrations in surface water and groundwater, likelihood of hydrodynamic changes associated with closure, and the sensitivity of the potential receptor to acidification products. The risk assessment can then be used as a tool for monitoring regime development. An ASS model for closure conditions will also be developed to inform closure risks and management strategies. *Contaminated sites* ERA maintains a register of potentially contaminated sites, identified on the basis of site activities including use and storage of chemicals. Targeted assessments have been undertaken at some known contaminated sites to assess the type and extent of contamination and inform remediation requirements, if necessary. ERA plans to undertake a whole of site contaminated sites assessment. The assessment will then trigger the development of remediation plans, if required, and update the contaminated sites register. Other contamination related studies conducted to date include potential contamination in the Land Application Areas (LAAs) and effective radiation dose estimates for members of the public from the LAAs. These works indicate the dose contribution from the all LAAs to be very low and, with the exception of Magela A and B, are below the exemption levels. These results indicate that no remediation for radiological contamination will be required in the LAAs. Work to assess soil contamination from metals in the LAAs is ongoing. As part of the feasibility study undertaken in 2018, a review of the contaminated sites register was undertaken. The review involved ensuring all areas of potential contamination were captured as well as aligning historical investigations undertaken to date, thereby developing a current knowledge based of site contamination. Sites were also classified according to risk. Following this review, a *Plume and contaminated site management plan* was developed. The plan describes future site assessments and BPT assessments, post remediation validation assessments and post-closure monitoring. Site assessments, in the form of a drilling program, were executed between November 2019 and January 2020 to sample soils, install groundwater monitoring wells and re-develop existing monitoring wells (Section 5.5.2.5). The results of this work are currently being analysed. Results will further inform the *Plume and contaminated site management plan.*

Area of study	Summary of studies
Health impacts of radiation and contaminants	In order to determine the achievement of closure criteria for both human health and environmental protection, ERA and the SSB have developed a pre-mining radiation baseline. All assessments against radiation closure criteria will be made based on the above-background mine-sourced radiation dose. A radiation dose assessment for the post-closure phase is currently in progress. The dose assessment includes two phases of modelling and will consider potential radiation exposure to members of the public as well as terrestrial and aquatic biota. The radiation dose assessments will be completed once the surface water modelling results provide the required data inputs.
Ecosystem rehabilitation	*Long-term flora and fauna baseline monitoring* In 2011, ERA implemented a long-term fauna and flora monitoring program on the RPA and in adjacent areas of Kakadu NP (in agreement with Mirarr Traditional Owners and Kakadu NP Management). The primary objective of the program is to study the natural woodland ecosystem for the development of fit for purpose closure criteria, and to inform the development of the rehabilitation strategy. Historical flora and fauna surveys, including targeted studies, and extensive ecological research on the Ranger Mine site and surrounds, have also contributed to development of closure criteria and measurement, and rehabilitation approaches. The program development, site selection and monitoring has been undertaken in collaboration with the SSB/ERISS. Soil, vegetation and ecohydrological studies undertaken have included: • plant responses to water stress in the wet-dry tropics • whole-tree sap flow • stand transpiration • stand evapotranspiration • canopy cover dynamics • seed provenance • total water requirements of the vegetation • shallow groundwater table and soil water dynamics Flora species composition and community structure studies include: • species selection • species establishment via seeding vs tubestock • emergent vegetative features in constructed waterbodies Ongoing monitoring of both the final landform and the analogue sites will continue to provide data to determine trends in the composition and abundance of flora and fauna, and any natural variability resulting from seasonal changes and fire. *Trial landform (TLF)* The eight hectare (ha) TLF, constructed in 2008/2009, was designed based on ERA and the ERISS studies of analogue sites and previous revegetation work conducted at the Ranger Mine. The TLF is four to seven metres above the original natural ground surface and is comprised of 800 k tonnes of primary and weathered waste rock. The design allowed for the performance testing of different types of substrates, different depths of mixed materials over the waste rock only layer, different planting methods and different irrigation regimes. Runoff and catchment management features and monitoring systems provide water quality data to inform decision-making on future water management strategies and landform design. The monitoring includes 66 soil moisture probes, a weather station and four erosion plots.

Area of study	Summary of studies
	The TLF was first planted with tubestock in 2009 and monitoring of revegetation performance and ecosystem development has been ongoing. Flora monitoring includes the growth, performance and survival of plants and vegetation communities under different conditions. Ten years of studies have assessed aspects critical to the successful closure and revegetation of the landform, including: • infiltration, runoff, soil erosion and solute loss • radon exhalation • plant available water • revegetation trials • establishment • performance • root distribution. Discussion on ecosystem establishment, including revegetation trials and seed provenance is provided in Appendix 5.1. This also includes a fine scale assessment, including plant species composition and relative abundance in the RPA, and surrounding natural analogue sites.
Climate change	A stakeholder workshop was held in March 2020 to undertake a first pass assessment of climate change risk to the closure of Ranger. The assessment was undertaken by subject matter experts from within and outside of ERA. A further on-line workshop was conducted with bushfire experts to gather additional expert input into this critical aspect. The process included delivery of a briefing on climate projections for the target area, based on available information obtained from reliable resources including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Bureau of Meteorology (BoM) and the National Climate Change Adaptation Research Facility (NCCARF). Additional information was drawn from published peer reviewed literature. In assessing risk, the current management plans and activities relating to the mine closure were discussed. Their role in addressing relevant climate change risks was assessed to enable any residual risk to be identified. Thirty-seven potential risks were discussed and assessed. Risks were classified into four key areas • onsite activities (management and monitoring) • vegetation • onsite and receiving water quantity, quality and ecology • erosion and sediment In general, the relatively short period (compared to climate change timeframes) of active onsite management and monitoring, expected before the site stabilises and meets close-out conditions, meant that the risk profile for the mine closure was fairly low. The outcomes of the risk assessment will be included in the 2021 MCP once the report has been finalised.

6 BEST PRACTICABLE TECHNOLOGY

The identification and use of Best Practicable Technologies (BPTs) are a key component of the ERs (described above). The ERs specify that:

> *12.1 All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT*
>
> *12.2 Where there is … agreement … that the primary environmental objectives can be best achieved by … (an) action which is contrary to the Environmental Requirements … and which has been determined in accordance with BPT, that proposed action should be adopted*
>
> *12.3 All environmental matters not covered by these Environmental Requirements must be dealt with by the application of BPT.*

A BPT is defined in the ERs (Annex A – 12.4) 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*. The definition of BPT in the ERs establishes a framework for assessment of currently available technology at any point during the operational and rehabilitation phases of mine life, rather than the ERs specifying particular technologies which may become obsolete.

A summary of each closure-related BPT submitted to regulators to date is provided within Section 6.2. Further BPT assessments will accompany each future closure application submitted to the MTC for assessment, as per the provisions outlined in the Ranger Authorisation.

Several ERs require environmental impacts to be as low as reasonably achievable (ALARA). ERA has researched and documented a process for the application of ALARA with respect to non-radiological hazards to demonstrate that environmental impacts on the RPA and exposure to chemical pollutants are ALARA. The process is described in Section 6.3 and Appendix 6.2 and adopts recommendations from the international literature to implement an holistic framework that combines options and risk assessments to derive and demonstrate an ALARA outcome. The process can also consider options that would result in levels of contamination in the riparian zones that are as low as technically possible, as requested by the Traditional owners.

7 RISK ASSESSMENT AND MANAGEMENT

The approach ERA has taken to risk assessment has been developed to identify hazards, aspects and opportunities in advance of project or activity implementation. The resulting risks and impacts to the business, people, property, assets and the environment are recorded and evaluated, and strategies are developed to manage them. The framework is consistent with recognised Australian standards and corporate management standards and practices including AS ISO 31000:2018 Risk Management – Principles and guidelines, AS/NZS ISO 14001 Environmental Management Systems and internal Rio Tinto and ERA standards and commitments. Risk management forms part of ERA's Health, Safety and Environmental

Management System, which has been certified to meet the requirements of the AS/NZ ISO14001:2015.

During the Ranger Mine Closure Feasibility Study, a series of risk assessment workshops were completed to further develop the Ranger closure risk register. In June 2019 the environmental risk assessment published in the 2018 MCP was updated with the outcomes of the feasibility study risk assessment and to consider the comments received from the Supervising Scientist on the 2018 MCP risk section. During 2020 the register has undergone several reviews including quarterly and annual risk reviews to ensure that the information remains current, risk trend update, control effectiveness, overall control effectiveness, action status and overall action status.

The current risk profile for Ranger Mine closure is provided in Section 7.4. There are 46 open risks as of June 2020. Of these, three are Class IV (Critical) risks:

- failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu NP.
- rainfall is greater than planned in the water model (P50) increasing the process water inventory. Additional water management, leads to a later completion of process water treatment than planned
- unable to inject brine into the underfill of Pit 3

The causes, impacts, existing controls, evaluation rationale and planned actions for each of the threats above are detailed within Appendix 7.1.

Seventeen risks were identified as Class III (high) with the majority of these related to impacts on project schedules and ERA's licence to operate. In each case, controls to mitigate the risks have been identified. All Class III (High) risks require ongoing management.

There are a total twenty one Class II (Moderate) risks and five Class I (Low) risks open as at June 2020 in the Ranger Mine closure risks register.

The Class IV risk detailed in the 2019 MCP, insufficient volume or quality of viable seed stock available for whole of site revegetation, was actively managed throughout 2019 and 2020 and has be re-evaluated to a Class III risk. Some of the actions completed during the past 12 months include the upgrade of the Ranger Nursery to increase security and fire protection, the evaluation of the viability of historical seed, the development of a seed tracking metric and the commencement of routine seed collection on the RPA. The current open actions for this risk are detailed within Appendix 7.1.

8 POST-MINING LAND USE, CLOSURE OBJECTIVES AND CLOSURE CRITERIA

The post-mining land use for the RPA is determined by the Environmental Requirements (ERs), which are conditions of the section 41 Authority issued under the *Atomic Energy Act 1953* and appended to the Ranger Authorisation (as Annex A) issued under the *Mining Management Act 2018 (NT)*

The pre-determined post-mining land use of the rehabilitated RPA includes the "potential incorporation into the Kakadu NP". It should be noted that any decision on the actual incorporation of the RPA to Kakadu NP will be made by the relevant authority in consultation with Traditional Owners and may not eventuate until sometime after closure.

Consultation has indicated that the Mirarr are likely to return to the area for:

- customary harvesting of bush foods and medicine
- recreation
- land management activities, and
- cultural site visitation and ritual responsibilities.

To meet these post-mining land uses, the closure of the Ranger Mine is required to fulfil a number of closure objectives. The ERs provide specific regulated closure objectives, which align to the post-closure land uses. These objectives were developed at the time of mining authorisation with the post-mining land use in mind. The objectives have been reviewed with stakeholders throughout the project and have been agreed as being appropriate for the project impacts and proposed land uses.

A key component of closure planning for the Ranger Mine is the development of closure criteria. The closure criteria represent performance metrics which will be used to measure the achievement of the rehabilitation closure objectives. These criteria represent direct measurable and quantifiable values, or tiered assessment processes based on industry best practice frameworks. Close-out certificates will be issued by the relevant authority upon the successful fulfilment of these closure criteria.

The closure criteria have been developed to align with the requirements of the ERs and Ranger Authorisation to achieve the overarching closure objectives. Development of the criteria has involved continuous consultation with stakeholders and input by the Closure Criteria Working Group with the support of various studies and reports. Section 8 provides justification for criteria development; identifies measurable parameters and provides a formal description for the individual closure criteria that have been assigned to each of the relevant closure themes. The closure criteria will be subject to further refinement, improvement and validation to ensure finalised criteria reflect acceptable standards and achieve desired outcomes.

In consultation with key stakeholders ERA developed a set of closure criteria themes, which are: landform, radiation, water and sediment, ecosystem (previously flora and fauna), soils, and cultural. For each theme the following have been identified, against the relevant ERs:

- Objectives
- Outcomes
- Parameters
- Draft or Final criteria.

The closure criteria presented in this MCP have been divided into two categories; proposed criteria for approval by the minister, and draft criteria for further review. These have been divided into separate tables in order to clearly identify the two categories. The draft closure criteria will continue to undergo review and refinement, based on studies and consultation with MTC members with a plan to finalise all criteria for the 2021 MCP.

9 CLOSURE IMPLEMENTATION

The primary goal of closure at the Ranger Mine is to rehabilitate the disturbed areas of the RPA, establishing an environment similar to the adjacent areas of Kakadu NP. The total area of disturbance in the RPA to be rehabilitated is approximately 1062.5 ha. The closure domains for Ranger are provided in Figure ES- 4 with a summary of closure activities to be completed for each domain provided in Table ES- 2.

ERA has undertaken significant progressive rehabilitation works since 2012, with more than AUD$600 Million spent on rehabilitation activities including tailings transfer, process water treatment and the backfill of Pit 1. Opportunities for the final revegetation of disturbed areas have so far been limited, in part due to efforts to maintain a minimum footprint and concentrate operational activities within the existing disturbed area. Despite this, over 12 ha of successful native revegetation has been completed

The closure implementation plan for Ranger Mine has been designed to mitigate the identified risks detailed in Section 7. The plan has been developed through the combination of the application of Best Practicable Technology (Section 6), business requirements and the outcomes of engineering, solute modelling and consolidation modelling.

The closure implementation plan includes the completion of the following key activities before January 2026:

- place all tailings into mined-out pits (transfer tailings in the TSF to Pit 3)
- following tailings deposition, backfill Pit 1 and Pit 3 with low-grade mineralised and waste rock
- eliminate the process water inventory
- manage salt and store brine in mined-out Pit 3

- demolish plant and associated infrastructure and for disposal within Pit 3
- deconstruct and rehabilitate the TSF and surrounds
- create a final landform that blends in with the surrounding environment
- revegetate disturbed areas to develop a self-sustaining ecosystem similar to the Kakadu NP
- demonstrate, with appropriate modelling, no detrimental impact from tailings for 10,000 years.

Closure planning is subject to continual revision as results of closure studies become available, and from continual assessment of implementation activities to ensure feasibility and a best practice approach to all closure activities. A schedule of all closure tasks is presented for each domain/activity within Section 9 and in Appendix 9.1.

The closure implementation plan factors in a number of contingency options for implementation in the event that the preferred option cannot be implemented or fails to achieve the desired outcome. The majority of these options are discussed in Section 6 as part of the best practical technology assessment with some specific contingencies further outlined in Section 9.

The proposed closure strategy is subject to ongoing review based on the outcomes of closure studies and assessment of implementation activities to ensure feasibility and a best practice approach.

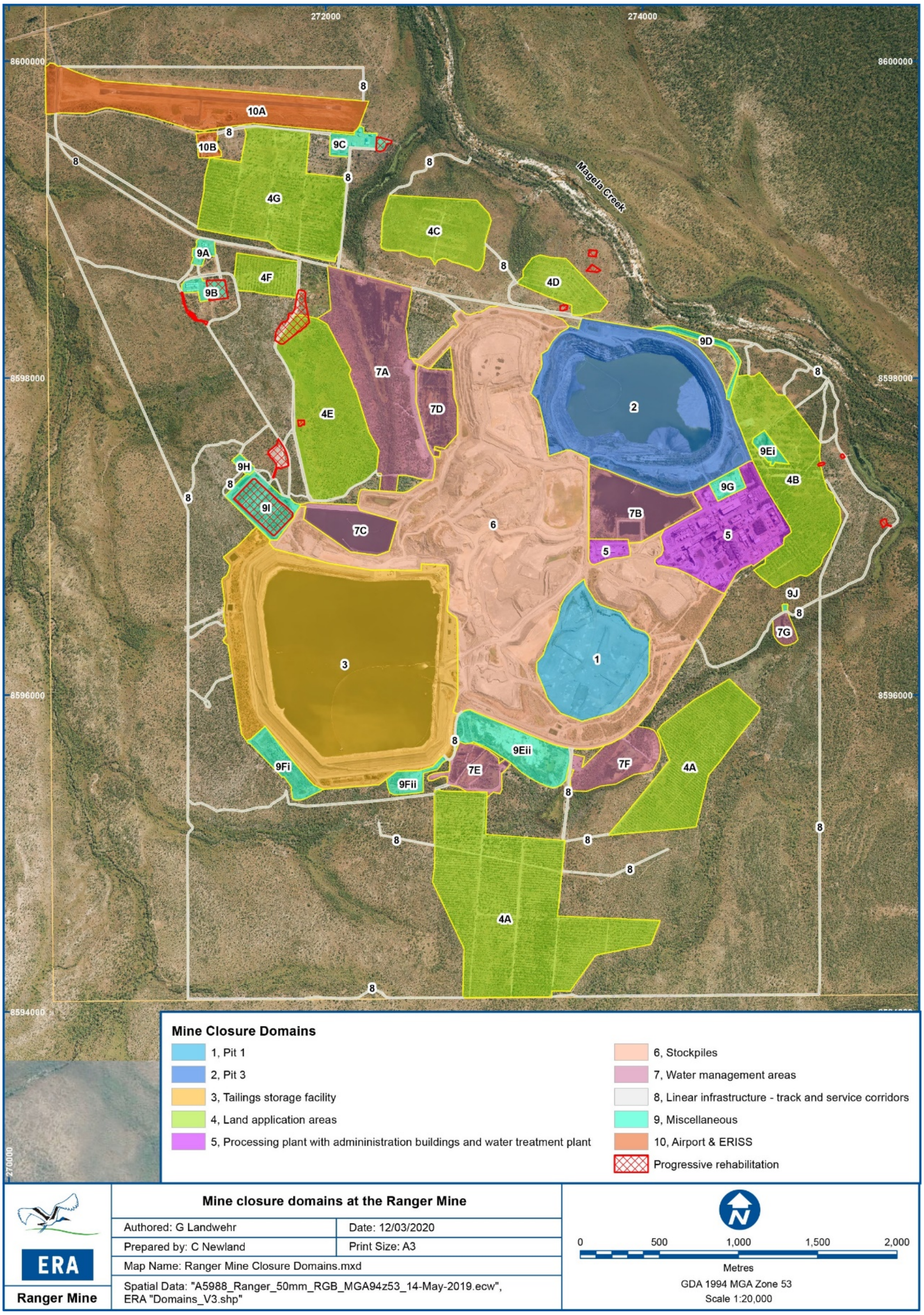

Figure ES- 4: Ranger Mine closure domain map

Table ES- 2: Closure implementation work program summaries

Area	Summary of closure implementation
Pit 1	ERA commenced deposition of neutralised tailings into Pit 1 in 1996 following an application to the MTC, approved by the NT Minister in 1995. Following the installation of prefabricated vertical drains (wicks) to promote consolidation in 2012, Pit 1 backfill activities commenced. Placement of waste rock to cap the tailings has now been completed with the final landform contouring and ripping scheduled to be completed by later in 2020. Revegetation activities will commence, with initial planting to occur during the 2020/2021 wet season. Water is removed from Pit 1 via the decant wells. Based on the results of the settlement monitoring it is expected that pumping from the wells will cease in late 2020.
Pit 3	Open-cut mining in Pit 3 commenced in July 1997 and ended in November 2012. Tailings deposition into Pit 3 commenced in 2015 and is estimated to end by December 2020, this will be followed by activities to facilitate tailings consolidation, as in Pit 1. Tailings deposition methods have been trialled and modified to improve consolidation and increase the likelihood of achieving the target closure date. Levels are managed so as to maintain the pit as a hydraulic sink and prevent outflows of solutes to groundwater. Decant wells will be installed during backfill options for tailings dewatering/consolidation. Prior to the placement of tailings in Pit 3, 33 Mt of waste rock was backfilled into the base of the pit to provide a flat surface for tailings deposition. This waste rock underfill was also designed to be a reservoir for long-term brine disposal. Brine is produced during process water treatment in the Brine Concentrator. Brine injection wells are installed to allow for placement of the brine into Pit 3 underfill and were operated for a short period in 2016 before being turned off due to issues with the underdrain bore. The underdrain bore has now been refurbished and brine injection is expected to re-commence later in 2020. Following completion of tailings deposition, pit capping will commence with works similar to Pit 1; including installation of prefabricated vertical drains (wicks), geofabric and an initial cap. Once sufficient geotechnical strength is obtained in the initial cap, bulk backfill will commence, followed by surface contouring to the final landform shape and revegetation. The bulk backfill of Pit 3 is scheduled to commence in 2023 with revegetation completed in November 2025.
TSF	To enable ERA to complete closure as planned, the TSF dredged tailings transfer to Pit 3 started in 2015 and will continue through 2020. After completion of tailings reclamation and transfer, the TSF will be cleaned of all visible tailings, infrastructure and foreign objects, prior to use as a process water storage dam. At the cessation of process water storage, the TSF will be deconstructed. The TSF will serve as an important storage facility for water, during Pit 3 closure works and then for disposed infrastructure (dredges) following appropriate decontamination and decommissioning processes. During closure, the TSF will act as a catchment to prevent the outflow of impacted rainwater. The TSF will then be deconstructed and converted to a release catchment. Final landform contouring and revegetation for the TSF site is planned for 2025.

Area	Summary of closure implementation
Water management	Process water, contained within the TSF, is fed to the Brine Concentrator (BC) plant for treatment via induced thermal evaporation. Distillate from the BC is released to the wetland filter system and brine is injected into the Pit 3 for disposal or recirculated to the TSF as required. A High Density Sludge (HDS) plant is available to support the BC and treat additional process water using a two-step process involving the application of lime and soda ash to promote precipitation. HDS permeate is suitable for further treatment within the pond water circuit and sludge disposal within Pit 3. Pond water is currently treated with a series of pond water treatment plants (WTPs), which involve ultrafiltration and reverse osmosis. Pond water treatment plant permeate is distributed to either the wetland systems or to Retention Pond 1 (RP1) for release onto the LAAs. Pond water treatment brine is fed to the Brine Squeezer (BS) for further treatment (reverse osmosis) with waste brine being directed to the TSF and permeate being released to the wetland systems. Modifications to the current water treatment system are being considered to increase the treatment capacity and capability in order to minimise the site water inventory post-closure. The water inventories relevant to closure are those associated with pond water and process water. To enable the successful closure of the Ranger Mine, both the pond and process water inventory on site must reduce to a zero balance, in time to allow for deconstruction of the water storage facilities prior to the closure of the RPA. The process water inventory is actively tracked, and additional water treatment facilities may need to be installed if expected water treatment and inventory targets are not met. The capacity of existing site infrastructure for treating process water is critical to meeting closure target dates and is being reviewed for suitability as closure processes and material volumes become clearer. Rainfall is a variable with the potential to impact closure water management and schedules. Should a number of higher than predicted wet seasons occur, in particular late in the closure project, additional water treatment capacity may be required in order to meet the final closure date in January 2026. Throughout closure, site water flows and facilities will be required for use and need to be managed. However, by January 2026 all water management areas will need to have been rehabilitated and require no active management. These areas include pond water storage, release water storage, wetland filters, water management sumps, land application areas and onsite billabongs that receive release discharge water. The exact timing and methods for rehabilitation of the various water management areas will depend largely on rainfall and the need for their continued use. Currently it is assumed within the closure schedule that all are to undergo rehabilitation toward the end of the closure period, commencing from 2023.
Plant and administration buildings	A decommissioning sequence has been determined for the areas of the plant, based on the interaction of the plant decommissioning with other activities in the overall RPA closure project. Decontamination of assets in the demolition area will be undertaken to allow safe and efficient demolition and disposal. Plant, equipment, buildings and other structures will be removed unless approval of the Traditional Owners and Commonwealth Minister is given for infrastructure to remain on the RPA. Demolished materials will need to be disposed of onsite at 6 m level deep below final landform if disposed amidst waste rock.
Ranger 3 Deeps	The proposed R3D underground mine project was not progressed and the decline was in care and maintenance since June 2015. ERA has now commenced transition

Area	Summary of closure implementation
exploration decline	to final closure. The ventilation shaft, portal and decline will be decommissioned in a staged closure approach with consideration given to geological and hydrological conditions. The first stages of closure of the decline commenced in 2019 with the removal of all infrastructure, the plugging of the base of the vent shaft and the flooding of the underground workings. Final decommissioning is planned for 2021.
Stockpiles	The bulk material movement of all waste rock to final destination and the construction of the final landform has been considered within the Ranger Mine closure Feasibility Study. A dynamic mine model, including haulage simulations, has been created to assist in producing the closure strategy. This confirmed a complex sequence of material movements to ensure all mineralised material ended up in the right part of Pit 3 and that access is not constrained. In 2008 an extensive stockpile block model was developed. The block model has been maintained, tracking locations of sources and destinations of materials since that time. Mineralised material stockpiled for processing will be processed prior to commencement of closure. All mineralised material not processed at the completion of milling in January 2021 will be placed well below final landform surfaces. Low 1s (non-mineralised material) has been scheduled to be used for final landform surface.
Other areas	Other areas subject to closure implementation and addressed in this MCP include: • waste material management • linear infrastructure • miscellaneous non-plant buildings • nursery and core-yard • Magela levee Under current legislation, ERA is obliged to rehabilitate the airport precinct. ERA is in consultation with key stakeholders regarding the ongoing operation of the airport. The ERISS offices and external services (Telstra) facilities are excluded from the Ranger Mine Closure Plan.
Contaminated sites	Soil remediation across the RPA will occur prior to decommissioning and will be based on the *Plume and Contaminated Site Management Plan*, refer section 5 above and Section 5 within the body of the MCP. Works have been undertaken to identify and risk rank potential contaminated sites. Remediation strategies have been broadly developed, including identification of further works to further define requirements. Remediation activities will be considered in relation to other closure activities for efficiencies and to avoid double handling of potentially contaminated sites. A schedule of rehabilitation of contaminated sites will be prepared at a later date based on the outcomes of ongoing work and further refinement of the closure schedule.
Final landform	A number of landform studies have been undertaken to address key closure issues and risks to inform the design parameters of the final landform and 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

Area	Summary of closure implementation
	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. The final landform design continues to mirror the original topography as much as possible. The model addresses: • total material available for closure works • flood modelling for erosion • control of infiltration • control of sediment movement • outcomes from land evolution modelling conducted by the SSB. The surface layer to form the final landform will be constructed as 1s waste rock (non-mineralised) to ensure that radiation doses from the final landform are ALARA and to facilitate successful rehabilitation. To achieve the revegetation objectives, plant available water, depth and heterogeneity of the waste rock surface layer, material chemical characteristics, and surface treatments to optimise nutrient cycling have been considered when developing the design and construction of the surface layer. The final landform construction of Pit 1 has been completed. The remainder of the final landform construction will not commence until March 2023 and will be ongoing to enable areas to be released progressively for revegetation. This will enable revegetation works to be completed by the completion of closure milestone (8 January 2026).

Revegetation strategy	There is approximately 1062 ha of land to rehabilitate and revegetate for the successful closure of the Ranger Mine, including 795 ha of waste rock covered area.
	Revegetation will be guided by the ERA revegetation strategy (Appendix 5.1) that was developed utilising knowledge from over 30 years of revegetation trials, analogue vegetation studies and particularly the findings from the trial landform. Ongoing monitoring of the trial landform will continue to inform the final approach to revegetation of the RPA.
	A key consideration of the closure strategy was to provide progressive handover of final landforms to facilitate achievable revegetation production rates for contractors. A maximum rate of 1.5 ha/day revegetation day was set as a target, with the schedule commencing in April 2023.
	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 and tubestock production. The initial revegetation process broadly includes:
	• planting design (planting density and distribution according to domain).
	• seed collection and plant production.
	• revegetation activities:
	  ○ site preparation (herbicide application, irrigation installation, planting site cultivation)
	  ○ tubestock planting (hole digging, fertiliser application, planting, watering in and/or irrigation).

Area	Summary of closure implementation
	Revegetation domains will be developed to reflect any physical and/or chemical constraints that may impact the type of revegetated ecosystem that is able to be re-established. These 'revegetation domains' will each have a suitable 'agreed conceptual reference ecosystem' identified, which will form the basis of the species list and target densities for revegetation planning and implementation. Whilst the conceptual reference ecosystems are yet to be finalised, the intention is to revegetate the majority of the landform post mining with open eucalypt-dominated woodlands that have similarities to the native vegetation typical of the surrounding areas near Ranger and within Kakadu National Park. In the meantime, a list of agreed tree and shrub species has been developed based on reference site monitoring, revegetation trials, and cultural consultation with Traditional Owners and forms the basis of current revegetation planning Over 60 species are currently being considered for initially establishment as tubestock, with a nominal planting density of 1,000 stems per hectare to allow for attrition during plant establishment and subsequent ecosystem development.

10 CLOSURE MONITORING AND MAINTENANCE

The monitoring programs developed for the Ranger Mine have been detailed in Section 10 and are designed to assess performance against the closure criteria.

The Ranger closure monitoring programs align with six closure criteria themes. The closure monitoring programs proposed build upon the existing, extensive monitoring regimes established during mining operations at the Ranger Mine. The closure monitoring program is required to assess rehabilitation success, including determination of the protection of potentially impacted ecosystems and environmental values.

Monitoring has already commenced as part of the progressive rehabilitation activities during operations and will continue into closure. The closure monitoring program will enable an adaptive management approach to site rehabilitation to inform performance strategy. The monitoring program will provide ongoing feedback of the site rehabilitation performance allowing for the refinement of the closure plan as required.

Monitoring programs associated with closure studies will also continue throughout the operation and closure phases.

The monitoring and maintenance program is initiated following the successful completion of closure (decommissioning and rehabilitation). This monitoring phase will occur after January 2026 when the site is progressing towards the development of a long-term stable landform and self-sustaining ecosystem that meets the closure objectives.

The focus of landform monitoring and maintenance program will be erosion control, and design of the program will utilise information derived from the TLF studies. Surface water monitoring in the post-closure period is required to assess rehabilitation success including identifying any unexpected events or COPC concentrations (compared to model predicted results), and assessing the protection of ecosystems, human health and environmental values by comparison of water quality against closure criteria (when agreed).

The aims of the post-closure surface water monitoring program are to:

- assess whether closure criteria are met, or if water quality is transitioning toward meeting criteria
- provide assurance that the environment is being protected
- validate and assess confidence in, the solute transport predictive models

The proposed surface water monitoring program details include the location, parameters, relevant closure criteria and frequency of sampling, and is applicable to both the closure and monitoring and maintenance phases.

The primary objective of the closure groundwater monitoring program will be to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and the regional groundwater environment remains protected. 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 proposed groundwater monitoring will comprise monthly measurements of standing water level and quarterly sampling and chemical analysis. The aim of groundwater monitoring 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. A representative sample of bores will remain for the groundwater monitoring program post-closure. As the groundwater environment stabilises, it is proposed that monitoring frequency requirements will decrease over time if no risks are identified.

Radiation monitoring, undertaken for the purposes of assessment of closure criteria, will be limited during the closure phase. The proposed 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 (e.g. radioactive dust)
- inhalation of radon progeny (Potential Alpha Energy Concentration)
- ingestion of radioactive material in (or with) food or water, and
- external irradiation from gamma rays (and beta particles).

Soil remediation at contaminated sites within the RPA will be monitored to confirm successful achievement of closure criteria.

Revegetation and fauna monitoring and maintenance will begin following initial planting. The majority of the infill planting and understorey planting activities will occur during the monitoring and maintenance phase. Initial annual monitoring may involve recording every planted stem, or belt transects, point centred quarter or other techniques to sample a subset of the stems. Some permanent plots will be established and repeatedly measured to gather information on rates of change of various attributes over time. Fixed photo points will be used to provide a visual representation of revegetation progress. For the initial monitoring attributes, consistent methods will be used each year, to enable comparisons over time and between sites, and into the long-term monitoring program.

As the vegetation matures, monitoring of species composition and density will remain essential, whilst other aspects related to ecosystem structure and function will become increasingly important. Attributes to be measured as part of this long-term monitoring program may include occurrence of flowering and fruiting, presence of understorey (including weeds) and leaf litter, canopy cover, tree height and diameter at breast height. Monitoring will also include aspects other than vegetation, such as surveys for fauna, pests, weeds and erosion.

Monitoring of established, maturing ecosystems will focus on comparison with closure completion criteria attributes, and will gradually provide a developmental trajectory including predictive trends towards achieving the criteria.

The fauna criteria is in draft and will require further studies and stakeholder consultation. Once closure criteria is finalised, appropriate monitoring plans will be developed. Monitoring of fauna recolonisation may be more suitable on a campaign (e.g. five-year) basis in the mature revegetation (along with similar surveys of the reference sites).

Alongside the development of the cultural closure criteria, consultant linguist Murray Garde 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. 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.

The GAC and the 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. The GAC and the NLC have been working with Traditional Owners and Murray Garde to build on previous work completed. Once GAC and NLC have finalised the proposed process, it will be reviewed by ERA and incorporated into future revisions of the MCP.

11 FINANCIAL PROVISION FOR CLOSURE

The ERA rehabilitation provision as at 30 June 2020 was $744 million.[5] The calculation of the rehabilitation provision relies on estimates of costs and their timing to rehabilitate and restore disturbed land to original condition.

The costs are estimated on the basis of this MCP and the closure model, taking into account considerations of the technical closure options available to meet the obligations of ERA. The provision for rehabilitation represents the net present cost at 30 June 2020 of the preferred plan within the requirements of the Ranger Authority.

The closure model is based on the closure feasibility study, completed in February 2019, which expanded on the previous prefeasibility study (PFS) completed in 2011. Key packages of work completed since 2012 include preliminary Pit 3 backfill, Pit 1 capping and design, construction and commissioning of the tailings dredging system. The Feasibility Study has increased the level of certainty regarding forecast rehabilitation expenditure.

Major activities for the execution of the rehabilitation plan include: material movements, water treatment, tailings transfer, demolition and revegetation. Major cost sensitivities include material movements, water treatment and tailings transfer costs.

The ultimate cost of rehabilitation is uncertain and can vary in response to many factors such as technological change, weather events and market conditions. It is reasonably possible that outcomes from within the next financial year that are different from the current cost estimate could require material adjustment to the rehabilitation provision for the RPA.

Separate to this MCP, each year ERA prepares and submits an Annual Plan of Rehabilitation (APR) to the responsible Commonwealth Minister for assessment and approval in accordance with the Ranger Uranium Project Agreement between ERA and the Commonwealth Government (Government Agreement). The specific purpose of the APR is to determine the securities amount to be held by the Commonwealth Government for rehabilitation obligations; these funds are held in the Ranger Rehabilitation Trust Fund. Once the APR is accepted by the Commonwealth Government, the APR is independently assessed and costed and the amount to be provided by ERA into the Ranger Rehabilitation Trust Fund is determined.

12 MANAGEMENT OF INFORMATION AND DATA

This section provides an overview of the information management systems used by ERA to manage closure-related data.

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

[5] The 30 June 2020 provision discounted at 2 per cent and presented in real terms ($785 million undiscounted in real terms).

- landform design and construction
- progressive rehabilitation.

The retention and management of this information is important to demonstrate the appropriateness of and adherence to the closure strategy, drive change where required and provide a history with which to inform any future issues.

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. ERA maintains these datasets within its various document management systems.

13 REFERENCES

Department of Mines, Industry Regulation and Safety (2020) Mine closure plan guidance – how to prepare in accordance with the Statutory Guidelines – March 2020.

http://www.dmp.wa.gov.au/Documents/Environment/REC-EC-112D.pdf

ERA Energy Resources of Australia Ltd

1. Scope and purpose

Issued date: October 2020

Revision number: 1.20.0

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FIGURES

TABLES

APPENDICES

Cover photograph: Coonjimba Billabong

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.
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.

ABBREVIATIONS & ACRONYMS

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

Abbreviation / Acronym	Description
APR	Annual Plan of Rehabilitation
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
GAC	Gundjeihmi Aboriginal Corporation
HDS	High Density Sludge
JTDA	Jabiru Town Development Authority
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
NLC	Northern Land Council
NP	National Park
NT	Northern Territory
RPA	Ranger Project Area
TSF	Tailings Storage Facility
WA	Western Australian

1 SCOPE AND PURPOSE

This Mine Closure Plan (MCP) is prepared by Energy Resources of Australia Ltd (ERA) to describe the plan for the Ranger Mine closure as at 30 June 2020 and meet its regulatory obligations and conditions under Annex B.2 of the Ranger Authorisation 0108-18 (Section 3). The MCP is submitted to both the Minister of Resources, Water and Northern Australia (Commonwealth) and the Minister for Mining and Industry (NT) for approval.

1.1 Background

The Ranger uranium mine (Ranger Mine) (Figure 1-1) is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 km east of Darwin in the Alligator Rivers Region of the Northern Territory (Figure 1-2). The RPA (Figure 1-3) is surrounded by Kakadu National Park (NP) 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.

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 in the 38 years since production began. The Ranger Mine has produced in excess of 130,000 tonnes of uranium (ERA 2019) 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. ERA shares are publicly held and traded on the Australian Securities Exchange, with Rio Tinto, a diversified resources group, currently holding 86.3 per cent of ERA shares.

Operations at the Ranger Mine are governed by both Australian and Northern Territory legislation and regulations. Details of the legal obligations of the closure of the Ranger Mine are detailed within Section 3. The key instrument that governs operations at the Ranger Mine on a day-to-day basis is the authority (the Ranger Authorisation) issued under the 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 operations (section 41 of the Authority). The Ranger Environmental Requirements (ERs) are attached to the section 41 Authority and set out environmental objectives which establish the principles by which the Ranger mining operation is to be conducted, closed and rehabilitated and the standards that are to be achieved. The *Mining Management Act* also requires the Ranger Authorisation to incorporate, by reference, the ERs.

Figure 1-1: Oblique view of Ranger Mine 2019

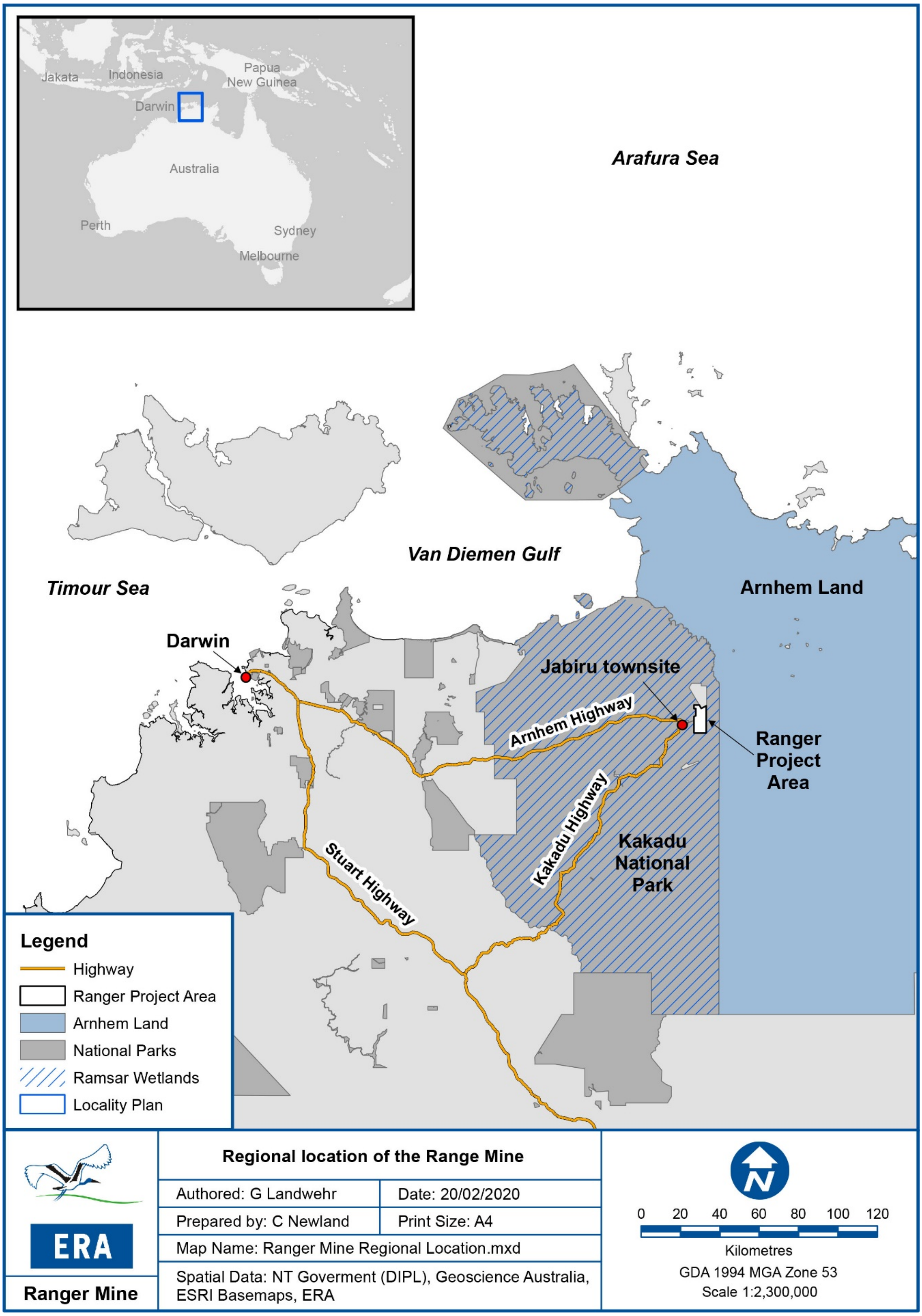
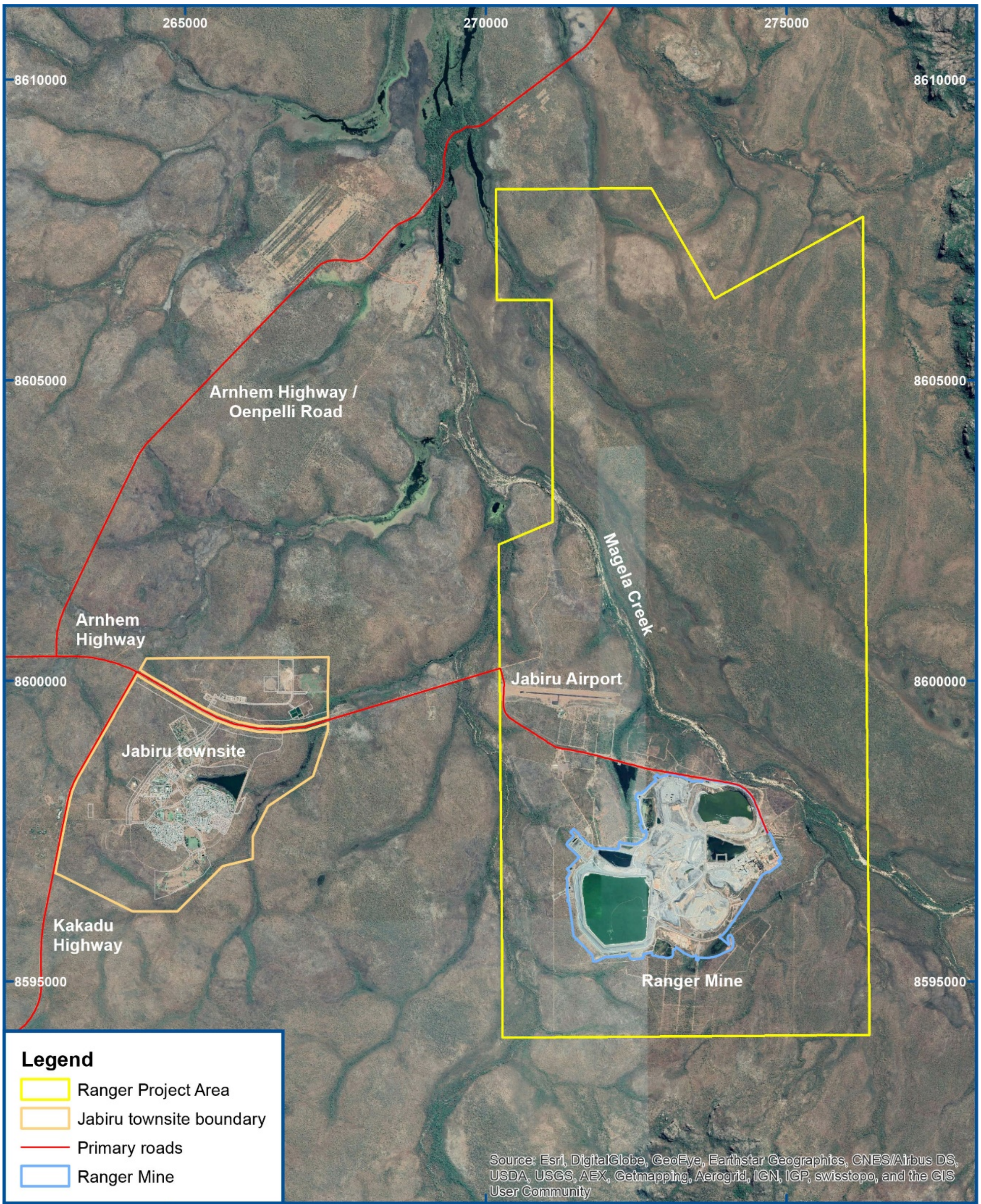


Figure 1-2: Regional location of Ranger Project Area



Ranger Mine	Ranger Mine Project Area		0 1 2 3 4 Kilometres
	Authored: G Landwehr	Date: 24/02/2020	GDA 1994 MGA Zone 53
	Prepared by: C Newland	Print Size: A4	Scale 1:80,000
	Map Name: Ranger Mine Project Area.mxd		
	Spatial Data: ESRI Basemap, NT Government (DIPL), ERA, Geoscience Australia		

Figure 1-3: Ranger Mine Project Area

1.2 Purpose of this MCP

This MCP has been prepared as part of the ERA obligations under the *Ranger Authorisation 0108-18.* It describes the ERA mine closure plan for the Ranger Mine as at 30 June 2020. This plan is the result of the past 40+ years of extensive scientific research, engineering design and stakeholder consultation. This MCP is an updated version of previous iterations presented to stakeholders (e.g. McGovern 2006, Puhalovich & Pugh 2007 and ERA 2019).

The 2019 MCP represented the updated Ranger Mine closure plan following the finalisation of the closure Feasibility Study for the rehabilitation of the RPA in February 2019 (Feasibility Study). ERA, supported by an experienced engineering service provider, undertook the Feasibility Study to further refine scheduled rehabilitation activities and plans. 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 from multiple internal and external reviews, including the Rio Tinto Technical Evaluation Group. The plan 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.*

As well as providing a concise description of the closure plan, the MCP includes an overview of the rationale and knowledge base used for the development of the document. It is acknowledged that further studies and works are ongoing, and that these will be utilised to feedback and further develop the annual updates of the MCP. The 2020 MCP is an update of the studies and closure planning from the 12 month period from 1 July 2019 to 30 June 2020.

Mine rehabilitation at the Ranger Mine is governed by several statutory approvals, including the Ranger Authorisation, the section 41 Authority and the ERs. Legal requirements for the assessment and approval of rehabilitation plans are prescribed in each of these documents, as well as separate working arrangements and a memorandum of understanding between the Commonwealth and NT Governments.

1.2.1 Ranger Authorisation and *Mining Management Act*

A variation of the state issued Authorisation (0108) 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') in accordance with Section 34 of the *Mining Management Act*. It is now a requirement that the MCP is reviewed and updated annually with submission to the Commonwealth Minister and the NT Minister due on or before 1 October each year. The MCP must demonstrate closure activities will achieve the relevant ERs and include:

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

After 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 then provided by these stakeholders to both Ministers. The Commonwealth and NT Ministers are then responsible for approving the MCP.

1.2.2 Section 41 Authority and ERs

The ERs are appended to the section 41 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:

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.

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 section 41 Authority are more broadly based than those of the Authorisation (discussed in Section 8).

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 and appendices provide further details on the complexities of the legislative framework.

1.2.3 Government agreement

In addition to the statutory obligations outlined above, and separate to this MCP, each year ERA prepares and submits an annual plan of rehabilitation (APR) to the responsible Commonwealth Minister for assessment and approval in accordance with the Ranger Uranium Project Agreement between ERA and the Commonwealth Government (Government Agreement). The specific purpose of the APR is to determine the securities amount to be held by the Commonwealth Government for Ranger Mine rehabilitation obligations, and these funds are held in the Ranger Rehabilitation Trust Fund. Once the APR is accepted by the Commonwealth Government, the APR is independently assessed and costed and the amount to be provided by ERA into the Ranger Rehabilitation Trust Fund is determined. Section 11 describes the current financial provision for closure.

1.3 Scope of this MCP

This MCP covers the RPA (Figure 1-3), which specifically refers to the following areas and assets:

- Ranger Mine infrastructure, mine pit voids, 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
- Jabiru Airport and associated infrastructure and utilities: discussions are progressing between ERA, Traditional Owner representatives and relevant government agencies to plan for the retention and transfer of ownership of the airport for future use. These discussions will include resolution of any rehabilitation obligations. However, in the absence of an agreed plan, ERA will begin a process to close the airport some time in 2021 with rehabilitation likely to commence in 2024.

The MCP is prepared in accordance with the obligations and commitments outlined in Section 3. It is also prepared with reference to mine closure standards and guidelines, also included in Section 3.

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

- the town of Jabiru: The Commonwealth Government's Director of National Parks has leased land for the town to the Jabiru Town Development Authority (JTDA), which has subleased parts of Jabiru to ERA. ERA and the JTDA are also party to a cost sharing agreement. Under these arrangements, which are due to expire in 2021, ERA has certain obligations to remove town assets and rehabilitate the land, if required. Discussions are underway between ERA, the relevant Commonwealth and NT Government agencies and key stakeholders to retain the existing township and associated infrastructure, given its significance as a tourist and business hub for the surrounding Kakadu National Park.

- 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 1-1. This timeline terminology is used throughout this MCP.

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

Operations & Closure Phase	Timeline	Closure Related Activities
Operations	Period prior to 8 January 2021	Progressive rehabilitation occurring, and operational, closure & research monitoring
Closure	Period between 8 January 2021 & 8 January 2026	Decommissioning, completion of rehabilitation groundworks & transition of monitoring requirements
Monitoring and maintenance	Period after 8 January 2026	Completion criteria monitoring (and maintenance rehabilitation works if required) [note – arrangements under which ERA has access to the RPA for this period to be finalised]
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

1.4 Review and updates

As closure activities progress, and at least annually (in accordance with the Ranger Authorisation), this MCP will be reviewed and updated to reflect changes that have occurred. Where a substantial or material change to the closure strategy described herein is required, ERA will submit a revision to the Commonwealth and NT Ministers.

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 Mine Technical Committee (MTC) and the Commonwealth Minister[2]. These activities were identified during the stakeholder workshop held in May 2017. The remaining applications for assessment and approval are listed Table 1-2.

[2] The functions of the MTC and other ERA key stakeholders are described in Section 5.

The 2019 MCP was subject to stakeholder review and detailed feedback has been considered for the preparation of this document (Appendix A). The 2019 MCP incorporated substantive changes in content compared to the 2018 version. This 2020 update has incorporated any updates to closure activities or operations from the period of July 2019 to June 2020, as outlined in the summary of changes table at the front of this document.

In reviewing this 2020 MCP, stakeholders are requested to utilise the form provided in Appendix 1.1 for feedback for consideration in the next annual review process.

Table 1-2: Future applications to be submitted

APPLICATION TITLE	APPLICATION TYPE	PLANNED SUBMISSION DATE	SCHEDULED APPROVAL DATE	CONTENT
Pit 3 closure	Commonwealth Ministerial approval required	November 2020	September 2021	Detail of planned tailings consolidation and isolation, capping layer, wicking and geotextile, backfill. Include contamination transport modelling, contaminated material placement and update of water inventory model.
Final landform	Commonwealth Ministerial approval required	May 2022	March 2023	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).
TSF deconstruction	Commonwealth Ministerial approval required	August 2023	August 2024	Detailed plan of deconstruction of walls, and potential remediation of subfloor.
Completed closure works report	Commonwealth Ministerial approval required	30 June 2026	N/A	Final report detailing all completed closure activities.

1.5 Content and structure of this MCP

Clause B6 of the Ranger Authorisation 0108-18 requires that the MCP must be prepared in accordance with mine closure guidelines accepted by the Commonwealth Minister. The currently adopted guidelines are the Western Australian (WA) 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 1-3.

Table 1-3: 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	An historical overview of the Ranger Mine ore deposits and mine development, including a description of the current mining operations and major mine components/infrastructure. Land disturbances will be provided within Section 9: Implementation.
3. Closure obligations and commitments	Presents the legal obligations, commitments, standards and guidelines as 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 chapter.
5.Baseline and closure date, and analysis	Overview of the existing environment of the RPA in relation to the local and regional setting, including the nearby sensitive receptors. Summary of the extensive studies and research that have contributed to the closure risk assessment, closure criteria and proposed closure strategy. A link of studies to Key Knowledge Needs is included as Appendix 5.4.

Section	Content
6. Post-mining 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 2020).
7. 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.
8. Risk assessment and management	Description and outcomes of the closure risk assessments.
9. Closure implementation	Description of the proposed closure strategy, which was informed by the Feasibility Study, 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, to track the progress of the rehabilitation against the closure criteria. 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 original condition.
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 regarding the 2019 MCP.

1.6 References

Department of Mines, Industry Regulation and Safety 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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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 2020 MINE CLOSURE PLAN STAKEHOLDER FEEDBACK FORM

2020 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 …...*

Energy Resources of Australia Ltd

2. Project overview

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Revision#: 1.20.0

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Cover photograph: High Density Sludge Plant (2019)

FIGURES

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APPENDIX

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.
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 Mine 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 TSF 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
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.
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
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
BC	Brine Concentrator
CCWLF	Corridor Creek Wetland Filter
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
HDS	High Density Sludge

Abbreviation/ Acronym	Description
LAA	Land Application Area
MTC	Minesite Technical Committee
NLC	Northern Land Council
NT	Northern Territory
NP	National Park
OBS	Osmoflow Brine Squeezer
R3D	Ranger 3 Deeps
RL	Reference Level
RP1	Retention Pond 1 - also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
RPC	Release Plan Calculator
SSB	Supervising Scientist Branch
TSF	Tailings Storage Facility
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 the current minesite activities.

2.1 History

The initial discovery of the Ranger Mine deposits was made in October 1969 by an exploration joint venture between Peko-Wallsend Operations Limited (Peko) and Electrolytic Zinc Company of Australasia Ltd (EZ) through aerial radiometric survey. Further drilling confirmed the feasibility of mining two ore bodies, 'Ranger 1' and 'Ranger 3'. In June 1971, Peko and EZ established Ranger Uranium Mines Pty Ltd to manage and develop the deposits.

The grant of a mining lease to allow development of the project was deferred whilst the new Commonwealth Government, elected in December 1972, defined and implemented a policy of public ownership of certain energy resources, including uranium. To comply with the energy resources policy of the Government, Peko, EZ and the Australian Atomic Energy Commission (AAEC), as an agent for the Government, signed the 'Lodge Agreement' in October 1975. Under this agreement: (i) the AAEC retained ownership of the uranium and financed 72.5 percent of the project; (ii) Peko and EZ were to fund the balance in equal shares; and (iii) the AAEC would sell the uranium for the Commonwealth Government, with Peko and EZ entitled to share in 50 percent of the net sales proceeds.

A new Commonwealth Government announced approval of the project under the 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. The Commonwealth Government made the decision to approve the project following the recommendations of the First and Second Reports of the Ranger Uranium Environmental Inquiry, which had been established under the *EPIP Act* (termed 'the Fox Inquiry') into the potential impacts of uranium mining in the Alligator Rivers Region (Fox *et al.* 1976, Hart & Jones 1984a).

At the same time, much of the Alligator Rivers Region was declared a National Park (NP) and Aboriginal people were given a major role in the Kakadu NP management. The Commonwealth Government introduced laws covering the Alligator Rivers Region (*Commonwealth Environment Protection (Alligator Rivers Region) Act 1978*) and established several research bodies and committees to overview the environmental regulation of mining in the region. These included the Supervising Scientist and the Environmental Research Institute of the Supervising Scientist (ERISS), the Alligator Rivers Region Advisory Committee (ARRAC) and the Alligator Rivers Region Technical Committee (ARRTC).[2] In 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

[2] The functions of these committees and research bodies are described further in Section 4.

Commonwealth Government entered an agreement with the Northern Land Council (NLC) to permit mining to proceed.

Construction of the Ranger Mine began in January 1979 and the mine came into full production in October 1981. During the early stages of construction, the Commonwealth Government announced its intention to divest its interest in the project. Peko subsequently established a new company, Energy Resources of Australia Ltd (ERA), to purchase the existing partners' interests.

Mining of the Ranger 1 orebody (Pit 1) was completed in December 1994 and development of the adjacent Ranger 3 orebody (Pit 3) commenced in 1996. Mining in this pit continued through to the end of 2012, after which time ERA has been producing uranium from stockpiled ore.

Uranium product from the Ranger mine is sold to power utilities in Asia, Europe and North America under strict international and Australian Government safeguards[3].

In 2008, ERA announced a significant mineral exploration target, 'Ranger 3 Deeps', of 15 to 20 million tonnes with a potential for 30,000 to 40,000 tonnes of uranium oxide. In 2011, ERA approved the construction of an exploration decline to conduct close spaced underground exploration drilling of Ranger 3 Deeps and works began on constructing the exploration decline in May 2012. On 16 January 2013, ERA submitted a referral and notice of intent under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) and *Northern Territory Environmental Assessment Act*, for the Ranger 3 Deeps underground mine (EPBC 2013/6722). Although an Environmental Impact Study (EIS) was lodged for the proposed mine in 2014 (ERA 2014b), in 2015 ERA announced that the Ranger 3 Deeps Project would not proceed to final feasibility study due to a depressed uranium market and project economics.

2.1.1 Ranger Mine EIS assessment

In February 1974, an EIS was submitted for the Ranger Mine under the repealed *EPIP Act*. Supplements 1 and 2 to the EIS were submitted in May 1975. As outlined above, in August 1977 a new Commonwealth Government announced approval of the project, following the assessment of the proposal via the Ranger Uranium Environmental Inquiry, or Fox Inquiry (Fox *et al.* 1976, 1977).

The draft EIS and supplements described all components of the proposed Ranger Mine, including but not limited to:

- geographic location of the proposed Ranger Mine, uranium ore deposits and estimated U_3O_8 content
- conformance with standard open cut mining practices proposed for ore extraction
- intended milling and processing method

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3 The Nuclear Non-Proliferation Treaty, the Convention on the Physical Protection of Nuclear Material and Australia's other various bilateral cooperation agreements.

- water treatment and management, including descriptions of, for example, Retention Ponds 1 & 2 and water release strategies during operations
- the proposed tailings dam, known as the Tailings Storage Facility (TSF), construction and operation, including future wall lifts, intended to ensure there was always an adequate height of embankment above the water surface in the TSF
- management of potential radiation, air and water pollutants, and
- proposed rehabilitation and the continuing protection of the surrounding region.

The proposed Ranger Mine, as defined in the draft EIS, was fully assessed as part of the Fox Inquiry. The Fox Inquiry made several recommendations including conditions specific to rehabilitation and closure. Further detail is presented in Section 3.

2.2 Overview of operations

Sections 2.2.1 to 2.2.8 provide an overview of the components of the mining and processing operations at the Ranger Mine (Figure 2-1), including the associated key activities and infrastructure. Section 2.2.9 summarises the site wide water management system. Discussion on the closure of Jabiru East area is not included within the Mine Closure Plan.

Conventional open cut mining of uranium ore ceased in November 2012. The processing of stockpiled ore continues through the Ranger Mine processing plant, where uranium is leached from the ore using sulfuric acid. The uranium is then purified, concentrated, precipitated, calcined (dried), placed into drums and exported. Components of the mining and processing operations are shown in Figure 2-1 and Figure 2-2 and include:

- processing plant area, including a power station (which also provides power to the town of Jabiru), administration and maintenance facilities
- one tailings dam (referred to as the TSF)
- two mined-out pits – Pit 1 and Pit 3
- ore and waste rock stockpiles
- several water retention ponds, water storage structures and constructed wetland filters
- water treatment plants
- irrigation areas for the disposal of managed release water
- an access road and service tracks
- Ranger 3 Deeps exploration decline with associated vent shaft and portal, and
- Jabiru Airport, Jabiru East and associated infrastructure.

These components are described in the following sections.

Site layout for the Ranger Mine

Authored: G Landwehr	Date: 24/02/2020
Prepared by: C Newland	Print Size: A3
Map Name: Ranger Mine Site Layout .mxd	
Spatial Data: "A5988_Ranger_50mm_RGB_MGA94z53_14-May-2019.ecw", ERA "Ranger_Mine_Features_V2.shp"	

Ranger Mine

0 500 1,000 1,500 2,000
Metres
GDA 1994 MGA Zone 53
Scale 1:20,000

Figure 2-1: Ranger Mine site (aerial 2019)

ERA	Ranger Mine	Site layout for the processing plant at the Ranger Mine				N	0 100 200 300 400 Metres GDA 1994 MGA Zone 53 Scale 1:3,500
		Authored: G Landwehr	Prepared by: C Newland	Date: 24/02/2020	Print Size: A3		
		Map Name: Ranger Mine Site Layout Processing Area.mxd					
		Spatial Data: "A5988_Ranger_50mm_RGB_MGA94z53_14-May-2019.ecw", ERA "Ranger_Mine_Features_V2.shp"					

Figure 2-2: Ranger Mine plant layout

Site Layout

01, Car Park
02, Security
03, Bulk Fuel
04, Shellsol
05, Simon Carves Yard
06, Water Management Yard
07, Ammonia Handling
08, Emergency Dump Tank
09, Calciner & Product Packing
10, Solvent Extraction
11, Sand Filters
12, Administration
13, Water Management & Environmental Services
14, Engineering & Supply
15, Ranger 3 Deeps Portal
16, Decline Laydown Area
17, Ranger Closure 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
79, ROM

Ranger Mine	Index for Site Layout Figures - Ranger Mine			
	Authored: G Landwehr	Prepared by: C Newland	Date: 24/02/2020	Print Size: A3
	Map Name: Ranger Mine Site Layout Index.mxd		Spatial data: ERA "Ranger_Mine_Features_V2.shp"	

Figure 2-3: Index for site layout figures (2-1 & 2-2)

2.2.1 Mining

Mining activity at the Ranger Mine involved a conventional open cut process, which commences with drilling and blasting. Pit 1 was mined out in 1994 and mining in Pit 3 ceased in November 2012. Prior to the completion of mining in the pits, mined material was categorised by a discriminator, which measured the uranium grade for either stockpiling or immediate processing (Table 2-1). Low-grade ore and non-mineralised rock was stockpiled and will be returned as backfill to the mined-out pits and contoured to create the final landform.

Table 2-1: 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	Non-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

2.2.2 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 hours, more than 90 percent of the uranium in the ore is dissolved using sulfuric acid and pyrulosite (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 TSF, 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, which is a dark green powder.
- The product is packed into 200 litre steel drums. These are sealed and transported by road, using an accredited transport company, to a secure holding facility and then exported by ship.

2.2.3 Ranger 3 deeps exploration decline

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 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' (or R3 Deeps).

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, 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.

ERA received approval from both the Commonwealth and Northern Territory Ministers in April 2019 to commence rehabilitation and closure of Ranger 3 Deeps. Works to commence rehabilitation commenced immediately after approval of the plan. The 2019 rehabilitation works program included the removal of infrastructure and subsequent backfilling of the vent shaft access. The decline was then allowed to flood naturally flood to -25 mRL. This was undertaken by the end of June 2019. Since this time Ranger 3 Deeps has been in reduced care and maintenance. Further information is provided in Section 9.3.9.2.

2.2.4 Tailings storage

The Tailings Dam (TSF), Pit 1 and Pit 3 have been approved for the storage of tailings and process water in accordance with relevant conditions prescribed in the Ranger Authorisation (Section 3). Tailings are deposited to achieve the maximum practicable density, and both subaqueous (below water surface) and subaerial (in air) deposition methods have been used.

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

2.2.5 Tailings Dam (TSF)

The Ranger Tailings Dam was commissioned in 1980. The dam is classified as a “ring dyke” tailings dam and is in the form of an approximate square with sides of about 1 km in length. The initial dam design was based on a proposed crest level of 51.0 mRL[4]. Designed structural additions have allowed the crest level to attain 60.5 mRL. The eastern, southern and western walls run along ridges approximating catchment divides which separate Coonjimba Creek from adjacent surface water catchments, including Gulungul Creek to the west and the Djalkmarra and Georgetown catchments to the east.

Neutralized mill tailings were deposited within the tailings dam 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 again directed to the Ranger Tailings 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 Ranger Tailings Dam were estimated at 27 Mt.

Tailings management was initially subaqueous due to concerns with radon gas emissions. In 1987 tailings deposition within the dam 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”.

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

Performance of the dam is monitored and inspected annually by independent engineers, in accordance with the Ranger Authorisation. It is 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.

2.2.6 Pit 1

Approximately 18 million tonnes of ore were mined from Pit 1 between May 1980 and December 1994. Tailings deposition into the pit commenced in 1996, to an average height of +12 mRL, until deposition ceased in November 2008.

The proposed method and level of unconsolidated tailings deposition in Pit 1 was described in two applications to the MTC submitted in 1995 and 2005, respectively (ERA 2014a). The first

[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 TSF or depth of Pit 3.

application proposed the deposition of neutralised tailings to 0 mRL; the second application proposed tailings deposition to +12 mRL. Both applications received ministerial approval and were the precursor to the bulk backfill activities currently underway.

Between 1996 and November 2008, ERA deposited approximately 25 million tonnes of tailings into the pit. Pit 1 then functioned as a process water storage facility until 2012. Since then, various works have been undertaken to expedite pit tailings consolidation and facilitate bulk backfilling and landform development. The two latter activities commenced after ERA received Northern Territory (NT) and Commonwealth regulatory approval (via the MTC) for a predicted final average tailings consolidation level in the pit of approximately +7 mRL in March and April 2017, respectively.

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

2.2.7 Pit 3

Open-cut mining in Pit 3 commenced in July 1997 and ended in November 2012 with a base (floor) elevation of -265 mRL. In order to use the pit for tailings storage to achieve a good rate of rise and consolidation of the tailings, the pit was backfilled with 33.7 million low-grade ore and non-mineralised rock (known as underfill) to an approximate elevation of -100 mRL. The void within the underfill is being used for storage of residue from 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.

An application to backfill Pit 3 was submitted in November 2006 and approved in June 2007 by the NT Minister. The application sought approval to backfill Pit 3 *"… to an average interim fill level of ~RL-20m during the period from 2009 until 2014 …"* Following a pit expansion in 2007, and further advice to the MTC (e.g. Shell 50), it was indicated that the pit tailings would likely be significantly lower than the original predicted height.

The 2006 application was followed up with a "notification" submitted in August 2014, on the *"Assessment of Potential Environmental Impacts from an 'Interim' Final Tailings Level of RL-20 m in Pit 3" (ERA 2014a)*. The predicted modelling was based on *"… the designated maximum tailings (RL-20 m) and maximum brine (RL-118 m) levels within Pit 3 as a constant level over the full 10,000 year assessment period. In the case of the Pit 3 tailings level this is a very conservative assumption as the expected average tailings level in 2026, after consolidation, is expected to be RL-30.2 m."*

The transfer of tailings from the mill to Pit 3 began in early 2015 and will cease when mill processing stops. Dredging and tailings transfer from the TSF commenced in December 2015. All TSF tailings transfer resulting from routine dredging or the final TSF floor and wall clean will be completed in 2021.

In April 2019, ERA submitted an MTC application to seek approval to modify the dredged tailings deposition method from subaerial to subaqueous, and consequently to modify the final maximum tailings level from -20 mRL to -15 mRL at the end of deposition. Approval was received in August 2019 to increase maximum tailings level to -15 mRL, applying specifically to the discharges from the fixed mill deposition spigots situated along the south and eastern pit perimeter. A tailings deposition level of -20 mRL was instated as the final average level of deposited tailings. This approved final deposition level was further increased in August 2020 to maximum height of -10mRL across the pit. This increase acknowledges the limitations on ERA that all remaining tailings must be deposited in Pit 3 and recognises that the risk to the offsite environmental during deposition is low provided process water levels in Pit 3 remain below 3.5 mRL.

The most recent modelling (August 2020) indicates that the combined tailings from the mill and TSF will fill the Pit 3 void from a starting elevation of approximately - 100 mRL to a maximum of approximately -13 mRL and an approximate level across the majority of the pit of -15.8 mRL at the end of deposition. Approximately 37 million tonnes of tailings have been deposited into Pit 3 since the beginning of tailings deposition in 2015.

2.2.8 Stockpiles

Several stockpiles comprising of ore grade material and waste are situated within the vicinity of the mine pits and the TSF. Approximately 21 million tonnes of ore will be processed from these stockpiles, whilst about 252 million tonnes of waste exist within the stockpiles, which will be used for backfilling of pits and shaping of the final landform for closure.

Throughout the mine life, the stockpiles have been segregated according to both grade and material type. Details of grade segregation is provided in Section 2.2.1.

Three main material types are used: primary, weathered and laterite. Primary material consists of unweathered host rock, which consists 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 that is generally 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 with the primary material being fed to the processing plant. In more recent years, a separate laterite processing circuit was developed that allowed this material to also have uranium recovered.

2.2.9 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. It encompasses all aspects of water capture, storage, supply, distribution, use and disposal. Water is managed according to the Ranger Water Management Plan, which describes the method used to control water on site (ERA 2019). 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 both the wider environment and Magela Creek from the impacts of mining and processing operations

- meet all current statutory requirements
- manage water inventories and discharge mechanisms based on water quality according to the whole of mine approach rather than the source of the water
- 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 2-2).

The Ranger Mine footprint is divided into catchment areas (Figure 2-8) which generate surface runoff and/or seepage as a result of incident rainfall. Each catchment may comprise of several elements such as retention ponds, sumps, collection basins and groundwater interception ponds. The water circuit for the Ranger Mine, including the five water classes, the different treatments and water management features, are shown in Figure 2-10. A description of the individual water management elements is provided in the following sections.

Figure 2-5: Corridor Creek wetland filter (CCWLF)

2.2.9.1 Retention ponds

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

- Retention Pond 1 (RP1) (capacity = 390 ML) comprises 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 (Figure 2-1, 59).
- Retention Pond 2 (RP2) (capacity = 1,150 ML) comprises 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 (Figure 2-1, 42).
- Retention Pond 3 (RP3) (capacity = 61 ML) is an earthen impoundment within RP2. Water from RP3 is transferred to RP2 via a spillway and pumped for use on site (Figure 2-1, 43).
- Retention Pond 6 (RP6) (capacity = 976 ML) is a turkey-nested, double-lined pond that receives water from RP2 transfers and rainfall (Figure 2-1, 56).

Table 2-2: Water classes and their management

Water class	Description and treatment
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.
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.
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 (Figure 2-8).
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.

Water class	Description and treatment
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. 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.
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

2.2.9.2 Water treatment plants

Ranger Mine operates three water treatment plants to treat excess pond water to a level suitable for release to the environment. All water treatment plants are currently configured to treat only pond water to a required standard for release or disposal via land application. The treatment process of pre-filtration followed by reverse osmosis results in four distinct streams that may be directed to specific destinations: permeate, backwash from pre-filtration, chemical clean water and water treatment plant brine.

Figure 2-6: Water treatment area at Ranger Mine

2.2.9.3 Brine Concentrator

The BC was commissioned in September 2013 with the capacity to produce 1.83 GL per annum of clean distilled water (distillate) by using mechanical vapour recompression technology to evaporate water sourced from the process water inventory (Figure 2-7). Distillate from the BC is discharged through the Corridor Creek Wetland Filter prior to release to Magela Creek, with brine currently transferred direct to the TSF. In 2015, ERA completed the installation of five injection bores from the surface of Pit 3 to the underfill. The purpose of the injection system is to pump brine from the BC directly into the underfill layer at the base of the pit for final storage.

2.2.9.4 Brine Squeezer

Commissioning of the Brine Squeezer began in June 2019 and is expected to be fully operational by the 2020/2021 wet season. The Brine Squeezer has been approved to treat both pond and process water. The Brine Squeezer provides an additional stage of treatment for the treatment of pond water through the water treatment plants (WTP) 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 BC. However, the WTP brines are less concentrated than process water (less than 25 percent brine of process water concentration), and treatment via the Brine Squeezer is more cost effective than treating WTP brines alone. More detail on the Brine Squeezer is included in Section 9.4.3.3.

2.2.9.5 High Density Sludge plant

The High Density Sludge plant was built in 2005, overhauled in 2009 and recently recommissioned following a period of inactivity, due to the installation of the BC. ERA has obtained approval to operate the recommissioned plant with discharge of the product water to the pond water inventory. Provisional approval has also been obtained to direct the product water on to the pond water treatment plant 1 (WTP1) to complete additional test work on the product water quality. It is expected that the confirmation of this water quality will occur in the second half of 2020, with the permeate then being approved for release.

The HDS plant treats process water, through to a water quality similar to pond water, through two stages of softening. The process creates a sludge which is discharged from the HDS plant into the processing plant neutralisation tank and then pumped to Pit 3 via existing mill tailings pipeline. Within Pit 3, the sludge will be co-disposed with mill and dredge tailings, until the cessation of mill operations. After this, the sludge must be disposed of in an alternative manner. Approval will be sought for the alternative disposal option following a BPT assessment.

Treated water is discharged from the HDS 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.

Further detail on the HDS plant in included in Section 9.4.3.2.

Figure 2-7: Brine Concentrator

2.2.9.6 Release of treated water

Releasing in the wet:

Discharge of treated pond water can be to Retention Pond 1 (RP1), Collection Basin 2 (CB2), Corridor Creek Wetland Filter (CCWLF) and Georgetown Creek Mine Bore L pond (GCMBL) in accordance with regulatory approvals, where applicable. Water can be released from the RPA from the following locations:

- Collection Basic 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 the Magela Creek all of these locations are incorporated in the Release Plan Calculator (RPC) to assist with determining water quality at MG009 during releases.

Releasing in the dry (irrigation):

ERA defines land application as the process by which water (release water, permeate, wetland polished water) is irrigated to the Land Application Areas (LAAs) (Section 2.2.9.8). 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.

2.2.9.7 Wetland filters

RP1 wetland filter comprised a series of earthen embankments forming an impoundment with discrete cells arranged in 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 (passive flow) to RP1, used in land application, used in operations for dust suppression or used 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 2-1, 50). This wetland filter is a combination of natural and constructed wetlands (or cells) with a surface of approximately 17 ha and a total water volume (at full capacity) of approximately 38 ML. 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 brine concentrator distillate (clean water from process water treatment, Section 9.4.3). The wetland filter continues to polish ammonia from distillate.

Figure 2-8: Surface water monitoring points on the RPA

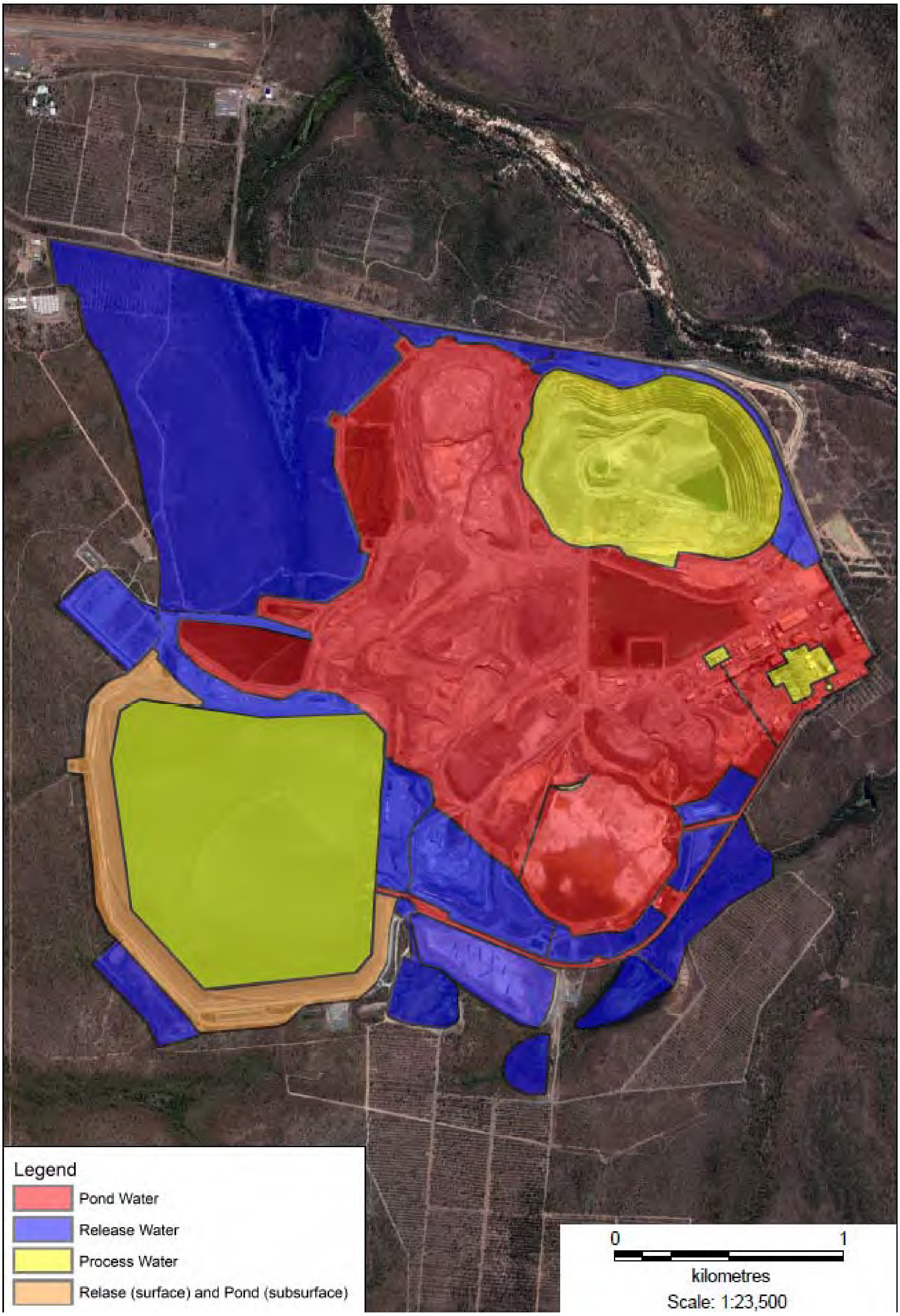

Figure 2-9: General arrangement of water class catchments on the RPA (Deacon 2017)

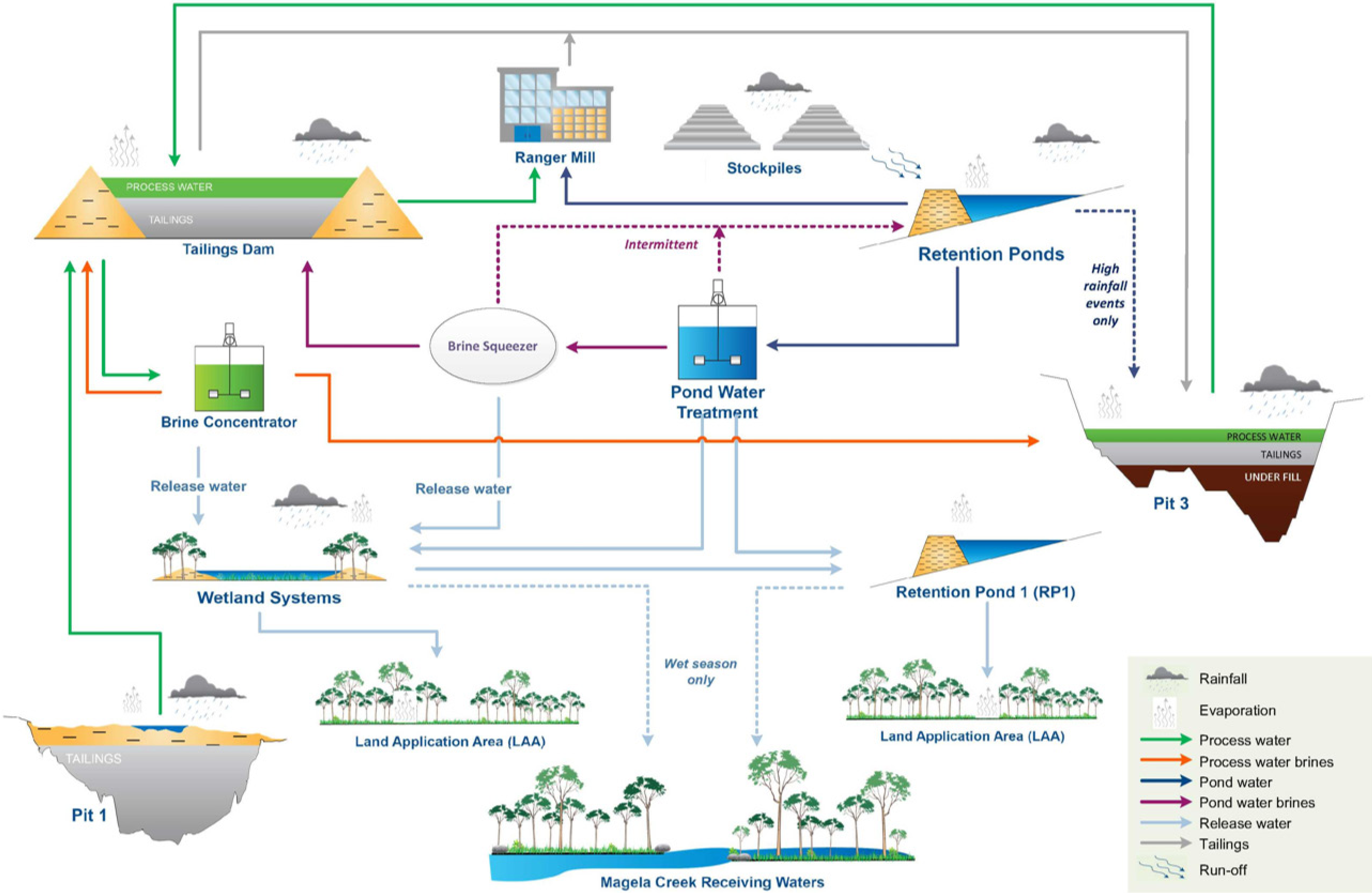

Figure 2-10: Current Ranger Mine water circuit

2.2.9.8 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, thereby maximising evapotranspiration loss whilst minimising surface pooling and seepage, and preventing surface runoff during operations. Table 2-3 provides a generalised description of each operational LAA. Figure 2-11 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.

Table 2-3: 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 hectares. This area receives waters from Georgetown Creek median bund leveline (GCMBL) and Georgetown Creek Brockman Road (GCBR) and is operated during daylight hours only (Figure 2-8). 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 hectares. 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.

Figure 2-11: Land Application Areas

2.2.9.9 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 is implemented using OPSIM, an operational simulation package for the modelling of water resource systems (OPSIM Pty Ltd 2017).

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 2026, as described in Section 9. Elements included are the process and pond water catchments and storages, the water treatment plants, the mill, the BC and planned additional 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, is routinely tested by an annual validation and calibration process that has been conducted since the model was first introduced. This validation and calibration process take advantage of the extensive array of water related measurements at the RPA to reconcile model predictions against actual observations and provides updates to the model which addresses any identified variations. 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.

The forecasting approach used applies multiple sequential periods of historical daily rainfall data to the model, using the multiple periods of historical rainfall 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 30 June 2016.

Typically, median forecasts are used for planning over 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, changes in closure plan tactics and recommendations arising from the annual model validation and calibration process.

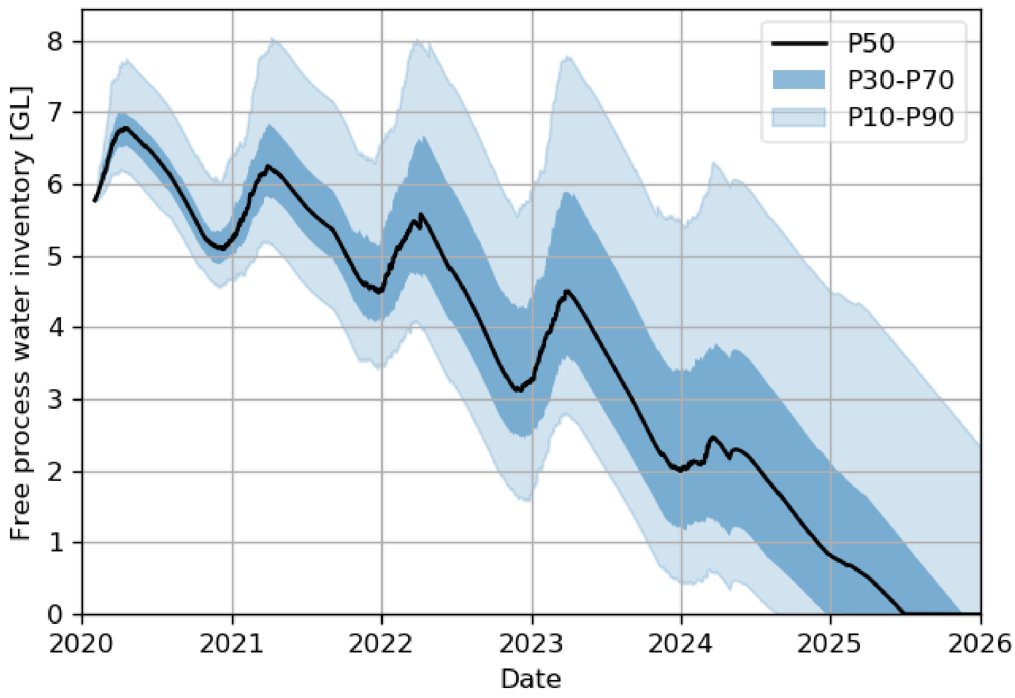

Figure 2-12: Site water model free process water inventory forecast (June 2020)

2.2.10 Jabiru Airport & Jabiru East

Jabiru Airport is located within the RPA at the location know as Jabiru East. The airport caters for light aircraft such as those providing tourist flights, location community charters, medical services and fly in/fly out services from Darwin.

Other infrastructure located with the Jabiru East vicinity include:

- Nursery
- Core storage facilities
- Ranger Mine Village
- Gagadju Yard.

These areas are discussed in Section 9.3.10.

Infrastructure located within the Jabiru East area not to be considered within the Mine Closure Plan consists of:

- Commonwealth Government buildings occupied by the Supervising Scientist Branch (SSB)
- external services (Telstra).

The Commonwealth Government is responsible for the removal and remediation of the Jabiru field station (ERISS buildings) occupied by the SSB . The core yard is included within the closure implementations strategy (Section 9).

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APPENDIX 2-1 WATER MANAGEMENT TERMINOLOGY

TERMS OF REFERENCE (WATER)

TERM	DEFINITION
Water Class	A grouping of a source or inventory of water, based on its properties and management requirements. There are four water classes at Ranger – process water, pond water, release water and potable water.
Process water	All water that either has passed through the uranium extraction circuit; has come into contact with the processing circuit (i.e. milling, leaching, extraction, tailings, washing processes); or has come into contact with a process water storage facility (i.e. TSF, Pit 1 decant and Pit 3 underdrain). The quality of process water is characterised by high dissolved solids. Process water must be contained within a closed system, unless it is treated via an approved process.
Pond water	Water derived from rainfall that falls on active mine-site catchments or disturbed surfaces, that is of a quality which requires active management or treatment prior to release.
Release water	Water derived from rainfall runoff, or the various treatment product streams, which can be released off site without further treatment while complying with regulatory water quality criteria.
Potable Water	Water that can be used for drinking and ablution purposes. Potable water is also used in safety showers, and in parts of the plant where high quality water is required.
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.
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.
Retention Pond	A large constructed storage facility that collects runoff and stores pond water for treatment (RP2 & RP6) or release water post-treatment (RP1).
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.
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.
Land Application Area	A designated area where irrigation of release water may occur during the dry season.
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

TERM	DEFINITION
	Treatment Plants (WTPs), Brine Squeezer (BS) and High Density Sludge (HDS) plant.
Brine Concentrator (BC)	A treatment facility that treats process water by distillation to produce a clean product stream (distillate) and a waste stream (brine).
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).
Brine Squeezer (BS)	A treatment plant that uses reverse osmosis to further process brine generated from the WTPs to recover additional permeate.
High Density Sludge (HDS) Plant	A treatment plant that treats process water (in parallel to the BC) with lime and soda ash to produce a moderately clean product stream (HDS product) and a waste stream (HDS sludge).
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).
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.
WTP permeate	The WTP product stream which has significantly reduced dissolved solids to achieve water quality objectives and regulatory criteria for disposal.
HDS product	The HDS product stream which is of a quality similar to that of pond water. HDS product requires further treatment by the WTPs before it can be considered for disposal.
Treatment waste	The waste stream produced by the 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.
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.
High density sludge	The waste stream generated from the HDS plant which is a mixture of solids such as gypsum and various metal hydroxides, and water. This is directed to Pit 3 or another approved location for final disposal.
Transfer	The process of physically distributing water across the water management system using pumps, pipes, valves and other supporting infrastructure to meet operational requirements.
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).

TERM	DEFINITION
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.
Evaporation	A form of disposal where water is lost as water vapour into the atmosphere.

Energy Resources of Australia Ltd

3 Closure obligations and commitments

Issued date: October 2020

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APPENDICES

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
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.
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	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 NT 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	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 mine closure guidelines	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
BPT	Best Practicable Technology
DITT	Department of Industry Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
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
ICRP	International Commission on Radiological Protection
MCP	Mine Closure Plan
MTC	Mine Technical Committee
NLC	Northern Land Council
NP	National Park
NT	Northern Territory
NTP	Northern Territory Portion
RPA	Ranger Project Area
SSB	Supervising Scientist Branch
TSF	Tailings Storage Facility
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 State and Commonwealth (Cth) 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) (Figure 3-1).

It is implicit that ERA will comply with all necessary legal obligations and uphold internal standards during closure to ensure the ongoing protection of the environmental values surrounding Kakadu National Park (NP), the health and safety of the community and preservation of cultural values. ERA is committed to protecting these values by implementing the required management controls. These management controls are described and discussed in Section 9.

Section 3.1 below provides an overview of the ERA regulatory framework and includes a list outlining ERA key legislative instruments and agreements. A Closure Legal Obligations Register has been developed and included within Appendix 3.2 This register forms a subset of the overarching ERA legal register for all operations at Ranger Mine that are relevant to closure.

3.1 Legislative framework

As outlined in Section 1.2, rehabilitation operations at Ranger Mine are governed by both Commonwealth and Northern Territory (NT) legislation and regulations.

3.1.1 Applicable legislation and agreements

The following Acts and Regulations are relevant to closure activities at the Ranger Mine. 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.

- *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)
- Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council (also under the Atomic Energy Act 1953)
    - Ranger Uranium Mining Project Agreement between the Northern Land Council and ERA (2013)
- 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* –
- 'Mining Agreement' (the Ranger uranium mining project agreement between the 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 (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)
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- *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
- *Heritage Act 2011* (NT)
- IAEA Regulations for the Safe Transport of Radioactive Material
- *Industrial Chemicals (Notification and Assessment) Act 1989* (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* (NT)
    - Licence to transport and store U3O8
- Radiation Protection Regulations 2007 (NT)
- *Territory Parks and Wildlife Conservation Act 1977* (NT)
- Territory Parks and Wildlife Conservation Regulations 2001

- 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*
- 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 following the recommendations of the first and second reports of the Ranger Uranium Environmental Inquiry, which had been initiated under the *EPIP Act* (termed 'the Fox Inquiry') into the potential impacts of uranium mining in the Alligator Rivers Region (Fox *et al.* 1976, 1977 and Hart & Jones 1984a).

The proposed Ranger Mine, as defined in the draft EIS, was fully assessed as part of the Fox Inquiry (Fox *et al.* 1976, 1977). The Fox Inquiry provided the following final recommendations specifically 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 the section 44 Agreement with the Northern Land Council (NLC) under the *Land Rights Act*. The original mining authorisation of the Ranger Mine was granted on 9 January 1979 (as mentioned above) under section 41 of the *Atomic Energy Act 1953 (Commonwealth).* Known as the section 41 Authority, this approval provides the key tenure and land access approval required for the operations.

The section 41 Authority (Cth) established fundamental Environmental Requirements (ERs), which are inclusive of rehabilitation obligations applicable to Ranger Mine. The ERs were appended to the main Commonwealth authority issued under section 41 of the *Atomic Energy Act 1953* (Cth) (*Atomic Energy Act*). In general, the ERs set out 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. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation.

The rehabilitation of Ranger Mine is not subject to assessment under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*. As outlined in Section 43(a) of the *EPBC Act*, certain actions that started prior to 16 July 2000 are exempt from the assessment and approval provisions of the Act.

3.1.3 Northern Territory

As outlined in Section 1.1, the key regulatory instrument that governs operations at the Ranger Mine on a day-to-day basis is the NT Authorisation 0108 (the Ranger Authorisation) issued under the NT's *Mining Management Act 2018* (*Mining Management Act*). The Department of Industry Tourism and Trade (DITT), formally the Department of Primary Industry and Resources (DPIR) regulate 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 Ranger Authorisation and the ERs. Annex A of the Ranger Authorisation includes the

ERs, which includes 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 (Variation of Authorisation 0108-18) includes Annex B which addresses the requirements for submission and assessment of the MCP (this document). 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 repealed by the *EPBC Act* in 2000. Land tenure surrounding the RPA is a combination of Aboriginal and Commonwealth Government freehold land managed through a number of 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 claim to traditional ownership under the Act.

The Mirarr are the Traditional Owners of the land encompassing the RPA. The Mirarr estate encompasses the RPA, 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 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 (Figure 3-1). 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.

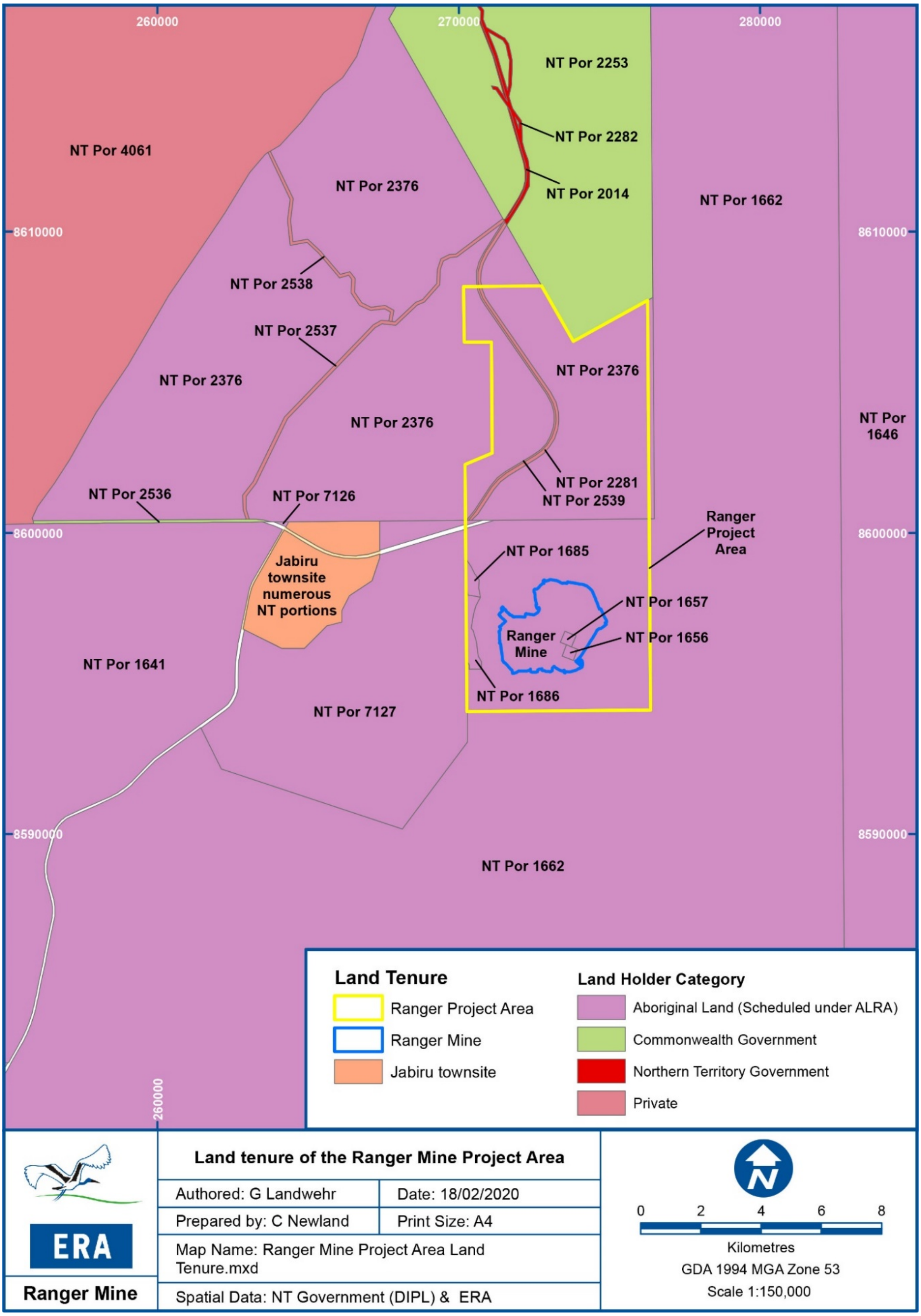

Figure 3-1: Land portions relevant to the RPA

3.1.5 Post-closure tenure and land access

In accordance with schedule 5.1 of the section 41 Authority, ERA must cease/suspend all mining operations by 8 January 2021. Schedule 3 of the section 41 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 section 41 Authority (Schedule 5.2). The rights of ERA to access and occupy the RPA, under the current section 41 Authority, continues until 8 January 2026.

The section 41 Authority requires ERA to undertake a monitoring program "following cessation of operations until such time as a relevant close-out certificate is issued." Following January 2026, rehabilitated areas will undergo stabilisation and monitoring works 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 rehabilitation is completed.

The rehabilitation obligations of ERA will cease over any part of the RPA where a 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 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.

3.1.5.1 Legal framework beyond 8 January 2026

Section 10 of this Mine Closure Plan discusses the need for a period of monitoring and maintenance following the completion of rehabilitation activities. ERA notes that at the present time there are no tenure arrangements in place which provide ERA with ongoing access to the Ranger Project Area (**RPA**) beyond 8 January 2026. Following expiry of the current Section 41 Authority, ERA will require an extended or new land tenure arrangement to enable access for monitoring and maintenance purposes.

ERA also notes that the Environmental Requirements are linked to the current Section 41 Authority. A legal framework is required to preserve the Environmental Requirements until the close-out process has been completed.

ERA has been liaising with Traditional Owner representatives and the Commonwealth to determine an appropriate mechanism and pathway to facilitate access to the RPA and to preserve the Environmental Requirements beyond 2026. This has included detailed discussions regarding proposed amendments to the Atomic Energy Act 1953 (Cth).

ERA supports a minor amendment of the Atomic Energy Act, which would enable ERA to apply for a further Section 41 Authority, as an appropriate mechanism to extend the existing legislative framework. The grant of a new Section 41 Authority by the Commonwealth would meet the objectives of land access for monitoring and maintenance purposes and also maintain the Environmental Requirements as the basis for the close-out of Ranger.

ERA is working with the Commonwealth Government and in consultation with Traditional Owners to finalise an appropriate amendment in a timely way.

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 2014)
- Code of Practice & Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)
- WA Government Guidelines for preparing Mine Closure Plans (DMIRS 2020)
- National standards for the practice of ecological restoration in Australia. Second Edition. (SRG 2018)
- ICMM (2019) Integrated Mine Closure: Good Practice Guide
- 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).

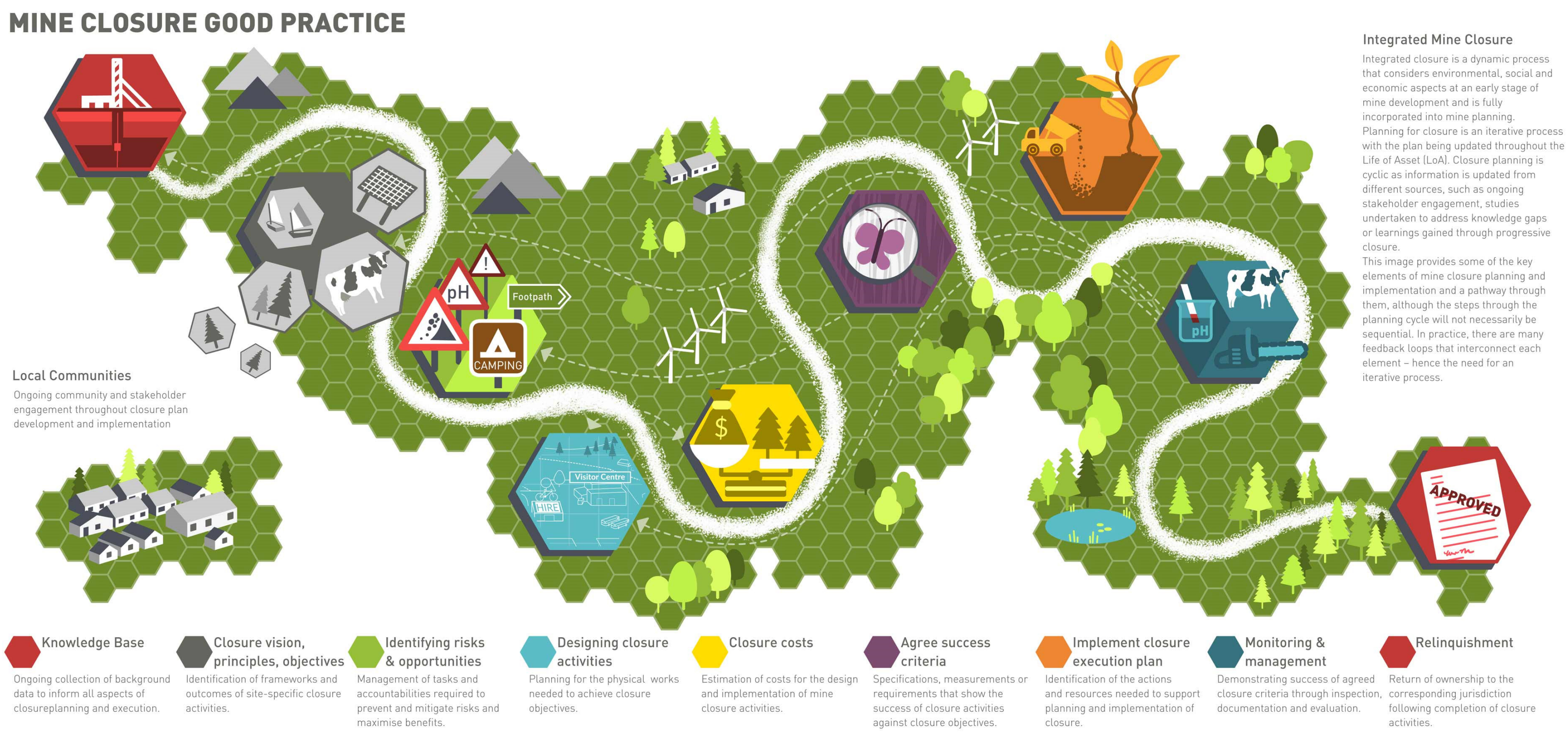

Figure 3-2: Integrated mine closure good practice framework (ICMM 2019)

3.2.1 Corporate policies and standards

ERA and Rio Tinto both have a number of internal Health, Safety and Environmental and Community policies and standards as part of the business model for their operations. The Closure Standard is an element of the Rio Tinto sustainable development framework, designed and developed to incorporate the International Council on Mining and Metals (ICMM) Sustainable Development Framework (Rio Tinto 2014, ICMM 2015). The Rio Tinto internal management applicable to closure, which has been adopted by ERA, include:

- C1 Isolation
- C2 Electrical safety
- C3 Vehicles and Driving
- C4 Working at heights
- C5 Confined spaces
- C6 Cranes and lifting
- C7 Aviation Safety
- D3 Management of slope geotechnical hazards
- D5 Management of tailings and water storage facilities
- D6 Process Safety
- D7 Functional safety (projects)
- H1 Chemicals & hazardous substances
- H2 Noise exposure
- H3 Manual tasks & workplace ergonomics
- H4 Fitness for work in safety critical jobs
- H5 Vector-borne and infectious disease
- H6 Radiation exposure
- E11 Water quality protection
- E12 Air quality protection
- E13 Chemically reactive mineral waste
- E14 Land management & rehabilitation

- E15 Hazardous materials & non-mineral waste, and
- E16 Biodiversity & Natural Resource Management (NRM).

The Rio Tinto Closure Standard (HSEC-B-27) requires each Rio Tinto operation (globally) to develop and implement a plan for closure which sets the minimum requirements. 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 is that the natural and cultural values of the surrounding World Heritage-listed Kakadu National Park 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 other 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 Supervising Scientific Branch (SSB) rehabilitation standards

The SSB drafted nine rehabilitation standards for the Ranger Project Area dated 8 August 2018 (Department of the Environment and Energy, 2018), which are listed in Table 3-1.

Table 3-1: SSB rehabilitation standards for the Ranger Project Area

Closure theme	Rehabilitation standard
Landform	Landform stability and erosion
Radiation	Environmental radiation protection
	Public radiation protection
Water and sediment	Magnesium in surface water
	Uranium and manganese in surface water
	Ammonia in surface water
	Sulfate – (acid sulfate soils) in surface water

Closure theme	Rehabilitation standard
	Other metals in surface water
	Turbidity and sedimentation (in progress)
Ecosystem restoration	Ecosystem restoration (flora, fauna, ecological processes)

These standards will be considered 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 absence of any NT closure plan guidelines to date, this MCP has been prepared with reference to the WA Guidelines for Preparing Mine Closure Plans (the WA Guidelines) (DMIRS 2020). 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 should 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 Ranger Authorisation. The level of information required needs to recognise 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 towards 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 2020).

3.3.1 Other closure and rehabilitation resources

There are general information sources on the process and management of rehabilitation and closure to the mining industry which, although not directly referenced throughout the MCP, provide a baseline to identifying whether the ERA closure practices are conforming to industry standards and that the necessary planning and management aspects are being considered. Some of the primary closure information resources providing general guidance to rehabilitation and closure processes are:

- 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).
- Kakadu Management Plan 2016 - 2026 (Director of National Parks 2016).

3.4 Closure permits and approvals

The transition into closure will involve applying for regulatory approvals to authorise new requests or to modify the currently authorised activities. Applications will be required for activities that may result in an environmental impact which may require amendment of the Ranger Authorisation; cause or has potential to cause disturbance to intact or undisturbed areas of the RPA; or is likely or has the potential to impact downstream values (DPIR 2011). It is assumed that no areas outside of the existing footprint will be disturbed during closure. Therefore, no additional permits or approvals relating to land disturbance will be required.

Permits for decommissioning works, post-closure and access approvals, such as the 'Permit to Decommission Facility' under the *Nuclear Non-Proliferation (Safeguards) Act* 1987, will be submitted to relevant authority as needed. Contractors will be responsible for acquiring permits to undertake specific works such as deconstruction of infrastructure, transport of materials and seed collection. In accordance with Annex B.7 of the Ranger Authorisation, the MCP must include a summary of activities, which ERA propose to seek approval for via specific applications and indicative timing of these applications. Where practicable, requests for approval will be identified and detailed within Section 11 (Implementation) of the MCP, as part of the annual submission.

Alternatively, standalone applications will be submitted to the Minesite Technical Committee (MTC). The MTC is responsible for reviewing the application and advising matters for consideration as part of the 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. All proposals to amend or introduce operational approaches, procedures or mechanisms must be supported by a BPT analysis including all environmental matters not covered by the ERs.

The list of standalone applications currently pending submission and the associated indicative timeframes for submission, assessment and approval and detailed within Table 3-2.

Table 3-2: Applications pending submission

APPLICATION	TYPE	FORECAST SUBMISSION DATE	MTC ASSESSMENT PERIOD	MTC ACCESSMENT COMPLETED	ERA RESPONSE PERIOD	ERA RESPONSE COMPLETED	MTC ACCEPTANCE PERIOD	MTC ACCEPTANCE OF RESPONSES	MINISTERIAL APPROVAL TIMELINE	MINISTERIAL APPROVAL
PIT 3 CLOSURE**	*Ministerial Approval	Dec 2020	6 months	June 2021	2 months	Aug 2021	1 month	Sept 2021	1 month	Oct 2021
TSF DECONSTRUCTION	*Ministerial Approval	Nov 2021	7 months	June 2022	2 months	Aug 2022	2 months	Oct 2022	1 month	Nov 2022
FINAL LANDFORM	*Ministerial Approval	May 2022	6 months	Nov 2022	6 weeks	Dec 2022	2 months	Feb 2023	1 month	Mar 2023
FINAL COMPLETED CLOSURE WORKS REPORT	*Ministerial Approval	July 2026								

**matters requiring Commonwealth ministerial consultation according to the update sent from the Department of Industry, Innovation and Science & Department of Primary Industry and Resources (April 2017)*

*** Application does not include final 6 m (which will be included within the Final Landform application)*

3.5 References

ARPANSA, 2005, *Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, Radiation Protection Series Publication No. 9*, August 2005, Australian Radiation Protection and Nuclear Safety Agency, Australian Commonwealth Government

Australian Government 2011. *Guide to Leading Sustainable Development in Mining*.

Australian Government 2016a. *Mine Closure – Leading Practice Sustainable Development Program for the Mining Industry*.

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Australian Radiation Protection and Nuclear Safety Agency 2005. *Code of Practice and Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*. Commonwealth of Australia, Canberra.

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Department of Mines and Petroleum & Environmental Protection Authority 2015. *Guidelines for Preparing Mine Closure Plans*. Government of Western Australia 2015.

Department of Mines, Industry Regulation and Safety (2020a) Statutory Guideline for Mine Closure Plans

Department of Mines, Industry Regulation and Safety (2020b) Mine Closure Plan Guidance – how to prepare in accordance with the Statutory Guidelines.

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Rio Tinto 2014. *Rio Tinto Closure Standard*. Rio Tinto.

Standards Reference Group 2018. *National Standards for the practice of ecological restoration in Australia*. Second edition. Society for Ecological Restoration Australasia.

Young R, Manero A, Miller B, Kragt M, Standish R & Boggs, G 2019. *Completion Criteria Framework: an overview*. Western Australia Biodiversity Science Institute. 2019.

APPENDIX 3.1: OVERVIEW OF PRIMARY LEGISLATION, AGREEMENTS AND AUTHORISATIONS

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Aboriginal Land Act 1979 (NT)	NT Department of Infrastructure, Planning and Logistics	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 Minister of State for Families, Community Services and Indigenous Affairs s44 Agreement	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 and Department of the Environment and Energy	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.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Atomic Energy Act 1953 (Cwlth)	Department of Industry, Innovation and Science (DIIS) Minister for Resources and Northern Australia	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 the Environment and Energy (DEE)	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.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Environment Protection and Biodiversity Conservation Act 1999 (Cwlth)	Department of the Environment and Energy (DEE)	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)	Department of Tourism, Sport and Culture (DTSC)	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)	NT Department of Primary Industry and Resources (DPIR)	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.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Northern Territory Aboriginal Sacred Sites Act 1989 (NT)	NT Minister for Environment and Natural Resources	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)	Department of Communication and the Arts (DCA)	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)	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	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

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Management in Mining and Mineral Processing (2005)	Protection and Nuclear Safety Agency (ARPANSA) Ranger Authorisation	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 Industry, Science and Resources Northern Territory Minister for Resource Development	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.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
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 Industry, Science and Resources Northern Territory Minister for Resource Development *Mining Management Act 2001* (NT)	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)	Minister for Department of Industry, Innovation and Science *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.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
s41 Authority - Environmental Requirements (ERs)	Minister for Department of Industry, Innovation and Science *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 Relations	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 the Northern Land Council (November 1978) Renegotiated s44 Agreement (January 2013)	Northern Land Council *Aboriginal Land Rights (NT) Act 1976* (Cwlth)	Agreement was established to address payments to be made to the NLC and conditions for operating the Ranger Mine.

Overview of Primary Legislation, Agreements & Authorisations

Instrument	Governing Body/Parent Instrument	Description
Extension Agreement between the Commonwealth of Australia and the Northern Land Council (March 1999)	Minister for Indigenous Australian Minister for Resources and 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)	Minister for Resources and Northern Australia 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.

Overview of Primary Legislation, Agreements & Authorisations

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)	Minister for Resources and 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 Primary Industry and Resources (DPIR) *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 2020

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 1979 (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 1979 (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).

Instrument	Title	Section	Obligation
Legislation	*Aboriginal Land Act 1979 (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 landowners. The permit must be in writing and can be cancelled by the Land Council or the traditional Aboriginal owners.
Legislation	*Aboriginal Land Act 1979 (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 1979 (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 1979 (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 44- 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).

Instrument	Title	Section	Obligation
Legislation	*Atomic Energy Act 1953*	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.
Legislation	*Atomic Energy Act 1953*	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.

Instrument	Title	Section	Obligation
Legislation	*Atomic Energy Act 1953*	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*	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*	Section 41D - 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)

Instrument	Title	Section	Obligation
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.
Legislation	*Bushfires Management Act 2016*	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*	Section 70(5) - Property fire management plans	Owner of land within a fire protection zone 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*	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*	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*	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*	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).

Instrument	Title	Section	Obligation
Legislation	*Bushfires Management Act 2016*	Section 81(5) - Property fire management plans	Owner of land within a fire management zone 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*	Section 84(5) - 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*	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*	Section 90(2) - Duty of owner or occupier to control fires	Owner or occupier must: (a) take all reasonable steps to protect property on the land from fire, and prevent fire spreading from one land to other land (s90(1)) and (b) notify fire control officer or fire warden if : (i) unable to control the fire and (ii) if there is a person apparently over the age of 16 years present on that land.(Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).
Legislation	*Bushfires Management Act 2016*	Section 91(1) - Duty of person who lights fire to control it	ERA must protect property on the land from the fire, and prevent the fire spreading from the land to other land. (Penalty - Max: 500 Penalty Units or Imprisonment for 5 years).
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.

Instrument	Title	Section	Obligation
Code of Practice	*Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*	Section 2.9.4 - 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 decomissioning 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: 2 160 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.

Instrument	Title	Section	Obligation
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 1 924 penalty units and not more than 19 240 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 7 700 penalty units is applicable.
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 3 850 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.

Instrument	Title	Section	Obligation
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)).
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.

Instrument	Title	Section	Obligation
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; or d) 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 regulation 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).

Instrument	Title	Section	Obligation
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 4: Section 43 - 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 ; 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)

Instrument	Title	Section	Obligation
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 takes, 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 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). Strict Liability applies to (1)(b) (Penalty - Max: 5,000 Penalty Units).
Legislation	*Environment Protection and Biodiversity Conservation Act 1999 (CTH) and Environment Protection and Biodiversity Conservation Regulations 2000*	Part 15: Section 354 & 355 & 356 - 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.

Instrument	Title	Section	Obligation
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: (Body corporate) 600 penalty units). If ERA was reckless as to whether the information was false or misleading: Penalty - Max: (Body corporate) 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. 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*	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* .

Instrument	Title	Section	Obligation
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. (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 Act 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).

Instrument	Title	Section	Obligation
Legislation	*Fire and Emergency Act 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)
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)

Instrument	Title	Section	Obligation
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	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.

Instrument	Title	Section	Obligation
Legislation	*Mining Management Act 2001 (NT)*	Section 29	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.
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	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 Reanger 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	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.

Instrument	Title	Section	Obligation
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 - Certificates 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 sucessful closure of the site.
Legislation	*Mining Management Act 2001 (NT)*	Section 83 - Minister may cause action to be taken on a mining site	The Minister may cause action to be taken to complete rehabilitation of a mining site.
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

Instrument	Title	Section	Obligation
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.

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

Instrument	Title	Section	Obligation
			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
	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).

Instrument	Title	Section	Obligation
Legislation	*Public and Environmental Health Regulations 2014 (NT)*	Regulations 55, 56, 72, 74, 75 and 78	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); (e) comply with the directions given by the CHO regarding management or disposal of biosolids, septage or sludge (r74); and (f) ensure that any wastewater works is undertaken by an approved contractor (r75); and (g) not to obstruct inspection or testing of the on-site wastewater system (r78).

Legislation	*Radiation Protection Act 2004 (NT) and Radiation Protection Regulations*	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). 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); - 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); -not to cause another person to receive a dose of radiation that is higher than the prescribed dose limit (Penalty - Max: 1000 penalty units); - to ensure the owner of a radiation source holds a certificate of registration for the source (Penalty - Max: 5000 penalty units); - 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); - not to carry out any work on a radiation source unless the holder of a certificate of accreditation (Penalty - Max: 1000 penalty units); - not to issue a certificate of compliance for a radiation source unless the holder of a certificate of accreditation (Penalty - Max: 5000 penalty units); - not to issue a certificate of compliance for a radiation place unless the holder of a certificate of accreditation (Penalty - Max: 5000 penalty units); - not to supply a radiation source that is prescribed by the regulations to be a banned radiation source (Penalty - Max: 5000 penalty units); - not to possess a radiation source that is proscribed by the Regulations. To ensure that an application for a licence to possess a radiation source to carry out a radiation practice is accompanied by the

Instrument	Title	Section	Obligation
			proposed radiation protection plan for the radiation practice . To comply with the requirements in relation to authorised officers to provide name and address (Penalty - Max: 100 penalty units). 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).
Legislation	*Radiation Protection Act 2004 (NT) and Radiation Protection Regulations*	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*	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 - Monitor ing 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 (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 1977 (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)

Instrument	Title	Section	Obligation
Legislation	*Territory Parks and Wildlife Conservation Act 1977 (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)
Legislation	*Territory Parks and Wildlife Conservation By-Laws 1984 (NT)*	Part 3 - Control of Activities	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	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)

Instrument	Title	Section	Obligation
Legislation	*Territory Parks and Wildlife Conservation By-Laws 1984 (NT)*	Part 3 - Control of Activities	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.
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).

Instrument	Title	Section	Obligation
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)*	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 (sec 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 Chief Executive Officer 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 Chief Executive Officer has approved the transfer of the licence to another person.
			(3) ERA may, with the approval of the Chief Executive Officer, 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.

Instrument	Title	Section	Obligation
			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.
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)*	Section 15 - Obstruction of or interference with waterway prohibited	ERA must allow every waterway on its land to flow naturally. ERA must not interfere with or obstruct a waterway, or cause another person to interfere with or obstruct a waterway unless authorised to do so by or under this Act. A structure or other obstruction on land or on/in/below a waterway capable of interfering with the flow of water is evidence of an obstruction. (Penalty - Max: For a first offence -15 penalty units and for a second or subsequent offence not less than 15 penalty units or more than 85 penalty units or imprisonment for 2 years. Maximum default penalty: 1.5 penalty units).

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	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 contact 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)*	Section 40 - Prohibition of unauthorised works	ERA must not (unless authorised) construct or alter a dam, water storage or other water control structure in a waterway, or in such a way as to affect the flow or likely flow of water in a waterway. ERA is, however, entitled to construct, operate or maintain a dam for the retention or conservation of water for use on the land. (Penalty - Max: For a first offence -15 penalty units and for a second or subsequent offence not less than 15 penalty units or more than 85 penalty units or imprisonment for 2 years. Maximum default penalty: 1.5 penalty units).
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 41 and Regulation 6 - Grant of Construction Permit	ERA must apply for a Construction Permit if ERA wishes to construct or alter a dam, water storage or water control structure. The application must be in accordance with the approved form.
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 42 - Breach of term or condition of permit	If ERA holds a Construction Permit its terms must be complied with. (Penalty - Max: 15 penalty units and maximum default penalty: 1.5 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 45 and Regulation 8 - Licence to take or use water	If ERA wants to take or use 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.

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 46 - Breach of term or condition of licence	If ERA holds a licence to take or use water the conditions of the licence must be complied with. (Penalty - Max: 15 penalty units and maximum default penalty: 1.5 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 48, 49 and Regulation 10(1) - Drilling 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: For a first offence -40 penalty units or imprisonment for 3 months and for a second or subsequent offence not less than 40 penalty units or more than 85 penalty units or imprisonment for 12 months)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 56 & 57 and Regulation 7 - Bore Construction Permit	ERA must apply for a Bore Construction Permit if wanting to:
			a) drill, construct, alter, plug, backfill or seal off a bore,
			b) remove, replace, alter, slot or repair the casing, lining or screen of a bore or
			c) deepen a bore. An application for a Bore Construction Permit must be in accordance with an approved form. It is a defence if it is proved that the work was urgently required to prevent pollution, in the circumstances it was not reasonably practicable to apply for a permit, as soon as practicable a permit will be applied for and the Regulations relating to work carried out in those circumstances were complied with.
			(Penalty - Max: For a first offence -40 penalty units and for a second or subsequent offence not less than 40 penalty units or more than 85 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 58 - Breach of term or condition of permit	If ERA holds bore construction permit must be complied with the term or condition to which the permit is subject. (Penalty: 15 penalty units and maximum default penalty: 1.5 penalty units)

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 59, 60 and Regulation 9 - Prohibition of unlicensed extraction of groundwater	If ERA wishes to take groundwater the company must have a ground water extraction licence from the Controller. The licence must be in accordance with the approved form. Proof of pumping equipment or any other equipment used to take water from a bore, is evidence of an offence. (Penalty - Max: For a first offence -15 penalty units and for a second or subsequent offence not less than 8 penalty units or more than 40 penalty units. Maximum default penalty: 1.5 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 61 - Breach of term or condition of licence	If ERA holds a licence to take water from a bore, ERA must comply with its terms and conditions. (Penalty: 15 penalty units and maximum default penalty: 1.5 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	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)*	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.

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	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)*	Section 69 - Prohibition of waste	If ERA has land on which a bore is situated, ERA is required (if the bore is no longer in use) to properly plug, seal off or backfill the bore. ERA is required to ensure that it does not suffer or permit water from the bore to run to waste. (Penalty: 15 penalty units and maximum default penalty: 1.5 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	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)*	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)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 79 - 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 - not less than 40 penalty units or more than 220 penalty units. Maximum default penalty: 8 penalty units)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 98 - Destruction of works	ERA shall not cause, suffer or permit, or attempt to cause any works constructed or used as specified in a licence granted or power bestowed under this Act to be interfered with, damaged or destroyed, except as allowed by this Act. (Penalty - Max: For a first offence – 40 penalty units or imprisonment for 12 months and for a second or subsequent offence – not less than 40 penalty units or more than 85 penalty units or imprisonment for 2 years)

Instrument	Title	Section	Obligation
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 99 - Interference with supply and drainage	A person shall not interrupt/interfere with, attempt to interrupt/interfere with or cause, suffer or permit a person to interrupt/interfere with: a) the taking of water, b) the discharge or disposal of water or waste or c) the drainage of land, in pursuance of a licence granted, a power granted or an arrangement made under the *Water Act*, or the performance of an act authorised under the emergency powers to control pollution. (Penalty - Max: For a first offence – 40 penalty units or imprisonment for 12 months and for a second or subsequent offence – not less than 40 penalty units or more than 85 penalty units or imprisonment for 2 years)
Legislation	*Water Act 1992 (NT) and Water Regulations 1992 (NT)*	Section 100 - Prohibition of waste	A person shall not waste, or cause, suffer or permit a person to waste water or permit water to run to waste. Water is wasted where, irrespective of intention: a) more water is used than is reasonably necessary for the immediate purpose for which water is taken, including irrigation, b) an unnecessary or excessive flow or flood of water is allowed to occur or c) water is taken without adequate control or supervision. (Penalty- Max: 15 penalty units and maximum default penalty: 1.5 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)

Instrument	Title	Section	Obligation
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.
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.

Instrument	Title	Section	Obligation
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).
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).

Instrument	Title	Section	Obligation
Agreement	Ranger Uranium Mining Project Mining Agreeement 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) that such action is not inconsistent with a request or direction from the MTC or relevant regulatory agency.

Instrument	Title	Section	Obligation
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.

Instrument	Title	Section	Obligation
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):

Instrument	Title	Section	Obligation
			(i) light vehicles;
			(ii) demountable accommodation facilities; or
			(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 Agreeement 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.

Instrument	Title	Section	Obligation
			(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.
			(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 Agreeement 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 Agreeement 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.

Instrument	Title	Section	Obligation
			(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 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".

Instrument	Title	Section	Obligation
			(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.

Agreement	Ranger Uranium Mining Project Mining Agreeement 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 Teunination Date (or such longer period as the NLC in writing allows) furnish the NLC with a final

Instrument	Title	Section	Obligation
			Project Report for the period not already included in a previous Project Report. This clause survives termination of this Mining Agreement.

Agreement	Ranger Uranium Mining Project Mining Agreeement 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

Instrument	Title	Section	Obligation
			(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)

Instrument	Title	Section	Obligation
Agreement	Ranger 'Section 44' Agreement between the Commonwealth of Australia and Northern Land Council	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 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.

Instrument	Title	Section	Obligation
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.
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 resttictions 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 detennined 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.

Instrument	Title	Section	Obligation
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, detennine) 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. 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.

Instrument	Title	Section	Obligation
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.
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.

Instrument	Title	Section	Obligation
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. shallforward 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 and e) the Mining Agreement.

Instrument	Title	Section	Obligation
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 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.

Instrument	Title	Section	Obligation
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 followinga 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.

Instrument	Title	Section	Obligation
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.
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 processess 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.

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			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.
Authorisation	Variation of Authorisation 0108	Schedule 5 - Operation of Tailings Respositories	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 Objecitves in Annex C as approved by the Director in accordance with the advice of the Supervising Scientist.

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			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.
			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.

Instrument	Title	Section	Obligation
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.

Instrument	Title	Section	Obligation
			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 achieveable and conforms with relevant Austalian 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 impariment 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 achieveable, 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 oopinion of the Minister with the addvccie of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.

Instrument	Title	Section	Obligation
			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.
			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 wiht principles for rehabilitiation 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 wihtin the site.

Instrument	Title	Section	Obligation
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.

Instrument	Title	Section	Obligation
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 achieveable.
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.

Instrument	Title	Section	Obligation
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 Ranager Project Area, and that enviornmental impacts within the Ranger Project Area are as low as reasonably achieveable.
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.
			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; and b) 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.

Instrument	Title	Section	Obligation
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.
			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.

Instrument	Title	Section	Obligation
			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.

Instrument	Title	Section	Obligation
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 wiht the advice of the Supervising Scientist; and b) is sufficient to allow interpretive analysis of impacts from operations.
			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 Commmittee established under the *Environment Protection (Alligator Rivers Region) Act 1978*to ensable the committee to effectively co-ordinate environmental research in the region.

Instrument	Title	Section	Obligation
Authorisation	Variation of Authorisation 0108 (Annex A)	16 - Reporting Incidents	16.1 The company must directly and immediately notfiy the Supervising Authority, the Supervising Scientist, the Minister and the Northern Land Councl of all breaches of any of these Environmental Requirements and any mine-related event which: a) results in signficant 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 Aborigials 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 enviornmental managmeent over the preceding 12 month period; b) the company's proposals for complying wiht 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) enviornmental 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 trainign 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.

Instrument	Title	Section	Obligation
			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 approvall.
			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.
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 Plna 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 Minishter 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 recieveing them. The Operator may, in turn, provide any wrtitten comment to the Commonwealth Minister and NT Minister.

Instrument	Title	Section	Obligation
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.
			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 unitl 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.

Instrument	Title	Section	Obligation
			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 wier, 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.

Instrument	Title	Section	Obligation
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.
Application	Application: Pit 3 Tailings Deposition (July 2019)	Acceptance Letter (18 July 2019)	Depositing dredged tailings sub-aqueously, while continuing sub-aerial deposition of mill tailings (and dredged tailings as required) Implement a Maximum Operating Level (MOL) of +3.5mRL for water in Pit 3.
			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 - SSB ERA 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 4.3 - Monitoring Program	Implement a PIt 3 tailings monitoring program that includes 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 and post-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; and o one new bore to be installed on the north-eastern edge of the Pit 3 cap following completion of backfilling at this location.
Application	Application: Pit 3 Tailings Deposition (July 2019)	Acceptance Letter (29 August 2019)	Deposite tailing in Pit 3 to an average interim level of -15mRL. This level is for dicharges from the fixed spigot points situated along the south and eastern pit perimeter.
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: 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	Vegetation clearing to be managed through ERA's land disturbance permit process.

Instrument	Title	Section	Obligation
Application	Application to Operate a Brine Squeezer (January 2019)	Application Section 4.4 - Commissioning Schedule	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 4.5 - 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 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	Application to progress Pit 1 final landform (March 2019)	8 - Monitoring and Research	Implement a monitoring and research program, as described in the Pit 1 Progressive Rehabilitation Monitoring Framework (Appendix 8 of Application). 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.
Application	Application to progress Pit 1 final landform (March 2019)	DPIR Acceptance (1 May 2019)	Pit 1 Progressive Rehabilitation Monitoring Framework to be under discussion with the planned Monitoring Evaluation and Research Review Working Group. (refer to the Supervising Scientist Branch letter).

Instrument	Title	Section	Obligation
			Appendix A - SSB We 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 the review of the Pit 1 Progressive Rehabilitaiton Monitoring Framework (SSB review). 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 suport the construction of the final landform.
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.
Application	Application: Ranger 3 Deeps Exploration Decline Decomissioning (September 2018)	4.2 - Care and Maintenance	• 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.

Instrument	Title	Section	Obligation
Application	Application - Ranger Tailings Dam Future MOL Amendments and Northern Wall Notching (October 2018) (TSF Notch North)	DPIR Acceptance Letter (Januray 2019)	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 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 exeeding 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 proccess, 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.

Instrument	Title	Section	Obligation
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 be subject to sampling and analysis by the ERA production laboratory on at least a daily basis, when the relevant plant is running.
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 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.

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)	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)
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 oeprating 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

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)	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 in Application 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.

ERA Energy Resources of Australia Ltd

4. Stakeholder engagement

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Cover photograph: Paul Arnold sitting with Yvonne Margarula and Nida Mangarrba in the first Relationship Committee Meeting on Mirarr Country at Djarr Djarr – Image courtesy of Gundjeihmi Aboriginal Corporation

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.
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.
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 • 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.
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.*
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.

Table of Abbreviations

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

Abbreviation/ Acronym	Description
ACF	Australian Conservation Foundation
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
BPT	Best Practicable Technology
DCM	Department of the Chief Minister
DIIS	Department of Industry, Innovation and Science
DITT	Department of Industry Tourism and Trade
DISER	Commonwealth Department of Industry, Science, Energy and Resources (formally DIIS)
DPIR	Department of Primary Industry and Resources (now DITT)
DPMC	Department of Prime Minister and Cabinet
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
GAC	Gundjeihmi Aboriginal Corporation
IAEA	International Atomic Energy Agency
JTDA	Jabiru Town Development Authority
KKN	Key Knowledge Needs
MCP	Mine Closure Plan
MOU	Memorandum of Understanding
MTC	Minesite Technical Committee
NGO	Non-government Organisations
NLC	Northern Land Council
NP	National Park
NT	Northern Territory
NTP	Northern Territory Portion
RCCF	Ranger Closure Consultative Forum
RPA	Ranger Project Area
SIA	Social Impact Assessment

Abbreviation/ Acronym	Description
SSB	Supervising Scientist Branch
TSF	Tailings Storage Facility
WA	Western Australia
WARC	West Arnhem Regional Council

4 STAKEHOLDER ENGAGEMENT

Energy Resources of Australia Ltd (ERA) has a diverse and complex range of stakeholders with interests in specific areas of the closure process or outcomes and/or in the more general closure objectives and successful achievement of the planned post-mining land use. The ERA approach to stakeholder engagement is focused on building enduring relationships based on mutual respect, active partnership, transparency and long term commitment. Throughout the life of the Ranger Mine, ERA has engaged, communicated and consulted with multiple stakeholder groups through various engagement activities (Appendix 4.1) ranging from formal to informal processes. The stakeholder engagement aims to both provide information and to seek feedback on closure plans.

ERA representatives are in frequent, regular contact with the Gundjeihmi Aboriginal Corporation (GAC), Northern Land Council (NLC), the Northern Territory Department of Industry, Tourism and Trade (DITT), Commonwealth Department of Industry, Science, Energy and Resources (DISER) and the Supervising Scientist Branch (SSB), both informally and formally through various stakeholder committees, including the Minesite Technical Committee (MTC). Other stakeholders are listed below (Table 4-1). Figure 4-1 demonstrates the linkages between stakeholders and the ERA. There are documented communications via forums including the Alligator Rivers Region Technical Committee (ARRTC) and Alligator Rivers Region Advisory Committee (ARRAC), which date back to 2001 (Appendix 4.1). Public communication on aspects of mine rehabilitation and closure can be traced back to the first ERA annual report in 1981 (ERA 1981; p 11).

This consultative engagement has covered all key aspects of closure, including:

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

Table 4-1: Ranger Mine closure stakeholders

Stakeholder group	Description
EXTERNAL	
Traditional Owners and local Aboriginal groups	Gundjeihmi Aboriginal Corporation (GAC) Northern Land Council (NLC) Djabulukgu Association Gagudju Association Warnbi Aboriginal Corporation West Arnhem Regional Council (WARC)
Federal Government	Aboriginal and Torres Strait Islander Commission Australian Safeguards and Non-Proliferation Office (ASNO) Australian Securities and Investment Commission (ASIC) Department of Environment Department of Foreign Affairs and Trade Department of Prime Minister and Cabinet (DPMC) Department of Industry, Science, Energy & Resources (DISER) Minister for Industry, Science and Technology Minister for Resources, Water and Northern Australia Parks Australia
Northern Territory Government	Department of Education Department of Health Department of Industry, Tourism and Trade (DITT) Department of Planning and Local Government Department of the Chief Minister (DCM) Minister for Mining and Industry Jabiru Kabolkmakmen Limited Northern Territory Treasury
Northern Territory Local Government	Jabiru Town Development Authority (JTDA) West Arnhem Regional Council
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
EXTERNAL	
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 Town Development Authority (JTDA) Local social and recreational groups Residents Tourists
INTERNAL	
ERA Board	Comprises non-executive and an executive director (Chief Executive)
Executive Committee (EXCO)	Chief Executive, Chief Financial Officer, Legal Counsel and Company Secretary, General Manager Operations, General Manager External Relations, General Manager Human Resources
Managers	Manager Business Services, Manager Finance, Manager Health Safety Environment and Communities, Manager Operations, Manager Mining and Infrastructure, Manager Closure, Manager Technical Studies.
Legal team	Legal Counsel and Company Secretary
Employees	ERA employees, partners and dependents
Contractors	ERA long term contractors

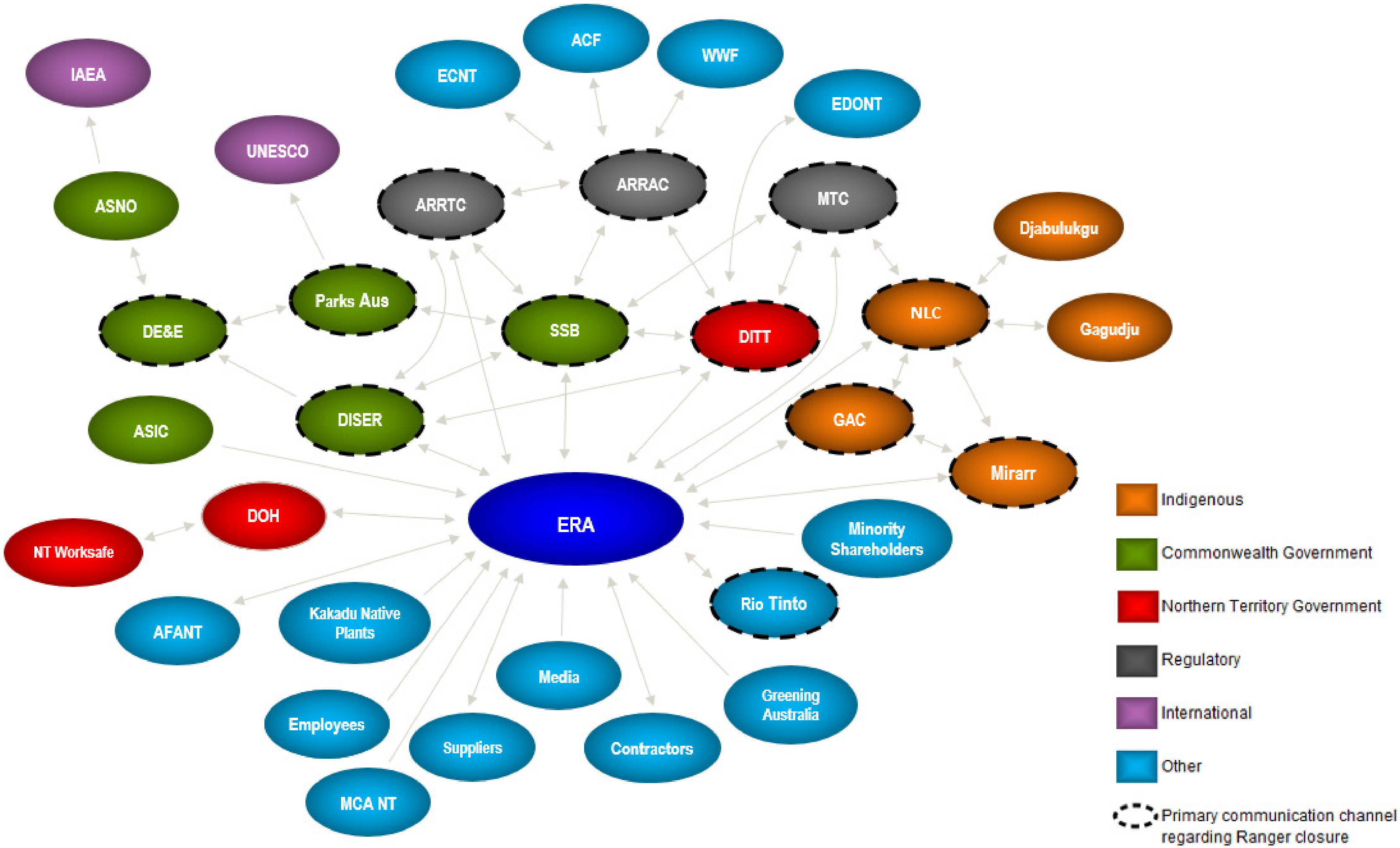

Figure 4-1: Ranger Mine stakeholder matrix

4.1 ERA stakeholder engagement principles

Throughout the life and closure of the Ranger Mine, ERA aims to build enduring and productive relationships with neighbours and local communities and to be responsive to their needs and concerns. To be meaningful for all parties, engagement must be open, inclusive, culturally appropriate and publicly defensible. Community engagement takes place in accordance with the following guiding principles:

- transparent – in order to develop and maintain a relationship of trust, information which is not commercially sensitive will be shared openly and in a timely manner.
- accessible – staff will be available, approachable and accessible and information will be available in a range of formats. Where appropriate and practical, translation into the local language will be provided.
- strategic – engagement will be provided regularly in a coordinated manner by key ERA staff with reference to key messages and issue management, and
- two-way – community stakeholders will be able to participate openly and honestly during engagement with their perspective, feedback and views.

Figure 4-2: Tourist facilities in Jabiru town

Table 4-2: Principles of stakeholder engagement

Principle	Outcome
Purposeful	Commence every engagement with a clear understanding of what ERA wants to achieve
	• be aware and acknowledge stakeholders' objectives, perspective, expertise and their level of influence • know why we need to engage and what success looks like, makes it easier to conduct focused and meaningful engagements • good planning of our communication and managing stakeholder expectations will contribute to building robust relationships with stakeholders as well as developing an understanding of stakeholders ability and desire to engage
Inclusive	Make it easy for stakeholders to engage
	• ensure community stakeholders have the ability to participate openly and honestly during engagement with their perspective, feedback and views • engagement to be provided regularly in a coordinated manner with reference to key messages and risks • identify suitable level of engagement and communication tool appropriate to the stakeholder e.g. meeting, forums, language, culture • provide stakeholders with appropriate information in a range of formats that the stakeholders needs to participate in a meaningful way
Timely	Agree on how and when to engage with stakeholders from the beginning
	• be available, approachable and accessible where appropriate and practical • discuss and negotiate timings/concerns with stakeholders • respond to information requests and feedback in a timely manner as agreed with stakeholder • record all engagements to ensure actions and commitments are met by agreed timeframes
Transparent	Be open and honest in our engagement and set clear business expectations
	• provide relevant information which is not commercially sensitive openly so stakeholders will participate in a meaningful way • clearly explain the business's engagement process being taken on the subject matter, the role of stakeholders in the engagement process, and how their input will inform the project
Respectful	Acknowledge and respect stakeholders
	• understand that engagement is both one-way (information sharing) and a two-way process (consultation, collaboration) • appreciate the benefits of mutual learning by respecting our stakeholder's expertise, perspective and needs • recognise the different communication style and engagement needs of stakeholders and try to meet those style and needs wherever possible • listen and be open and respectful of stakeholder's alternative views

Engagement activities aim to achieve broad community understanding of the planned activities and scheduling of the closure of the Ranger Mine, and the meeting of closure obligations. This includes working towards ERA being viewed as a trusted active member of the community.

The ERA consultation with stakeholders is undertaken in accordance with an engagement framework consisting of:

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

ERA engages directly with numerous stakeholders on closure aspects for the Ranger Mine, including communication in the following formats:

- regular updates on key closure activities, including in language for Mirarr members of the Relationship Committee, where possible;
- presentations of new, or updated, information outlining closure strategies, engineering studies, modelling predictions and research and development, as required;
- participation in the development and progress of scientific studies needs identified in forums such as ARRTC;
- site visits to the Ranger Mine to inform progress on closure activities and associated closure studies such as the trial landform; and
- knowledge sharing and peer review of closure strategies, studies and activities through workshops, conferences and scientific publications.

An overview of the engagement forums used to engage with stakeholders on closure is provided below (Table 4-2). The stakeholder consultation register provides an indication of the extensive engagement already undertaken by ERA on closure (Appendix 4.1). It should be noted that the register is not exhaustive and also does not cover social and economic engagements and analyses previously conducted that were not directly related to closure.

Table 4-2: Engagement forums

Engagement forum	Frequency	Comment
Minesite Technical Committee (MTC) meetings	Bi-annually (additional meetings held as required)	The MTC is the formal forum for key advisory and stakeholder groups, including representatives of the Northern Territory Department of Industry,Tourism and Trade (DITT) (Chair), Commonwealth Department of the Agriculture, Water and the Environment, Supervising Scientific Branch (SSB), Energy Resources of Australia Ltd (ERA), Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC), to discuss and resolve technical environmental management matters relating to the operation of the Ranger Mine. The MTC discusses matters relevant to the regulatory functions of the Northern Territory Government and the supervisory and assessment functions of the Supervising Scientist, as well as operational requirements of ERA and the views of the Mirarr and other affected Aboriginal people. In addition, Commonwealth Department of Industry, Science, Energy & Resources (DISER) is an observer to the MTC.
Ranger Closure Consultative Forum	Monthly	The Ranger Closure Consultative Forum (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 DISER, SSB, Northern Territory 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 (KKNs).
Alligator Rivers Region Technical Committee (ARRTC) meetings	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, member representing the NLC and a member representing environmental non-government organisations. Non-members typically in attendance include DITT, ERA, other current operator of the Nabarlek Mining Lease and Parks Australia. http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrtc

Engagement forum	Frequency	Comment
Alligator Rivers Region Advisory Committee (ARRAC) meetings	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 Australian government departments, non-government organisations, ERA and other uranium mining/exploration companies that operate in the region. http://www.environment.gov.au/science/supervising-scientist/communication/committees/arrac.
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 has 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.
Ecosystem Restoration Working Group (ERWG)	As required, several per year	Communication and consultation with stakeholders focusing on ecosystem restoration closure criteria and KKNs.
Water and Sediment Working Group (WASWoG)	As required, several per year	Communication and consultation with stakeholders focusing on surface water and sediment closure criteria and KKNs.
Monitoring Evaluation and Research Review Group (MERRG)	As required, several per year	MERRG was formed in response to the submission of the application to progress Pit 1 final landform, in order to further communication and consultation with stakeholders regarding Pit 1 revegetation monitoring activities.
Investor briefings	Bi-annually	Briefings provided by the ERA Chief Executive regarding ERA operations to all company shareholders.
Relationship Committee meetings	Quarterly	The Relationship Committee was established under the Ranger Mining Agreement between ERA and the NLC in 2013. The committee was established to ensure effective information sharing and review processes between ERA and the Mirarr Traditional Owners and their representatives.

Engagement forum	Frequency	Comment
Jabiru Town Development Authority meetings	Quarterly	Jabiru serves West Arnhem region as a centre for mining, tourism and community services. Membership includes a Northern Territory Government representative (Chair), two ERA representatives, a GAC representative and an elected member of the West Arnhem Regional Council.
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 meetings	Meetings held quarterly ERA update provided bi-annually	Kakadu National Park (NP) is a jointly managed park between Parks Australia and the Traditional Owners of Kakadu. A board of management has been established as part of the governance structure for the park and consists of Commonwealth Government representatives, Park Management and Traditional Owners from each region in the park. ERA provides a regular operations update, including mine closure status, and consults with the broader indigenous population through this forum.
ERA information centre	Ongoing	The centre, located next to a supermarket in Jabiru, displays current information on ERA operations including closure and rehabilitation, with ERA personnel on hand to provide face-to-face interaction.
State of the Nation	Quarterly	Presentation, and question and answer session, 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.

4.2 Managing socio-economic impacts

The extensive engagement with the Traditional Owners (the Mirarr), and the representative groups of the GAC and the NLC, have indicated that the key areas of concern for those stakeholders surround cultural heritage and land management, the incorporation of cultural criteria and requirements into the closure planning process for the Ranger Mine, and the outlook for the local economy and infrastructure after closure.

The legislation, agreements and ERA company processes, which make up the existing Cultural Heritage Management System, are important elements in the planning, execution and assessment of closure outcomes.

The potential socio-economic impacts of the closure of the Ranger Mine have already been the subject of significant engagement with key stakeholders and are reasonably well understood (Section 4.3). However, considerable work remains to be done in planning for the future and agreement on impact mitigation and transition strategies. This is the particular focus of work in the next phase of stakeholder engagement.

4.3 Ranger Mine closure

The ERA Ranger Mine operations are currently a significant contributor to the socio-economic life of Jabiru, the West Arnhem region and more broadly the Northern Territory (NT) both through economic inputs and social aspects such as its residential workforce and community involvement.

The contributions by ERA are well understood by the company and its stakeholders following the completion of the Jabiru Social Impact Assessment (SIA) in July 2017. ERA has updated the socio-economic baseline with the most recent information so that potential impacts and opportunities associated with closure and the exit by ERA from Jabiru can be accurately assessed.

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 and into closure. 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 the transfer of town assets under a new town head lease, executing such rehabilitation in the town as may be required, and supporting a smooth social transition.

ERA will update the SIA in early 2021 to incorporate both specific information on the cessation of Ranger Mine operations and recent developments around the future of Jabiru.

4.4 References

Energy Resources of Australia Ltd. 1981. *ERA Annual Report 1981* [Online]. Available: http://www.energyres.com.au/media/1981-annual-report/ [Accessed December 2016].

Energy Resources of Australia (2018) Community and Stakeholder Engagement Plan (internal document - CDM.03-0000-HV-PLN-00004)

APPENDIX 4.1: RANGER MINE CLOSURE STAKEHOLDER CONSULTATION REGISTER

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
26/06/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
26/06/20	Pit 3 tailings consolidation	SSB	Pit 3 consolidation	Non-minuted	Non-minuted
25/06/20	KKN Projects	SSB	KKN Projects Close-out timelines	Non-minuted	Non-minuted
25/06/20	Rehabilitation	NLC (Chris Brady)	Discussed ERA ERWG Pit 1 Planning - Reveg Trials (catchup)	Non-minuted	Non-minuted
22/06/20	Rehabilitation	NLC (Chris Brady)	Discussed draft ERA closure criteria	Non-minuted	Non-minuted
19/06/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
18/06/20	MERRG	SSB	Non-minuted	Non-minuted	Non-minuted
16/06/20	Feedback on ERWG	SSB	Landform constraints for ecosystem restoration- feedback on presentation to ERWG	Non-minuted	
15/06/20	Closure criteria	SSB	Non-minuted	Non-minuted	Non-minuted
12/06/20	Pit 3 tailings consolidation	SSB	Pit 3 consolidation	Non-minuted	Non-minuted
12/06/20	Casual catch-up	SSB (Kate Tuner), ERISS (Katherine Smith)	Non-minuted	Non-minuted	Non-minuted
11/06/20	Rehabilitation closure criteria	NLC	Preliminary draft criteria.	Requesting GAC advice on Cultural Key Target Species	Non-minuted
05/06/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
05/06/20	Rehabilitation closure criteria	CDU (Alan Anderson)	Invertebrate criteria, approaches to setting other criteria	Non-minuted	
29/05/20	Pit 3 tailings consolidation	SSB	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	Non-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 (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
26/05/20	ERWG update for individuals that missed previous meeting	ERWG member, Rio Tinto	Preliminary Pit 1 Revegetation Trail Planning	Non-minuted	Follow-up meeting scheduled.
26/05/20	ERWG	ERWG Members	Potential constraints for ecosystem development across the areas to be rehabilitated on the RPA Potential physical and/or chemical constraints to vegetation establishment and persistence across areas to be rehabilitated: (e.g. PAW, PSD, nutrients, hydrology, substrates). Knowledge of the drivers of ecosystem variability and species tolerances in the surrounding areas. Discussion on approach to linking identified constraints to species and ecosystem tolerance.	Non-minute	Non-minuted
22/05/20	Rehabilitation	SSB	Discussed draft ERA closure criteria (final landform constraints and mine domains)	Non-minuted	Non-minuted
22/05/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
21/05/20	Rehabilitation closure criteria	CDU (John Woinarski)	Preliminary draft criteria	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 about: Ranger Authorisation 0108 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 happy with ERA to use the new guidelines provided this is approved by 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 planned to be 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, ERA to set up workshop with stakeholders by end of July to discuss how ERA are going to comply with the Environmental Requirements to remove tailings from TSF to place in 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 full scale operation.	ERA to provide data comparison of BS process permeate with WTP brine permeate.
18/05/20	Discussion re ERWG	SSB, NLC	The purpose of the ERWG and plans going forward	Non-minuted	Non-minuted
15/05/20	MERRG	SSB	TLF Monitoring Plan	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
15/05/20	Pit 3 tailings consolidation	SSB	Pit 3 consolidation	Non-minuted	Non-minuted
15/05/20	Casual catch-up	SSB (Kate Tuner), ERISS (Katherine Smith)	Non-minuted	Non-minuted	Non-minuted
14/05/20	Rehabilitation	NLC (Chris Brady)	Discussed potential final landform surface preparation	Non-minuted	Non-minuted
12-13/05/20	ARRTC 44	ARRTC Members	ERA and SSB provided updates 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	Non-minuted	No new action raised.
11/05/20	ERA Faunal Study	GAC, NLC	ERA faunal study, approvals required for study	Non-minuted	Non-minuted
08/05/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
07/05/20	Rehabilitation	NLC (Chris Brady)	Discussed potential final landform surface preparation	Non-minuted	Non-minuted
05/05/20	WASWG	NLC, Rio Tinto, GAC, DPIR, SSB	Revise minutes for last meeting. Discussed the ERA-SSB joint project list for ARRTC. Upcoming applications.	Non-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.
05/05/20	ERWG	ERWG members	Pit 1 revegetation trials	Non-minuted	Non-minuted
01/05/20	Casual catch-up	SSB (Kate Tuner)	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 (Amie Leggett)	SW Uncertainty analysis	Non-minuted	Non-minuted
29/04/20	Rehabilitation	SSB	Discussed TLF Monitoring Plan content	Non-minuted	Non-minuted
24/04/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
23/04/20	Brine Squeezer [Process water] stakeholder update	DPIR, DISER, NLC, ERISS, SSB	Provide an update following risk workshop.	No major concerns.	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	Non-minuted	ERA to come back with suggestions on what is the best Fugro survey and/or tailings monitoring program to inform our environmental studies and the engineering for Pit 1.
17/04/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	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)	Non-minuted	Stakeholders – continued with review of application ERA – no action
10/04/20	Casual catch-up	SSB (Kate Tuner)	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 meeting	NLC, Rio Tinto, SSB, GAC, DPIR	Item discussed: Closure Criteria ALARA Project tracking	Non-minuted	Chris Brady to draft short statement for content that need to be provided to ARRTC.
08/04/2020	Rehabilitation	SSB	Discussed draft ERA closure criteria	Non-minuted	No action required
03/04/20	Casual catch-up	SSB (Kate Tuner)	Non-minuted	Non-minuted	Non-minuted
01/04/20	Rehabilitation closure criteria	CDU (John Woinarski)	Approach to identifying criteria, main themes to address	Non-minuted	No action required
24/03/20	Rehabilitation	SSB	Discussed draft ERA closure criteria	Non-minuted	Non-minuted
23/03/2020	Rehabilitation	NLC (Chris Brady)	Discussed draft ERA closure criteria	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
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	Non-minuted	ERA to provide suggestion to decide the best survey/ monitoring program input into environmental studies for Pit 1.
20/03/2020	Casual catch-up	SSB (Kate Turner)	Non-minuted	Non-minuted	Non-minuted
19/03/2019	Rehabilitation	SSB	Discussed draft ERA closure criteria and TLF Monitoring Plan	Non-minuted	No action required
17/03/2020	KNPS contract model	Kakadu Native Plants	KNPs presented with new contract model for approval.	Non-minuted	Greg Williamson to liaise with Peter Christoperson

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
13/03/20	MTC	MTC Members	ERA presents 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.
12/03/20	Water and Sediment Working Group	SSB, NLC, GAC, DPIR	Updates on acid sulfate sediment GW background COPC concentration Ecosystem vulnerability to magnesium KKN close out ALARA	Non-minuted	Non-minuted
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	No action raised.
10/03/2020	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
09/03/2020	Phone consultation	NLC	Revegetation of the Stage 13.1A	Non-minuted	No action required

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
04/03/2020	Rehabilitation	SSB	Discussed TLF Monitoring Plan content	Non-minuted	No action required
5/03/2020	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
5/03/2020	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
4/03/2020	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	
28/02/2020	Volunteer drivers for youth program	Red Lily Public Health	Discussed opportunities around ERA volunteer drivers for Youth program	Non-minuted	Non-required
27/02/2020	ERA Stakeholder Business Update	Jabiru Health Centre and Red Lily 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.	Non-minuted	Include photo timeline of Pit 1 at the SBU scheduled in the second half of the year
21/02/2020	Casual catch-up	SSB (Kate Turner)	Non-minuted	Non-minuted	Non-minuted
18/02/2020	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	Non-minuted	Non-required
10/02/2020	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	Non-minuted	Provide feedback to Peter regarding the safety aspects discussed at the meeting.
6/02/2020	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	Non-minuted	Provide list of standard operating procedures, policies and CRM sheets. Organise meeting with ER Supervisor to look at safety equipment.
5/02/2020	Business dev & safety	Kakadu Native Plants	Brief meeting with KNPs to discuss contracts	Non-minuted	To ensure procurement team meet with KNPS to discuss contract options
3/02/2020	Rehabilitation	SSB	ERA-SSB Ecosystem teams Catch-up	Non-minuted	No action required

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
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.
29/01/2020	Business development in Jabiru	GAC	Discuss opportunity for partnership in business dev officer role	Non-minuted	Non-required
23/01/2020	Discuss business development	Trade & Innovation Anne Pearce	Discuss business development officer role	Non-minuted	Determine NTG's appetite for partnership
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.
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	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 7th Feb 2020 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.

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06/12/19	MERRG meeting	ERA (Chris, Sarah, Dave), SSB (Amie)	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.	Non-minuted
11-13/11/19	ARRTC 43	ARRTC members	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.
13/11/2019	Rehabilitation	SSB	ERA-SSB Ecosystem teams Catch-up	Non-minuted	No action required
06/11/2019	Site visit by DPIR	DPIR, ERA	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.
01/11/2019	Rehabilitation	SSB	Ecosystem Reconstruction monitoring workshop for Pit 1 and Stage 13	Non-minuted	No action required
31/10/2019	Rehabilitation	SSB, CSIRO	Discussion on Ranger state and transition model (collaborative) project	Non-minuted	No action required

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31/10/2019	Rehabilitation	SSB	Ecosystem Reconstruction monitoring workshop for TLF	Non-minuted	No action required
28/10/2019	Rehabilitation	SSB, NLC	Meeting ERA-SSB Ranger Revegetation	Non-minuted	No action required
24/10/2019	Groundwater meeting	ERA (David, Chris, Andrew Nelson), SSB (Amie)	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)
21/10/2019	MERRG meeting	ERA (Chris, Ingrid), SSB (Amie)	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
18/10/2019	MTC Meeting 7	ERA, 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.
17/10/2019	Casual catch-up	DPIR Max Smith	Non-minuted	Non-minuted	Non-minuted

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17/10/2019	Rehabilitation	SSB, CSIRO	Discussion on Ranger state and transition model (collaborative) project	Non-minuted	No action required
8/10/2019	RMERRG	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.	No action required
19/09/2020	Rehabilitation	SSB, CSIRO	Discussion on Ranger state and transition model (collaborative) project	Non-minuted	Non-minuted
18/09/2019	ERA Closure update	Red Lily Health Board	Non-minuted	Continued engagement	Non-minuted
13/09/2019	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	No action required

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05/09/2019	Presentation	Conference delegates	Attended Sept. 2019 Perth AGC Closure Conference and presented paper: "Harnessing ecological processes in the Ranger Uranium Mine revegetation Strategy. By P. Lu and I. Meek.	Non-minuted	No action required
22/08/2019	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
14/08/2019	Rehabilitation	SSB/CSIRO	Discussion on Ranger state and transition model (collaborative) project	Non-minuted	Non-minuted
09/08/2019	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.
30/07/2019	ERWG meeting 4	NLC, ERA, 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
25/07/2019	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
23/07/2019	ERA-SSB Ecosystem teams Catch-up	SSB	Non-minuted	Non-mnuted	Non-minuted
24/06/2019	ERA-SSB Ecosystem teams Catch-up	SSB	Non-minuted	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
20/06/2019	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
11/06/2019	ERA-SSB Ecosystem teams Catch-up	SSB	Non-minuted	Non-minuted	Non-minuted
03/06/2019	ERA Stakeholder Business Update	Parks Australia	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
24/05/2019	MERRG	SSB	Monitoring	Ongoing consultation	No action required
23/05/2019	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
21/05/2019	Rehabilitation	SSB	Discussed draft ERA closure criteria	Non-minuted	
14-15/05/2019	ARRTC meeting 42	ARRTC members	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.
09/05/2019	ERA Stakeholder Business Update	Jabiru Health Center	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
09/05/2019	MERRG	SSB	Monitoring	Ongoing consultation	No action required
08/05/2019	ERA Stakeholder Business Update	SSB	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
02/05/20	ARRAC 51	ARRAC members	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.
30/04/2019	ERA Stakeholder Business Update	Jabiru Area School teaching staff	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
29/04/2019	MERRG	SSB	Monitoring	Ongoing consultation	No action required
29/04/2019	ERA Stakeholder Business Update	West Arnhem Regional Council, local businesses/organisations	Present an update on key events relating to ERA's operations.	Non-minuted	Non-minuted
26/03/2019	ERWG meeting 2	ERWG members	Ecosystem similarity	Species composition discussed.	General agreement that more detailed and clearer information from all parties is required.
15/03/2019	RCCF meeting	ERA, 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.
06/03/2019	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	No issues identified	No action required
March 2019	Visit by Mirarr Traditional Owners and rangers to the Trial Landform	Traditional Owners and rangers	Non-minuted	None-minuted	Non-minuted

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11/02/2019	ERWG meeting 1	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.
07/02/2019	MTC meeting 1 2019	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	No new closure related actions
18/01/2019	RCCF	ERA, 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
14/12/2018	MTC Meeting 6 2018	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	No closure related actions
13 – 14/11/2018	ARRTC meeting 41	ARRTC members and 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.
11/10/2018	RCCF meeting	ERA, 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
13/09/2018	AARAC meeting 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.

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12/09/2018	MTC meeting 5 2018	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.	No new actions were identified
04/09/2018	Ranger Progressive Rehabilitation Monitoring Workshop Meeting	SSB, ERA, 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.
24/08/2018	RCCF meeting	ERA, 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

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25/07/18	MTC meeting 4 2018	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	No issues raised	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 meeting Number 3 2018	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.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
25/05/2018	RCCF meeting	ERA, 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.

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16 – 17/05/2018	ARRTC meeting 40	ARRTC members	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: 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 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). 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.

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06/04/2018	MTC meeting 2 2018	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. 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.
16/03/2018	RCCF	ERA, 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.

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09/02/2018	MTC meeting 1 2018	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 – 6/12/2017	ARRTC meeting 39	ARRTC members and 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
28/11/2017	MTC meeting 5 2017	Minesite Technical committee	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 meeting 4 2017	Minesite Technical committee	ERA provided the draft plan on 21/12/2016. SSB provided their initial adequacy review on 7/4/2017. DPIR provided a response letter on initial review and NLC and GAC have provided ERA their initial adequacy response on 26/4/2017. DPIR provided comments on 31/7/2017 and SSB provided their assessment report on this date. NLC/GAC provided further comment on 21/8/2017. The next version of the Plan is hoped to be submitted prior to the end of 2017.	ERA provided the MMP on 16/3/2017. Comments for this plan are due by the extended date of 5/5/2017. Additional information was requested 23/5/2017 and provided on 23/6/2017. This MMP was approved on 23/8/2017.	SSB will circulate a draft attachment to the Authorisation for ERA to periodically report on closure metrics.

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14-09-2017	ARRAC meeting 48	ARRAC members and observers from MTC organisations	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 meeting 38	ARRTC members and observers from MTC organisations	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; David Jones) GAC, NLC, DPIR, DIIS, ERA and 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 meeting 36	ARRTC members	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.
16/06/2017	MTC meeting 3 2017	Minesite Technical committee	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.

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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	Outcomes of these informal discussions were not minuted.	No new actions
03/05/17	Ranger rehabilitation and closure workshop	Representatives from: DIIS, DPIR, NLC, GAC, ERA, 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.
20/04/2017	ARRAC meeting 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
19/04/2017	MTC meeting 2 2017	Minesite Technical committee	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.
10/02/2017	MTC meeting 1 2017	Minesite technical Committee	The Draft Mine Closure Plan was provided on 21/1/2017.	There was discussion regarding the future approach and how the Mine Closure Plan is expected to change and be reviewed over time.	No action required.

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29 – 30/11/16	ARRTC meeting 37	ARRTC members	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.
18/11/2016	MTC meeting 5 2016	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No action required.
11/11/16	CCWG meeting 2016 8	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 2016 7	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 2016 6	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 2016 5	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: Health – accepted as a good framework for progression. Noted that some metals are already higher than tolerable intake levels via natural processes 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. 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
15/09/16	CCWG meeting 2016 4	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 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.

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08/09/2016	ARRAC meeting 46	ARRAC members	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.	No closure related actions.
01/09/16	CCWG meeting 2016 3	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.
09/09/2016	MTC meeting 4 2016	Minesite Technical committee	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.

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19/08/16	CCWG meeting 2016 2	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.
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.

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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.
27/05/2016	MTC meeting 3 2016	Minesite Technical committee	An update on the Closure criteria Development Process was presented.	No issues raised.	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
28/04/2016	ARRAC meeting 45	ARRAC , SSB, NTDME, ERA	Closure criteria	No issues raised	No closure related actions
08/04/2016	MTC meeting 2 2016	Minesite Technical committee	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.	No action required.

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04/03/16	CCWG meeting 2016 1	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.	No new actions.
12/02/2016	MTC meeting 1 2016	Minesite Technical committee	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.	No issues raised.	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.	No actions minuted
30/11/15	CCWG meeting 2015 3	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.	No emerging issues were raised by stakeholders on the topics presented.	No action required.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
23 – 25/11/15	ARRTC meeting 35	ARRTC members	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.
13/11/2015	MTC meeting 7 2015	Minesite Technical committee	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.
10/09/2015	MTC meeting 6 2015	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No action required.

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09/09/15	ARRAC meeting 44	ARRAC members	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.	No actions required.
12/08/15	CCWG meeting 2015 2	CCWG members	Discussion on ERA proposed closure criteria.	No emerging issues were raised by stakeholders on the topics presented.	No actions required.
17/07/15	CCWG meeting 2015 1	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)
10/07/2016	MTC meeting 5 2015	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No actions required.
22/05/2016	MTC meeting 3 2015	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No actions required.

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18 – 20/05/15	ARRTC meeting 34	ARRTC members	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 meeting 43	ARRAC members	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.
10/04/2015	MTC meeting 2 2015	Minesite Technical committee	Report from Mine Closure working group presented.	Discussion was on the objectives and priorities of various closure criteria.	No actions required.
13/02/2015	MTC meeting 1 2015	Minesite Technical committee	Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	No issues raised.	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.
07/11/2014	MTC meeting 6 2014	Minesite Technical committee	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.	No issues raised.	No actions required.

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04 – 06/11/14	ARRTC meeting 33	ARRTC members	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.	No emerging issues were raised by stakeholders on the topics presented.	Mon 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.	No new actions
17/10/14	CCWG meeting 2014 2	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.	No new actions.
12/09/2014	MTC meeting 5 2014	Minesite Technical committee	Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	No issues raised.	No actions required.
09/09/14	ARRAC meeting 42	ARRAC members	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.	No responses or emerging issues from stakeholders.	Non minuted.

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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 2014 1	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.

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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.
11/07/2014	MTC meeting 4 2014	Minesite Technical committee	Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	No issues raised.	No actions required.
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.
09/05/2014	MTC meeting 3 2014	Minesite Technical committee	Report from Mine Closure working group presented. Draft version of detrimental impact was sent out to MTC members.	No issues raised.	MTC to respond with comments to the draft version of detrimental impact definition.

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07 – 08/05/14	ARRTC meeting 32	ARRTC members	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 meeting 41	ARRAC members	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.

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28/03/2014	MTC meeting 2 2014	Minesite Technical committee	Report from Mine Closure working group presented. Update on Pit 1 and Pit 3 presented.	No issues raised.	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.
17/02/2014	MTC meeting 1 2014	Minesite Technical committee	Report from Mine Closure working group presented. Update on Pit 1 presented.	No issues raised.	Draft version of detrimental impact definition has been completed – ERA will circulate to MTC.
27 – 28/11/13	ARRTC meeting 31	ARRTC members	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.	Closure criteria	ERA and SSD to provide an update on the status of the development of closure criteria (including trajectories). Addressed during ARRTC meeting 32.
15/11/2013	MTC meeting 5 2013	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised	No actions required.
03/10/13	CCWG meeting 2013 4	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.

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17/05/2013	MTC meeting 3 2013	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No action required.
06/09/2013	MTC meeting 4 2013	Minesite Technical committee	Report from Mine Closure working group presented. The working group has developed the scope of work for the technical working groups for each theme.	No issues raised.	No action required.
05/09/13	ARRAC meeting 40	ARRAC members	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.	No responses or emerging issues from stakeholders.	No action required.
16/07/13	CCWG meeting 2013 3	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

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21 – 22/05/13	ARRTC meeting 30	ARRTC members	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.	Completed. Addressed at ARRTC meeting 31.
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 2013 2	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 meeting 39	ARRAC members	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.	No responses or emerging issues from stakeholders.	No action required.

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15/03/2013	MTC meeting 2 2013	Minesite Technical committee	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.	No issues raised.	No action required.
07/03/13	CCWG meeting 2013 1	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
08/02/2013	MTC meeting 1 2013	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	ERA to nominate closure criteria meeting schedule for 2013 (carried over from last meeting).
07/12/2012	MTC meeting 7 2012	Minesite Technical Committee	Report from Mine Closure working group presented.	No issues raised.	ERA to nominate closure criteria meeting schedule for 2013.
05 – 06/12/12	ARRTC meeting 29	ARRTC members	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 meeting 6 2012	Minesite Technical committee	Report from Mine Closure working group presented.	No issues raised.	No action required.

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05/10/12	CCWG meeting 2012 5	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 meeting 38	ARRAC members	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 2012 4	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.

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23/07/12	CCWG meeting 2012 3	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.
20/07/2012	MTC meeting 5 2012	Minesite Technical Committee	Report from Mine Closure working group presented.	No issues raised.	No action required.
01/06/2012	MTC meeting 4 2012	Minesite Technical Committee	Report from Mine Closure working group presented.	No issues raised.	No action required.

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17 – 18/04/12	ARRTC meeting 28	ARRTC members	Current status of Pit 3 and expected completion of mining. Status of tailings dam groundwater monitoring program to improve the understanding of hydrogeology of the mine site in inform rehabilitation planning. Update on Phase I of the ITWC project, including tailings reclamation and dredge transfer to Pit 3; proposed Pit 3 backfill strategy; closure criteria update; Pit 3 tailings and brine disposal options; Pit 1 closure. Status of the CCWG which held its first meeting in December 2011. Presentation on deriving background concentrations of COPC in groundwater and soils to establish background water quality in the three aquifers. Investigation into potential seed provenance for Ranger's revegetation. Update on the status of various groundwater studies at Ranger, including groundwater investigations and modelling.	ITWC PFS: Emerging issues acknowledged by ERA included: how to optimise Pit 3 backfill to maximise consolidation (taking into account seepage control and settlement), identifying the best strategies for: placing material into the Pit, reclaiming the tailings dam, managing the underlying groundwater, closing Pit 1, implementing incremental brine concentrator treatment capacity to reduce the process water inventory to zero, storing the salt from the brine concentrator, achieving site infra-structure synergies (e.g. power and water systems) and demolition/removal of the plant. Decommissioning and rehab: risk based framework for prioritising the KKNs associated with the decommissioning and rehabilitation phases at the Ranger mine. ARRTC members will be involved where possible.	ITWC PFS: Closure has to be completed by 2026 in accordance with the Section 41 Authority. Any decisions regarding an extension would be subject to outcomes of discussions with stakeholders. However, even if after extensive discussions all stakeholders agreed, the process would take some time due to the legal complexity involved. ERA outlined the integrated elements of the PFS strategy for Pit 3 closure and associated activities, and how these relate to the KKNs. Seed provenance: NB: On 12/8/15 GAC Board endorsed the proposed seed collection zone with KNP, based on local provenance study presented at ARRTC. Decommissioning and rehab: ERA and SSD should undertake further work as part of the proposed risk assessment process to draft a risk based framework for prioritising the KKNs associated with the decommissioning and rehabilitation phases at the Ranger mine. Completed.
04/04/12	ARRAC meeting 37	ARRAC members	Status of the ITWC study: still in definition stage until May 2012, then engineering design will commence focusing on closure issues and progressive rehabilitation. Key focus on salt management; Pit 3 backfill strategy optimisation; tailings dam reclamation and decommissioning; demolition and infrastructure scheduling; risk mitigation work; and, water treatment strategies. Status of wick installation in Pit 1.	No responses or emerging issues from stakeholders.	Minuted
05/04/2012	MTC meeting 3 2012	Minesite Technical Committee	Report from Mine Closure working group presented.	No issues raised.	No action required.
03/04/12	CCWG meeting 2012 2	CCWG members	Ongoing discussion and progression of closure criteria for the RPA.	ERISS identified that old ERISS infrastructure was noted for removal during site rehabilitation. ERISS requested that this infrastructure remain. Closure criteria report almost ready for review, draft criteria to be circulated for review and finalisation.	GK requested a copy of the landform slide to provide to Mirrar to show progress. NJ to progress this with GK outside of the meeting. NJ committed to consulting with eriss on infrastructure to be removed prior to completing this project.
08/03/12	CCWG meeting 2012 1	CCWG members	ERA discussed the development of broad ranging closure criteria as a journey for ERA and its stakeholders.	No responses or emerging issues from stakeholders.	No action required.
20/01/2012	MTC meeting 01 2012	Minesite Technical Committee	ERA proposes to hold special MTC meeting to discuss closure.	No issues raised.	ERA to arrange and host closure special meeting.

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13/12/11	CCWG meeting 2011 1	CCWG members	The purpose of this meeting was to restart the closure criteria process.	Agreement to review all KKNs so that they are more specific to the particular needs of closure and criteria development. Definition of 'detrimental impact' questioned. The need to define detrimental impact was added to the agenda for future meetings. SSD requested that ERA add "decision points" on the PFS schedule document for the various criteria. This way all are aware of when criteria need to be developed by and will provide us with a priority list. It was agreed that 6 months would be allowed on top of all "decision points" to allow for the approvals process. Agreement to prioritise groundwater criteria to allow Pit 1 closure. Agreement that ERA were the owners of the closure criteria and should be the main drivers. Discussion was held regarding the under-resourcing of NLC.	ERA to develop a plan for progressing cultural criteria and engaging traditional owners. Definition for 'detrimental impact' remains outstanding. ERA to update the chart with decision points. ERA to consider reinstating the old Jabiru Area Manager position that funded a mining officer position in the Jabiru Regional office.
29 – 30/11/11	ARRTC meeting 27	ARRTC members	Overview of the ERA integrated process water, tailings and closure (ITWC) pre-feasibility study Phase 1, looking at technologies and science. Overview of the Pit 1 closure wicks project. Overview of the Pit 3 tailings deposition strategy. Update on groundwater monitoring and modelling. Gulungul Creek catchment review. Update on the status of the trial landform, including the revegetation strategy, flowering and fruiting species. Update on the LAA rehabilitation studies.	ITWC PFS: ARRTC agreed that the KKNs (and projects under each KKN) should be prioritised based on current mine closure and rehabilitation timeframes. ARRTC requested an update on the current closure schedule components, and the relative priority and status of research addressing these, under each relevant KKN.	ITWC PFS: ERA advised the process water, tailings and closure strategy has 4 phases and the PFS is focused on phases 3 and 4. The PFS comprises a large number of integrated elements, and as part of the baseline strategy to 2026 decisions need to be made on when to cease milling as this creates process water that needs to be managed. ERA outlined the various concurrent stages of the PFS up until April 2013 and advised further consultation with stakeholders and the MTC would be required.
08/09/11	ARRAC meeting 36	ARRAC members	Update on brine disposal options under consideration, including crystalliser and deep well injection of brine in Pit 1 or Pit 3.	GAC raised concerns regarding the slow rate of progress in planning for closure.	No closure related actions.
07 – 08/04/11	ARRTC meeting 26	ARRTC members	Trial landform update. Ecohydrology at analogue sites.	ERA staff commended on the quality of their presentations and thanked for providing the opportunity for ARRTC to visit Ranger.	Minuted
28/03/11	ARRAC meeting 35	ARRAC members	Status report on Pit 1 closure activities.	GAC raised concerns regarding the slow rate of progress in planning for closure.	No closure related actions.
11/11/10	CCWG meeting	CCWG members	Feedback on the use of sentinel wetlands post closure. Defining the meaning of culture. Defining how feedback on closure criteria is updated in relevant documents. Pit 1 closure. Agree on appropriate closure criteria for: Water, radiation; and soil sediment.	No responses or emerging issues from stakeholders.	No closure related actions.

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09/09/10	CCWG meeting	CCWG members	Information on the types of acceptable sentinel wetlands post closure. Defining the meaning of culture. Rio Tinto stewardship principles and IAEA sources for consideration. Inclusion of glossary in closure documents. Pit 1 closure. Provision of surface water datasets to CCWG and review of threshold criteria for groundwater release. Agree on appropriate radiation closure criteria. Agree on appropriate soil sediment closure criteria.	No responses or emerging issues from stakeholders.	No closure related actions.
25/08/10	ARRAC meeting 34	ARRAC members	Status on the closure of Pit 1, including future installation of wicks (Q4 2010) to promote consolidation of the tailings for final bulk backfill and pit closure.	No responses or emerging issues from stakeholders.	Minuted
08/07/10	CCWG meeting	CCWG members	Feedback on the use of sentinel wetlands post closure. Defining the meaning of culture. Inclusion of Rio Tinto stewardship principles in closure documentation. Pit 1 closure. Radiation closure criteria. Draft soil sediment closure criteria.	No emerging issues were raised by stakeholders on the topics presented.	Closure document updated with Rio Tinto principles of stewardship. Water closure criteria: Criteria amended to read "groundwater release (“seepage”) from the final landform will not induce flow to Magela Creek".
21/04/10	ARRAC meeting 33	ARRAC members	ERA presented an overview of the process water management strategy, which is a long term strategic plan, highlighting elements of water management.	Water management plan requested by the Environment Centre (NT).	ERA advised that the report would be provided at the ERA presentation later in the year.
07 – 08/04/10	ARRTC meeting 25	ARRTC members	Conceptual rehabilitation options for the Ranger LAAs, including preliminary dose estimates for LAAs. Groundwater flow and tailings consolidation modelling, Pit 1 closure. Update on trial landform monitoring results. Hydrochemical considerations relating to process water treatment and salt management.	No emerging issues were raised by stakeholders on the topics presented.	ERA advised that a Pit 1 consolidation model report would be completed in a few months. Updates on the trial landform would continue. Update on LAAs provided.

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04 – 05/11/09	ARRTC meeting 24	ARRTC members	Trial landform construction, planting and ongoing management and monitoring. Characterisation of catchments in the Ranger region. Development of complex surface water models to understand fate and behaviour of process water permeate in the system. Ongoing collection of ecophysiology and soil-moisture monitoring data at the Corridor Creek analogue site. Assessing the extent of radiological contamination in the LAAs. Evaluation of catchment issues and hydrological-hydrochemical behaviours in the RP1 catchment. Pit 1 closure studies (incl. surface water – ground-water interactions in the Corridor Creek catchment).	No emerging issues were raised by stakeholders on the topics presented.	Pit 1: ERA to present on the current status of Pit 1 closure issues and planning at the next meeting. LAAs: ERA to present the conceptual rehabilitation plan for the LAAs at the strategic level at the next meeting. ERA to outline what makes that plan robust and check the science is there etc. Trial landform: ERA to provide six-monthly updates on both the trial landform and the eco-hydrology analogue site study.
22/10/09	CCWG meeting	CCWG members	Presentation given on developing cultural closure criteria in tropical Australia. Key assumptions available for comment - ongoing. Water modelling to determine trajectory and impacts of ground water on environment. Feedback on the use of sentinel wetlands post closure. Initial flora and fauna criteria. Identify land use and vegetation types. Identify criteria for Gulungul Creek.	Meeting adjourned to Nov 2009.	No actions required
27/08/09	ARRAC meeting 32	ARRAC members	Closure planning update on development of the trial landform.	Method of operation of process water treatment questioned.	Method of operation described by ERA representatives during the meeting.
07/05/09	CCWG meeting	CCWG members	Draft statement of next land use attributes to developed using existing documents. Key assumptions available for comment. TOR updated. Consider how to incorporate other water bodies into closure criteria - ongoing. Land zonings as controls for locations that are not suitable for uses above the identified beneficial use - ongoing. Groundwater trajectory modelling as closure criteria – ongoing. Closure criteria water model forwarded to CCWG for feedback.	Djalkmarra Billabong will need to have a closure criteria quality, which can be determined through water modelling to determine the trajectory and impact of ground water on the environment. Traditional owners’ view is that there should be no new water bodies on site.	No closure related actions

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07/04/09	ARRAC meeting 31	ARRAC members	Commencement of active process water treatment and disposal options, including bench scale testing in the brine concentrator to make distilled water. Examination of passive process water treatment and disposal options, including evaporation ponds. Trial landform progress, including: Installation of soil moisture probes; planting of tubestock in Mar 09; near completion of 1 of 4 erosion plots; and, partial installation of watering system over 2.67 ha.	Method for long term isolation of tailings requested. The complexity of accelerated evaporation ponds was highlighted for ERA's consideration.	Ranger Authorisation specifies tailings must be placed back in pits. Complexity of evaporation ponds was noted.
18 – 20/03/09	ARRTC meeting 23	ARRTC members	Pit 1 hydrogeological conceptualisation and initial calibration solute transport model Reaching of agreement by CCWG on the terms of reference; progress on the trial landform Revision of the closure model; assessment of radiological contamination levels in LAAs Pit 1 geochemical studies	Pit 1: ERA commended on its comprehensive forward program for the two Pit 1 closure studies and endorsement of the proposed approach. LAAs: ARRTC member noted the work appears to be covering the key issues and the key issues are not so much the actual values being measured but the difference between pre-mining and present. Trial landform: Delays in progressing the construction of the trial landform and management of the proposed irrigation regime.	ERA to arrange for progress reports on the WRL and CSIRO work on hydrology and tailings modelling to be provided to ARRTC member. Trial landform: ERA stressed the importance of gaining knowledge and experience regarding irrigation during the dry season, as it may be a vital strategy in order to complete revegetation within the planned timeframe.
16/02/09	CCWG meeting	CCWG members	Develop a draft statement of next land use attributes. Review and add to list of key assumptions. Incorporate other water bodies into closure criteria. Land zonings as controls for locations that are not suitable for uses above the identified beneficial use. Appropriateness of groundwater trajectory modelling as closure criteria. Distribution of Ranger closure criteria water model to CCWG.	Land use should use existing document sources, such as: Closure model, NLC traditional land use, environmental requirements. Water quality criteria will need to be met; Djalkmarra Billabong will need to have a closure criteria quality. This can be determined through water modelling to determine the trajectory and impact of ground water on the environment and other. Traditional owners' view is that there should be no new water bodies on site. Agreed that modelling should be used to determine trajectories for impact on the environment.	NLC and GAC to engage with stakeholders for feedback on sentinel wetlands ERA identify existing bores and how they may be used to identify areas for groundwater modelling.
09/12/08	CCWG meeting	CCWG members	Develop a draft statement of next land use attributes. Stakeholders to review and add to the list of key assumptions. Review KKNs and provide feedback. Agree timeline for closure criteria. Incorporate water bodies into closure planning. Ensure safe future use of groundwater and surface water; reduce risk to future users of the land.	Key assumptions for progressing closure and closure criteria.	Additional agreed key assumption all other infrastructure removed from site. (NB: this can be in the form of infrastructure removed from the surface and buried in the pits.)

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10/11/08	CCWG meeting	CCWG members	Stakeholders to start documenting a list of key assumptions. ERA to commence a list of assumptions and send to stakeholders. Compare themes with Key Knowledge Needs.	Key assumptions for progressing closure and closure criteria.	CCWG agreed the following key assumptions: Next land use statement developed to define post closure land use. Jabiru East airport and associated tourist infrastructure will remain post closure (Jabiru town out of scope). New power supply for Jabiru established. Ranger power station removed. Jabiru East camps removed. Public access road decommissioned back to a nominal point (i.e. airport turnoff). Access to site maintained as track. RPA boundary fencing removed. Tracks decommissioned except where access required for monitoring. Minor post-closure infrastructure retained at agreed location on lease. All services currently supplied to Jabiru East will be supplied from Jabiru, i.e. Power, Water. ERA's mining operations end at 2020, with lease expiry in 2026.
22 – 24/10/08	ARRTC meeting 22	ARRTC members	ERA update on a number of closure studies, including: Evaluation of Pit 1 closure strategies; solute transport modelling; geochemical behaviour of tailings; establishment of the MTC CCWG and draft terms of reference.	No emerging issues were raised by stakeholders on the topics presented.	Minuted
01/10/08	CCWG meeting	CCWG members	Discuss future land use by traditional owners as a basis for deciding closure criteria themes. Set themes, priorities and future actions.	Key assumptions for progressing closure and closure criteria.	CCWG agreed the following key assumptions: Scope of closure criteria working group to be focussed on RPA. Jabiru East airport will remain post closure.
19/08/08	CCWG meeting	CCWG members	ERA to update on TOR as part of 1.a with assumptions. Ranger Environmental Requirements to be discussed within the context of closure. Issue paper on traditional ecological knowledge to be distributed to members.	Groundwater abstraction post closure.	CCWG agreed that a constraint on groundwater abstraction from Ranger operational area and some surrounds will be needed to prevent bores being sunk in areas where water will be unsuitable for use.

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07/08/08	ARRAC meeting 30	ARRAC members	Planning for the trial landform, which will confirm ecosystem re-construction strategies; and behaviour of rehabilitated landforms at Ranger prior to closure Progressing evaluation of Pit 1 closure strategies – e.g. CSIRO solute transport modelling; and CSIRO geochemical behaviour of tailings. Establishment of a MTC CCWG – draft TOR with stakeholders for comment; and meetings to initially finalise TOR and working arrangements, and then commence development of final closure criteria set for 19 Aug 08. Ongoing field investigations of LAAs, ahead of preparation of rehabilitation plans.	Laterite use in trial landform queried. No responses provided for other topics.	Response regarding laterite experiments provided during the meeting.
18/03/08	ARRAC meeting 29	ARRAC members	Oct 07 evaluation of closure implications completed for Shell 50 extension. Substantially revised Ranger Closure Model (v3) submitted to stakeholders for comment in Nov 07. Planning for construction of a demonstration (final) landform in 2008 – progressing. Establishment of a MTC CCWG, TOR paper in preparation - planned for Apr 08.	Use of Shell 50 and its implications for closure was questioned No responses provided for other topics.	Response to Shell 50 queries provided during meeting.
06 – 07/03/08	ARRTC meeting 21	ARRTC members	ERA update on Ranger operations including the preparation for the closure of Pit 1. ERA presentations on the following: Assessment of radiological condition in the land application areas (LAAs) and rehabilitation planning; update on the Ranger surface water – groundwater interaction study; status of planning for the trial landform. Other closure activities covered included: An update on the development of closure criteria – e.g. derivation of water quality closure criteria for Georgetown and Coonjimba Billabongs; analysis of soils from analogue sites; and the status of the ecological risk assessment of the Magela Floodplain. The requirement to define the baseline data/ reference state that existed at the Ranger site prior to development. This will inform the process of the development of closure criteria, which is compatible with the ERs.	LAAs: Traditional owners requested scraping of the top 10 cm of the whole MLAA and are highly concerned about the status of the other LAAs. General ARRTC support for ERAs project on the radiological characterisation of the LAAs. Trial landform: ARRTC stressed the need to maximise opportunities from the trial. ARRTC noted ERA's proposed approach for the landform planning, and was fully supportive of progress so far. ARRTC requested they be formally consulted by ERA in relation to the design and implementation of the trial landform.	LAAs: The definition of radiation exposure pathways in the LAAs and the estimation of radiation doses to the critical group using a Dose Model will determine the level of rehabilitation that ERA will need to undertake. Trial landform: ERA noted the need to also keep the trial simple; that the key is to lock in a species list as soon as possible and then have further discussion on how to measure turbidity in runoff and other details.

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08 – 10/10/07	ARRTC meeting 20	ARRTC members	Discussion on the estimated timeframe for closure of Ranger, in particular the closure of Pit 1 and Pit 3. ERA presentations on: Environmental tracers in modelling groundwater recharge/discharge at Ranger overview of the status of the trial landform and understanding plant-water relationships, erosion rate, and natural diversity accumulation the status of closure planning and geotechnical investigations around Pit 3 an outline of the various water management strategies/ scenarios to minimise water inventory, including restoring catchments, use of rock lined channels and evaporation basins.	Trial landform: ARRTC to comment on the initial design of the trial landform to be provided by ERA. Stakeholder engagement: No defined process for stakeholder engagement on closure issues over the preceding 18 months. Pit 1: Potential to delay closing Pit 1 if ERA intended to use the pit for additional tailings storage.	Stakeholder engagement: ERA stressed the need to adopt a flexible approach which provides for addressing stakeholder input, otherwise the process may be perceived as being a rubber-stamping process. Pit 1: ERA commenced tailings deposition in the pit in August 1996. In May 2005, ERA submitted a second application to the MTC, to increase the tailings deposition level in the pit to an interim 12 mRL, which was approved by the Minister in August 2005.
21/08/07	ARRAC meeting 28	ARRAC members	Drafting update to Closure Model for issue in September. Trial landform construction planned before year end. Pit 1 tailings modelling completed, proposed schedule: Installation of wick drains 2009; Pit kept open as potential contingency for process water / tailing storage; Backfilling scheduled for 2012 / 2013 Water balance model completed and in use for developing both short and long term water strategies. Next phase to address development of closure criteria and associated studies	The use of Pit 1 and Pit 3 as tailings repositories was queried.	The Ranger Authorisation specifies tailings must be placed back in pits.
12/04/07	ARRAC meeting 27	ARRAC members	Closure planning update on decommissioning of the acid plant.	Clarification sought as to whether the acid plant would be removed as part of decommissioning.	Acid plant was decommissioned as part of the construction of the brine concentrator.
08 – 09/03/07	ARRTC meeting 19	ARRTC members	ERA presentations on: Vegetation types and environmental trends in Ranger analogue areas Ranger landscape design and reconstruction update on land management projects at Ranger and the drafting of an issues paper on ecosystem closure criteria site-wide hydrological characterisation of the Ranger mine.	ARRTC requested a copy of the ERA vegetation criteria report. ARRTC expressed interest in commenting on the experimental design document for the trial landform and to visit the site in the future.	ERA agreed to provide a copy of the requested report and engage further with ARRTC on the design of the trial landform.
Mar 07	Kakadu Board of Management (KBM) meeting	KBM members	Discussion on ERA's planning for the eventual closure of the Ranger mine. This included an outline of ERA's 3-stage closure program: Development of initial closure strategy, which defines the current knowledge base and identifies gaps to be filled. Development of a detailed closure strategy which includes determining the best options to close the Ranger site. Addressing knowledge gaps and developing detailed project implementation plans.	No emerging issues were raised by stakeholders on the topics presented.	ERA agreed to continue to provide regular updates to board members.

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Nov 2007	Issue of Ranger Closure Model	MTC members	Closure model document (v2007) was circulated to stakeholders, which elicited feedback from SSB.	Feedback on closure model provided by SSB.	Feedback from SSB was incorporated into 2010 closure model.
15/11/06	Meeting with traditional owners at Manabadurma (Mula II)	Mirarr, GAC Members, NTDPIFM, OSS, ERISS, NLC, ERA	Discussion took place on the following: Reoccupation of traditional lands. The closure schedule. Similarity of the final landform to the pre-mining landscape. Remediation of the tailings dam. Clean soil and edible bush tucker.	Main issues raised at the meeting included: Fire Weeds – use of aerial herbicide spraying and ongoing weed management. The size of rocks on the surface of the final landform. Mirarr want to see rock sizes like the natural sizes that exist in undisturbed places. Access to riparian areas of the RPA as early as possible post-closure for the purpose of teaching their children traditional values and practices. Concern that extensions to Pit 3 and potential underground mining will delay rehabilitation and closure. Underground access to R3D and possible leakage to the environment. The performance of the Pit 1 barrier. Clean up of riparian zones, and other places on the RPA identified by Mirarr.	Fire and weeds: The plan is to exclude fire from revegetated areas for several years until the new plants have become established. After that, traditional fire management would be introduced progressively on those areas. A fire management plan was being developed for use as a weed management tool instead of relying on aerial herbicide spraying. ERA looking at the best methods of controlling weeds. ERA requested TO advice on their traditional fire management practices, weed management techniques, fruit and tucker species for inclusion in the revegetation mix, and distinction between “weeds” and useful plants, whether native or introduced. Revegetation: ERA noted that seedlings are more expensive than seeds, but can have higher success rates. Surface of final landform: Rock size was acknowledged as requiring attention. Land access: ERA supported Mirarr requirements in respect of land access once it knows what those requirements are. Pit 1 barrier: Currently working as predicted. 2026: ERA confirmed its intention to rehabilitate and close the RPA by the statutory date of January 2026.
17 – 18/10/06	ARRTC meeting 18	ARRTC members	ERA presentation on long term closure planning at Ranger including: Background, outline, objectives and key stages of the closure process.	No emerging issues were raised by stakeholders on the topics presented.	No actions required
22/08/06	ARRAC meeting 26	ARRAC members	Feedback from GAC on the “first pass” draft closure model 2005.	Traditional owners were pleased with many aspects of the model but had reservations on some aspects, which would be outlined in their response.	Traditional owner expectations to be progressed at the next consultation – Mula II on 15 November 2006 and include the following topics: The GAC has suggested 25 years of monitoring following this date, 5 years not considered long enough. Incorporation of RPA into KNP – ideal outcome. Change vs impact.
Jul 2006	15th Australian Weeds Conference	Peer review	Paper presented on developing closure criteria for weeds on Ranger mine	N/A	No actions required
04/04/06	ARRAC meeting 25	ARRAC members	Closure planning update including overview of infill planting at Jabiru East and MBL bund on RPA.	No responses or emerging issues from stakeholders.	No actions required
Mar 2006	Issue of Ranger Draft Closure Model	MTC members	Closure model document was circulated to stakeholders, which elicited a detailed response from tradition owners on final landform issues.	Extensive stakeholder feedback on the closure model.	Stakeholder feedback considered in ongoing iterations of the model/ plan.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
27 – 28/02/06	ARRTC meeting 17	ARRTC members	Discussion on grade 2 and 3 ore and implications for backfill during the rehabilitation phase. Status of investigation and modelling for approval to deposit tailings in Pit 3.	No emerging issues were raised by stakeholders on the topics presented.	No actions required
06/12/05	ARRAC meeting 24	ARRAC members	Life of mine update including overview of key assumptions outlined in the "first pass" Ranger closure model, completed June 05.	No responses or emerging issues from stakeholders	No actions required
02/12/05	Technical workshop	MTC members, Charles Darwin University, External consultant	Landform workshop, focussing the selection and analysis of analogue landforms which have similar geomorphological and hydrological characteristics to that likely to occur on the rehabilitated landform. The concept for the rehabilitated landform is based on: design rules radiation protection seepage/hydrology controls The general concepts for the landform should not be affected significantly by any changes to the life-of-mine-plan; on the basis of current knowledge that there are not likely to be large waste rock volume changes.	Tailings dam: What's planned for the tailings dam in terms of rehabilitation and final landform construction? How will the dam core be dealt with? A question was raised about the fate of the groundwater mound. The matter of catchments reconstruction was raised – should surface drainage (and seepage) be directed towards Coonjimba or Djalkmarra? What's the timing for removal of the mine access road? If landform stockpile covers are used, what purpose does a cover serve (for example, erosion protection, radiation suppression, ecosystem support)? What designs are needed? The geotechnical stability of the final stockpile landform should be addressed. The impact of extreme events on the stability-behaviour-geomorphic evolution of the final landform is an issue to be addressed. Have off-site hydrogeological assessments been considered? What about flows from seepage into (through) sentinel wetlands?	ERA plans to have a first draft of the final landform concept to the MTC in December 2005 or early 2006. The design of the final landform should be approved as soon as possible, and well before mining in Pit 3 ceases at Ranger. This will enable the construction of the landform to commence as soon as possible after this event, depending on detailed scheduling of operations.

16/11/05	Meeting with GAC at Mula	NLC, Mirarr, former DIPM, ERA, Office of the Supervising Scientist, and ERISS	Discussion on final land use objectives, including aspects of final landform scheduling, backfilled pit landforms, land surface rockiness, tailings storage facility rehabilitation and water course reinstatement.	Rock size: The size of the rocks left on the surface outside of the pits –exposed rock should be no larger than golf-balls to allow easy foot access across the site. Erosion: The potential for erosion of the finer materials to expose such rocks outside of the pits – the brown rocks and soils may wash away and expose larger or contaminated material. Land access: The length of time required before access to the land would be available for access. Radiation levels: Material high in radioactivity may remain on the surface. Seepage from pits: May impact upon useable water supplies downstream at Mudginberri. Flow of contaminated water into the reconstructed Djalkmarra Billabong: Considerable concern over the potential for flow of contaminated water into this creek. The future of RP1: Mirarr discussed three options for RP1; retain it, remove it or reshape it into a smaller wetland. Safety of food sources: Concern that geese and fish using RP1 may be contaminated and that this may occur in other areas where water pools on the rehabilitated site. Similar concerns about native fruits and transient animals, as these are important for hunting and gathering by their descendants. Mirarr believe that if revegetation is done properly then animals would return naturally to the site. Open woodlands of woolybutt, stringybark moving to pandanus and melaleuca would be acceptable. Speargrass and natural djilli djilli would be acceptable to promote the return of wallaby and goanna species, allowing for resumption of normal hunting patterns. Planting of edible native fruits is expected: Return of an environment containing green plums, red apple, white apple and yams is essential to allow resumption of normal gathering practices in the future. Rain halted discussions.	Rock size: ERA indicated that larger rocks are required for stability, but that the top 5 metres in the pits would consist mainly of brown, weathered rocks mixed with some larger rocks. It should be feasible to meet small size requirements for surface rocks, but this would need to be further investigated. Erosion: The weathered rocks are suitable for tree growth and would be utilised wherever possible to ensure a stable, vegetated surface. A low, flat contour would also assist. Use of imported soils could be considered, but this could lead to a significant increase in the presence of weeds. Land access: ERA indicated it will take several years to refill Pits 1 and 3 and the ultimate fate of the tailings dam needs to be carefully considered as it will seep contaminated water for a while after removal. Monitoring is expected to cease around 2030, so it is expected that full access would not be recommended for ten to fifteen years after closure. Radiation: Supervising Scientist indicated burial of the most highly radioactive material along with tailings at the bottom of the pit would significantly reduce the amount of radiation and other associated chemicals that could be transported to the surface. Seepage from pits: ERA indicated that groundwater flows off-lease are not yet well known and that more work tracking them is required. Flow of contaminated water to reconstructed Djalkmarra Billabong: ERA suggested that a sharp rise on this side of reclaimed Pit 3 may be required to direct water flow inwards to wetland Filters and the re-established Coonjimba Creek bed. A wetland filter in this location may be required to manage water coming from the site of the resumed tailings dam and direct it into Coonjimba for final polishing. Future of RP1: The main aim is to ensure that the smallest amount of water possible is allowed to pool on the rehabilitated pit area. The preference would be to remove RP1 and place the mud into the Pit. However, this may not be possible as RP1 may be the last part to be rehabilitated. Further thought is needed, but Mirarr indicated a preference for removal of RP1. Safety of food sources: ERISS have been testing these species for radiation contamination and that there have not been any indications so far of serious problems. Mussels that live inside the mud of RP1 may be contaminated as they bio-accumulate chemicals easily. ERISS are continuing with testing for contaminants in edible fruits collected from Nabarlek site. Animals tested so far

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
					do not indicate any signs of contamination, but further tests could be done.
04 – 05/10/05	ERA Ranger Weed Workshop	Representatives of KNP, ERISS, GAC,NLC, former NRETA Weeds Branch, DME, CDU, former DEH, and ERA	Establishment of a shared vision for weed thresholds upon closure of the Ranger mine. Identification of key knowledge gaps and ways in which these knowledge gaps can be closed.	The group developed a shared vision for the long-term management of weeds on the Ranger Project Area and identified actions needed to meet that vision.	Minuted meeting. Ongoing stakeholder collaboration. A draft list of weed species was prioritised for management, and ways to better manage these species were also discussed.
31/08 – 02/09/05	ARRTC meeting 16	ARRTC members	Update on ERA closure projects including Landform design ecosystem establishment groundwater dispersion water treatment and landform monitoring	ARRTC noted the need to consider higher resolution data to predict extreme rainfall events.	Minuted meeting with no closure related actions.
16/08/05	ARRAC meeting 23	ARRAC members	Closure planning update with briefing on the Ranger mine closure model, including life-of-mine decommissioning and rehabilitation; first pass assessment of full closure; and status of different assumptions.	Minutes not available.	N/A
28/02 – 01/03/05	ARRTC meeting 15	ARRTC members	Update on developing a framework for surface water quality closure criteria for the RPA. Assessment of the state of the irrigation areas and fate of contaminants and linkages with radiation does from the final landform. Update on the Ranger final landform design issue, noting the relationship between the land and the plant community on the land.	Main issues regarding surface water quality pertained to potential sulphate loads estimates. Stakeholders noted that the decommissioning of LAAs requires consideration of movement of contaminants through groundwater. General satisfaction with LAA (irrigation area) work. General satisfaction with final landform design project.	Minuted meeting ERA recommended a mixing model be adopted, incorporating a broader range of factors to assist with determining surface water quality closure criteria.
13 – 15/09/04	ARRTC meeting 14	ARRTC members	Update on ERA project funding and expected timeframes to address priority KKNs. ERA presented a paper *Hydrological and mining influences on solute flux in creeks flowing within the Ranger Lease – Phase 1: Concentration variation and solute loads in Magela Creek*. The study also described issues related to the Corridor Creek system which feeds into the Magela Creek system.	Further update on Magela Creek solutes loads requested.	ERA to provide an update paper and presentation on the Magela Creek work at the next ARRTC meeting.
15 – 16/03/04	ARRTC meeting 13	ARRTC members	Discussion around the timeframe for Ranger rehabilitation – e.g. whether it was realistic or indicative. ERA presentations on Ranger final landform design and Ranger revegetation strategy.	Questions raised by ARRTC members covered the following topics: landform slope ratios traditional owner input into landform design and floristic species composition current iteration of the landform design – i.e. first cut or pre-design species presence/absence versus species abundance.	Minuted meeting All issues raised were addressed during the presentations. ERA noted that (floral) community structure was based on initial species, and should be regarded as a first pass approach and is not a quantitative ecological examination. ERA also noted at traditional owners were being engaged on all aspects of closure.

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
15 – 17/09/03	ARRTC meeting 12	ARRTC members	ERA gave a presentation on mine closure criteria and paper, focussing on mine closure goals, the primary ERs, the closure philosophy, closure planning and the draft final landform.	Divergence in potential long-term revegetation research strategies between ERA and an ARRTC member. ARRTC: Noted Ian Hollingsworth's presentation on mine closure criteria; Endorsed the approach Expressed concern about whether a functional ecosystem could be reinstated, and The need to start canvassing social values.	Minuted meeting ERA indicated they did not need to agree with all feedback by ARRTC members on revegetation research and success. CSIRO undertook and assessment of ERA revegetation strategy in October 2002, which indicated "in principle" agreement with ERA's proposed revegetation strategy. The Key Knowledge Needs document to be finalised and provided to ARRTC.
17 – 19/02/03	ARRTC meeting 11	ARRTC members	ERA advised that closure criteria is an emerging issue and solicited members' views as to the processes that might be used to develop criteria. ERA outlined its process of developing a series of criteria for closure, with radiological, geomorphic, geotechnical and target ecosystems all being issues. Key areas of discussion included: the development of credible scientific models; the need to benchmark the surrounding region; the division of ERs into specific criteria with specifications/ numbers for each criterion; stakeholder communication; and developing workable closure criteria for progressing the landform.	Emerging issue was the process for developing and establishing closure criteria. ARRTC independent science member gave a presentation on the current gaps and potential process for development of a successful revegetation strategy. ARRTC members were solicited for their views on developing closure criteria. Conceptual model of ecosystem processes and pathways for pollutant/propagule transport in the environment of the Alligator Rivers Region' to be developed further; ARRTC members agreed that closure criteria would be discussed at the next meeting, with a concept paper (looking at the broad parameters) being provided to that meeting; and ARRTC asked for a single EWLS/ERISS paper on radiological monitoring to be produced for the next ARRTC meeting.	Minuted meeting. No response from ERA required
16/10/02	Ranger site visit and traditional owner consultation	NLC, GAC and 17 traditional owners.	Site visit to Georgetown analogue area to discuss the broad vision for landscape reconstruction.	No issues	No action required
09 – 11/09/02	ARRTC meeting 10	ARRTC members	ERA focus on generating knowledge required for closure and rehabilitation of the Ranger mine site, including: process water treatment, tailings densification, and the deposition of tailings in Pit 1 above RL0.	Stakeholder responses were directed at understanding broader mine closure aspects such as the legislative approval process and mine closure criteria closure process and revegetation.	Minuted – offline discussion between EWL Sciences and ARRTC independent science member regarding the development of a successful revegetation strategy to address emerging issues.
25 – 27/02/02	ARRTC meeting 9	ARRTC members	Pit 1 closure studies including: engineering behaviour of unconsolidated material; interaction between pore water and upper layers; interaction between pore water and other aquifers; integrity of sealing following consolidation; and subsidence with consolidation. Final landform construction including: Capped and revegetated pits; reformed tailings dam; and reformed waste stockpiles. Reconstruction of surface catchments.	No issues	No action required

Date	Description of engagement	Stakeholders	Ranger Mine closure topics	Stakeholder comments	ERA stakeholder response, actions and/or resolution
Nov 2001	ARRTC meeting 8	ARRTC members	ERA presentation "designing landforms to achieve ecologically sustainable outcomes". Objective was to achieve stakeholder agreement on the habitat targets for the final landform.	No issues	No action required

Energy Resources of Australia Ltd

5. Knowledge base

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ERA

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Cover photograph: Coonjimba Billabong

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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.
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, downstream of Ranger operations.
Magela Creek upstream	Abbreviated to MCUS. MCUS is the upstream statutory surface water monitoring point, location on the RPA.

Key term	Definition
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).
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.

Key term	Definition
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
AHD	Australian Height Datum
ALARA	As low as reasonably achievable
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
BC	Brine Concentrator
BOM	Bureau of Meteorology
BTV	Background Threshold Value
CCWLF	Corridor Creek Wetland Filter
COPC/COPCs	Constituent of Potential Concern/ Constituents of Potential Concern
CPT	Cone Penetration Test
CSM	Conceptual Site Model
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
EC	Electrical conductivity
ECVs	Environmental and Community Values
EDZ	Excavation-damaged zone
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
ERISS	Environmental Research Institute of the Supervising Scientist
ET	Evapotranspiration
GAC	Gundjeihmi Aboriginal Corporation
GCBR	Georgetown Creek Brockman Road
GCMBL	Georgetown Creek Mine Bund Leveline
GDE	Groundwater Dependent Ecosystem
GTB	Georgetown Billabong
HDS	High Density Sludge
HLU	Hydrolithologic Unit
HDPE	High-density Polyethylene

Abbreviation/ Acronym	Description
ISWWG	Independent Surface Water Working Group
ITWC PFS	Integrated Tailings, Water and Closure Prefeasibility Studies
KKNs	Key Knowledge Needs
LAA	Land Application Area
LAI	Leaf Area Index
LEM	Landform Elevation Model
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
NAQS	Northern Australia Quarantine Strategy
NLC	Northern Land Council
NSMC	Null space Monte Carlo
NP	National Park
NT	Northern Territory
OBS	Osmoflow Brine Squeezer
QQ plot	Quantile-quantile Plot
R3D	Ranger 3 Deeps
RCM	Ranger Conceptual Model
RL	Reference Level
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
RPC	Release Plan Calculator
PAW	Plant Available Water
PEST	Parameter Estimation Tool
PDF	Probability Distribution Function
PTF	Pit Tailing Flux
RSWM	Ranger Surface Water Model
SAQP	Sampling Analysis Quality Plan
SSB	Supervising Scientist Branch
TAN	Total Ammoniacal Nitrogen
TLF	Trial Landform
TPM	Total Particulate Metals
TPWS Act	*Territory Parks and Wildlife Conservation Act 1978 (NT)*
TSF	Tailings Storage Facility
TSS	Total Suspended Solids

Abbreviation/ Acronym	Description
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VAF	Vulnerability Assessment Framework
WRD	Water Resources Division
WTP	Water Treatment Plant

5 KNOWLEDGE BASE

The following section provides an overview of the environmental setting of the Ranger Mine, and a summary of completed and planned studies informing the closure implementation strategy. The section provides the context to planning mine closure and is a summary of a substantial knowledge base that has been accumulated by Energy Resources of Australia Ltd (ERA) and stakeholders from more than 30 years of monitoring and research investigations of the site and surrounding environment.

5.1 Social setting

5.1.1 Aboriginal culture and heritage

There is recent evidence of Aboriginal occupancy of the Kakadu region dating back more than 65,000 years.[2] 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 National Park (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 5 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

[2] 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

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 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.

5.1.2 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 and are discussed in Section 5.3.2.1.

5.2 Physical environment

With increasing contact between the region's Aboriginal people and other cultures from around the 17th century and a more permanent non-indigenous presence evident from the late 1800s (ERA 2014b). Historical land use within the Alligator Rivers Region has included indigenous occupation, buffalo hunting, missions, pastoral grazing, agriculture, mining exploration, uranium mining and tourism (Levitus 1995). The Magela catchment within the region (Figure 5-1) currently contains several land use types, including Kakadu NP, mining and native title lands. The catchment is largely within Kakadu NP, a World Heritage listed area and Ramsar site (Figure 5-2).

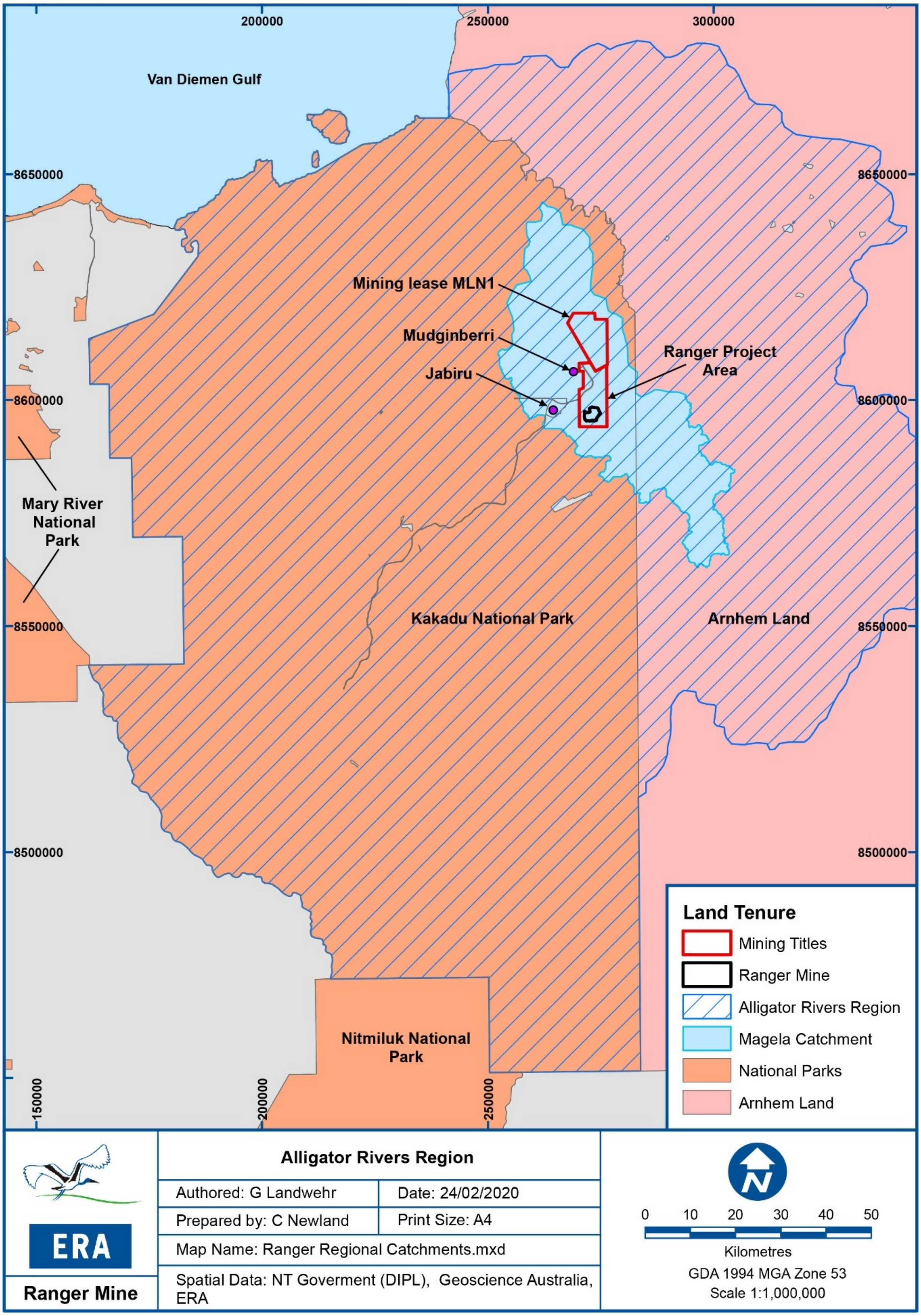
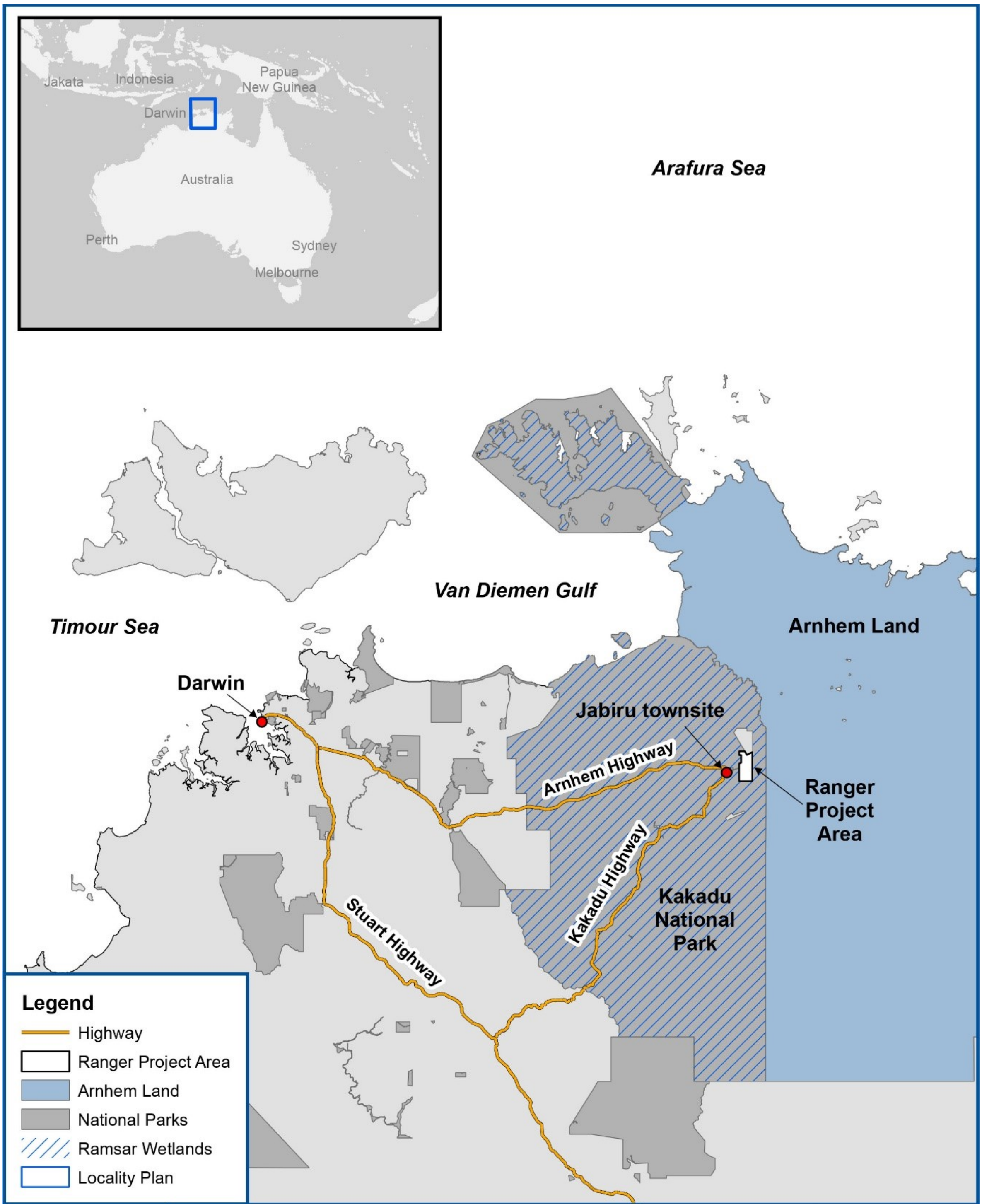


Figure 5-1 Geographic context for closure activities



Ranger Mine	Regional location of the Range Mine		0 20 40 60 80 100 120 Kilometres
	Authored: G Landwehr	Date: 20/02/2020	GDA 1994 MGA Zone 53
	Prepared by: C Newland	Print Size: A4	Scale 1:2,300,000
	Map Name: Ranger Mine Regional Location.mxd		
	Spatial Data: NT Goverment (DIPL), Geoscience Australia, ESRI Basemaps, ERA		

Figure 5-2 Regional location of the Ranger Mine

5.2.1 Climate

The climate of the Alligator Rivers Region, within which the Ranger Mine is located, is dominated by a seasonal wet-dry monsoon cycle with the large inter-annual and intra-seasonal variability largely associated with the effects of the El Niño Southern Oscillation, the Madden-Julian Oscillation and tropical cyclone activity (Trenberth *et al.* 2007). The wet season generally extends from late October to early April with predominantly westerly winds, whilst the dry season is dominated by easterly to south-easterly winds and extends from May to September. Historical climatic conditions for the Ranger Mine area are presented in Table 5-1.

The tropical cyclone season in northern Australia typically extends from November to April, averaging around two cyclones a year, with peak activity from December to March (BOM 2019a). Increased cyclone activity in the Australian region has been 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.

The region has a hot climate, with mean maximum temperatures ranging from just under 32 °C in June and July to just under 38 °C in October (BOM 2019b). 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.

Table 5-1: Historical weather data, Jabiru Airport

Parameter	Value	Month
Mean maximum temperature	37.7 °C	October
Mean minimum temperature	18.7 °C	July
Maximum average daily evaporation*	9.5 mm	October
Minimum average daily evaporation*	5.6 mm	March
Annual average daily evaporation*	7.2 mm	-
Annual rainfall	1,565 mm	-
Annual evaporation*	2,628 mm	-

Source BOM 2019b
**data available for 1973-1990 only*

5.2.2 Land systems

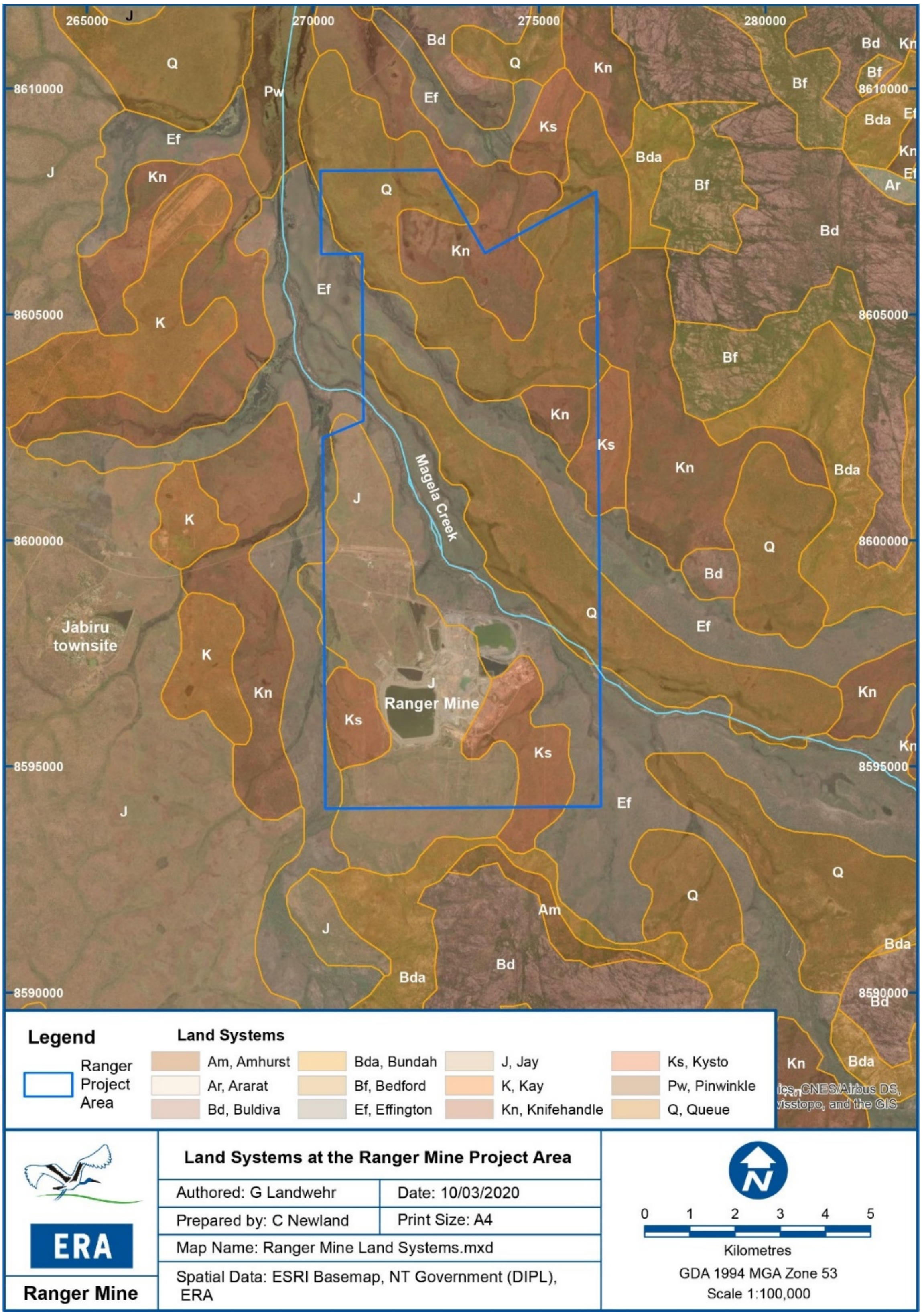


Figure 5-3 Land Systems at the RPA

5.2.3 Topography

The Ranger Mine lies on plains to the north of the Mount Brockman Massif, which is an outlier of the Arnhem Land Plateau. These plains are generally flat with numerous swamps and are rarely more than 45 m above sea level. South and east of Ranger Mine, the Arnhem Land Plateau escarpment rises to between 200 and 300 m above sea level. A major feature of the landscape is Mount Brockman, which rises 170 m above the plain, approximately 3.5 km south of Ranger Mine (Figure 5-4).

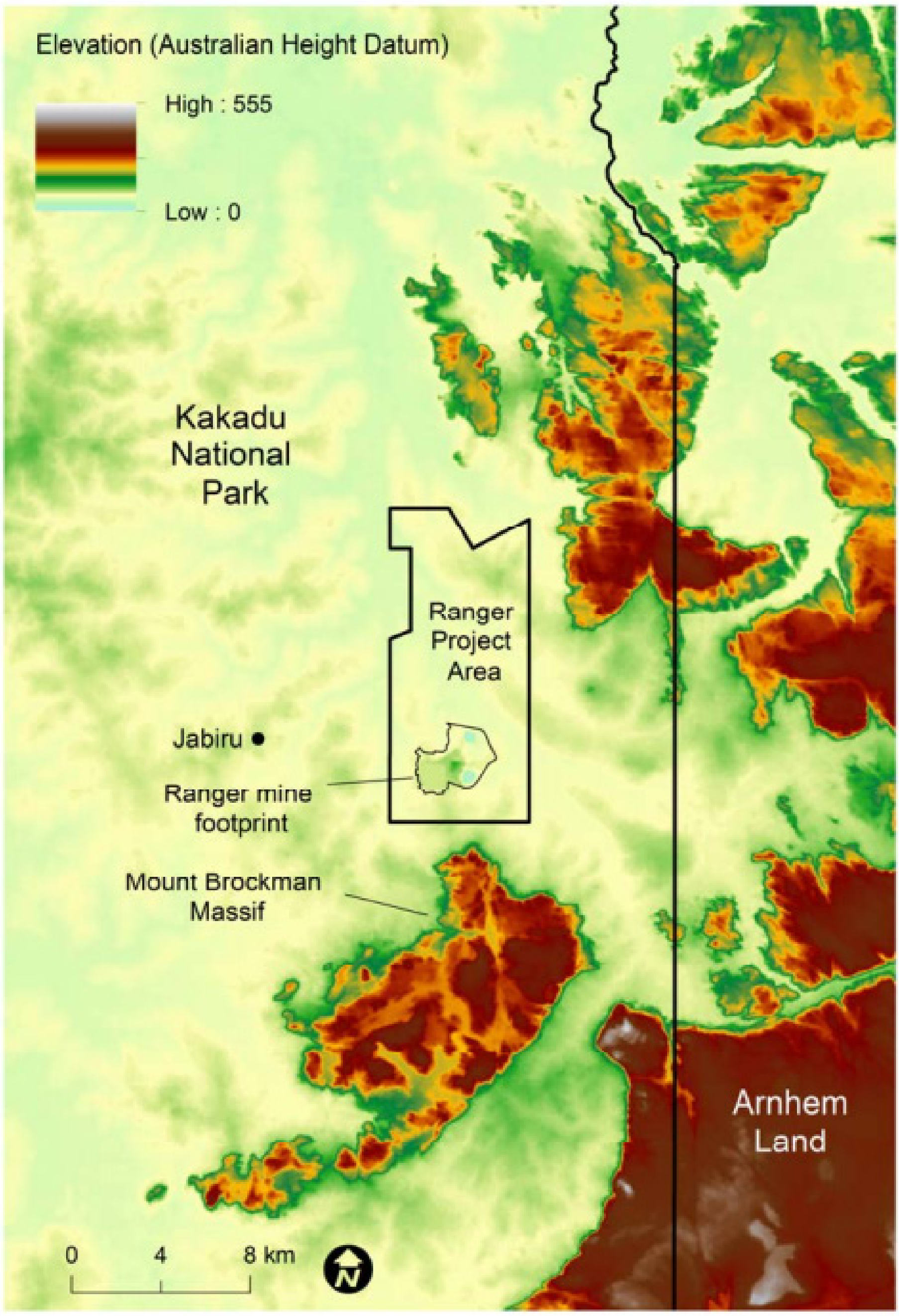


Figure 5-4: Elevation of RPA and the surrounding region

The Ranger Mine is influenced to varying degrees by the following four land surface categories:

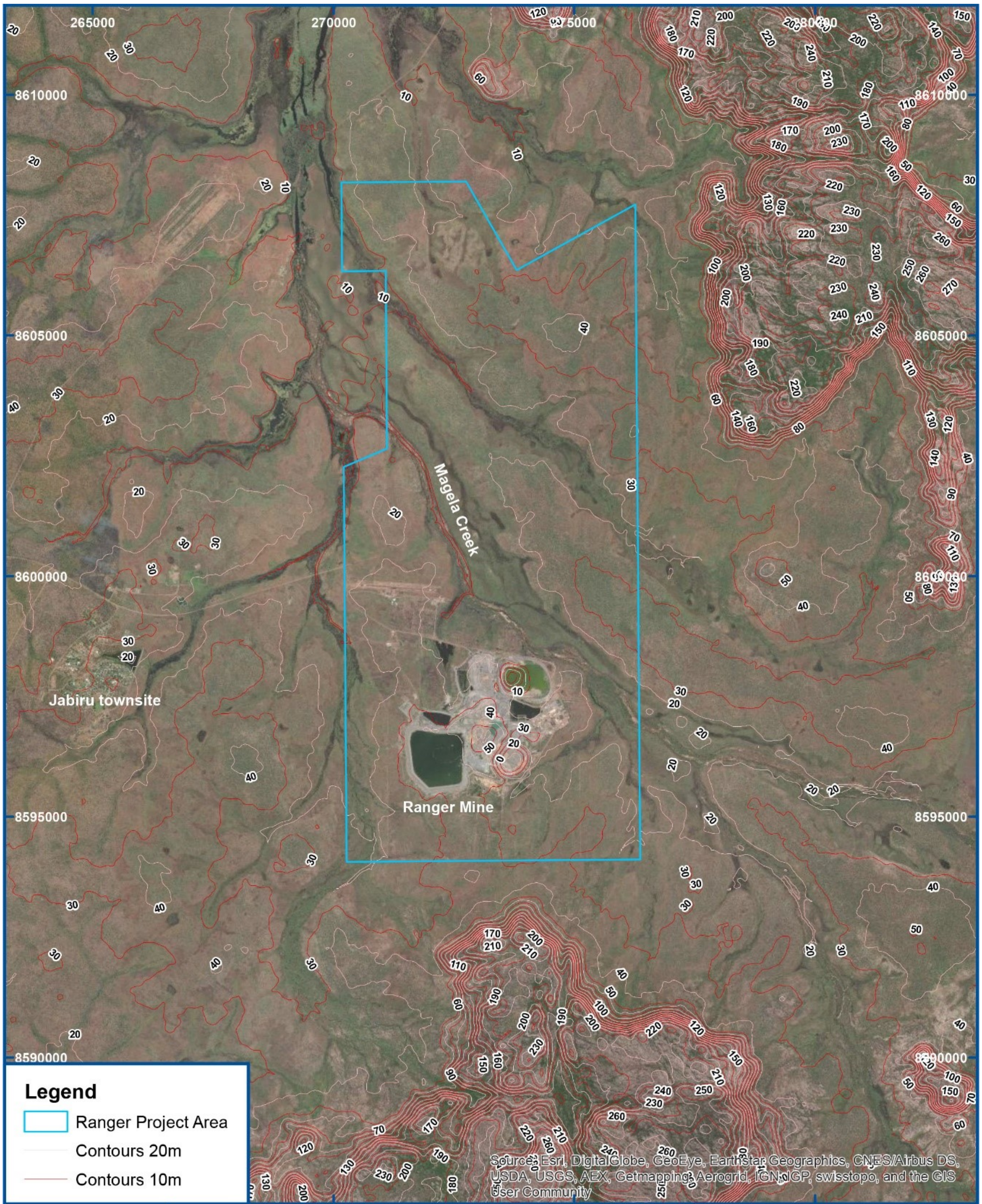
- The Mount Brockman Massif is a massive quartz sandstone outlier. Its steep escarpment and skeletal soils constitute part of the watershed of the Magela and Gulungul creek systems. Due to its resistance to erosion and low soil moisture retaining capacity, a large volume of localised rainfall is readily accumulated in the surface drainage networks and causes 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 part of the year, many months after the last rainfall.
- The Koolpinyah Surface, corresponding to the plains on which the Ranger Mine is located, is characterised by level, rolling or dissected lowlands. The surface consists of deeply weathered bedrock partly overlain by Late Tertiary to Recent sediments derived from the erosion of Cretaceous, Middle Proterozoic and Lower Proterozoic formations. These are mantled by ferruginous soils and ferricrete crusts.
- Alluvial plains have been formed by the flow of numerous rivers across the Koolpinyah Surface. The Magela and Gulungul Creeks flow in a northerly direction from the Mount Brockman Massif and dissect the RPA. Alluvial materials have been deposited by these creek systems to form the flat Magela floodplains to the northwest. Coarse, sandy Late Tertiary and Quaternary alluvial deposits cover part of the plains. These occupy channels of diverted streams and anabranches.
- Coastal plains extend north of the Koolpinyah Surface. These are flat, poorly drained and penetrate far inland along the broader river valleys.

5.2.4 Soils

The type (class) and distribution of soils across the land surfaces of the Ranger Project Area (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 particular 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 Section 5.2.5). The cation exchange capacity 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 5-6.



Ranger Mine	Contour map for the Ranger Project Area		GDA 1994 MGA Zone 53
	Authored: G Landwehr	Date: 10/03/2020	0 1 2 3 4 5 Kilometres
	Prepared by: C Newland	Print Size: A4	Scale 1:100,000
	Map Name: Ranger Project Area Contours.mxd		
	Spatial Data: ESRI Basemap, ERA, Geoscience Australia ELVIS contour data (Gallant *et al.* 2011)		

Figure 5-5 Contour map of the RPA and surrounds

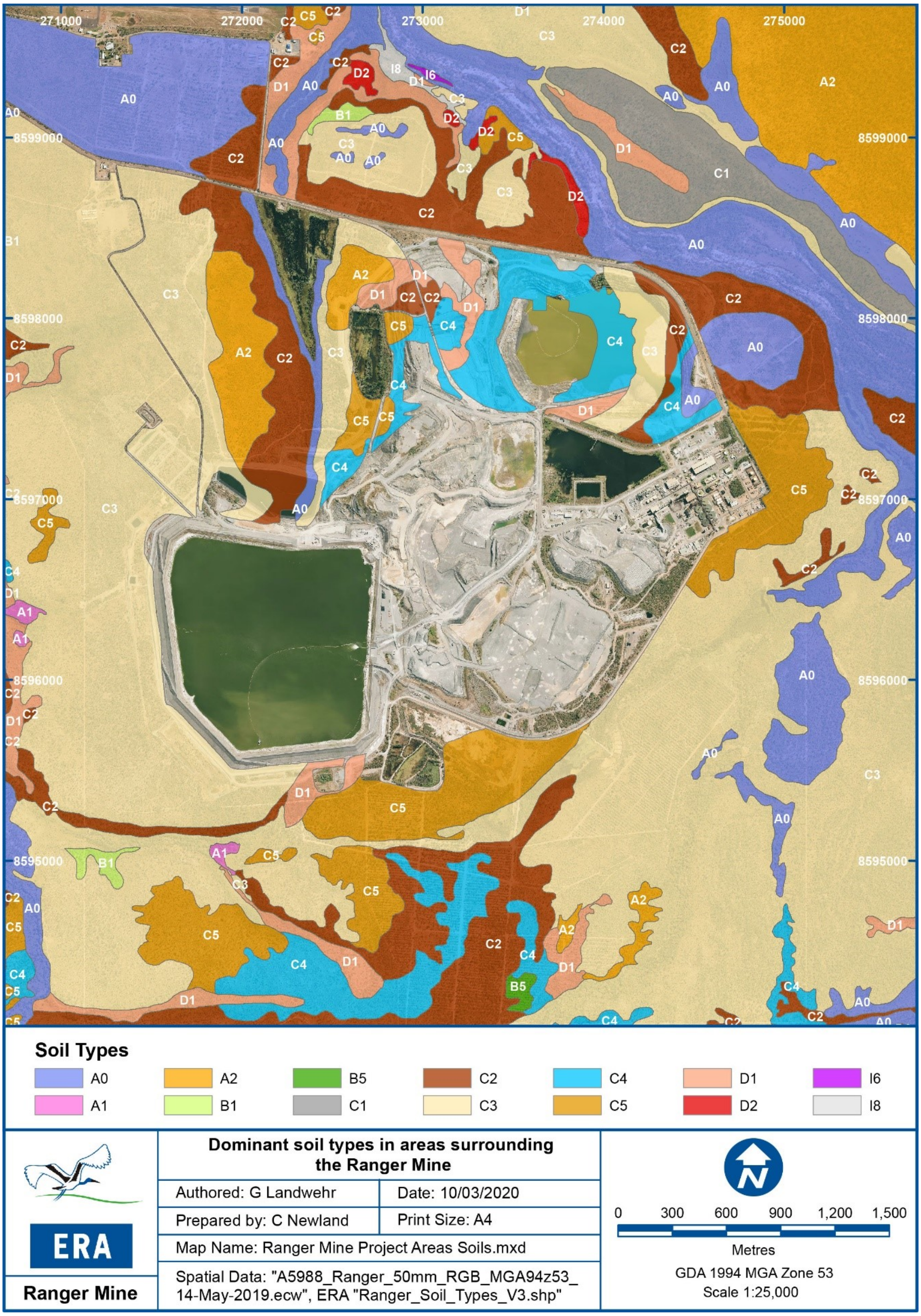


Figure 5-6: Dominant soil types in areas surrounding the Ranger Mine

Table 5-2: Brief description of soil characteristics around the Ranger Mine (Figure 5-6)

Map unit (Hollingsworth, 1999) (refer Figure 5-6)	**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, on account of the presence of naturally occurring piping, to impervious. The A and B horizons 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 (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.

5.2.5 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 5-7). 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 5-7

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 when saturated, weakly structured topsoils	Most erodible, very vulnerable to slope wash and gully type erosion, due to dispersive 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

5.2.6 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.

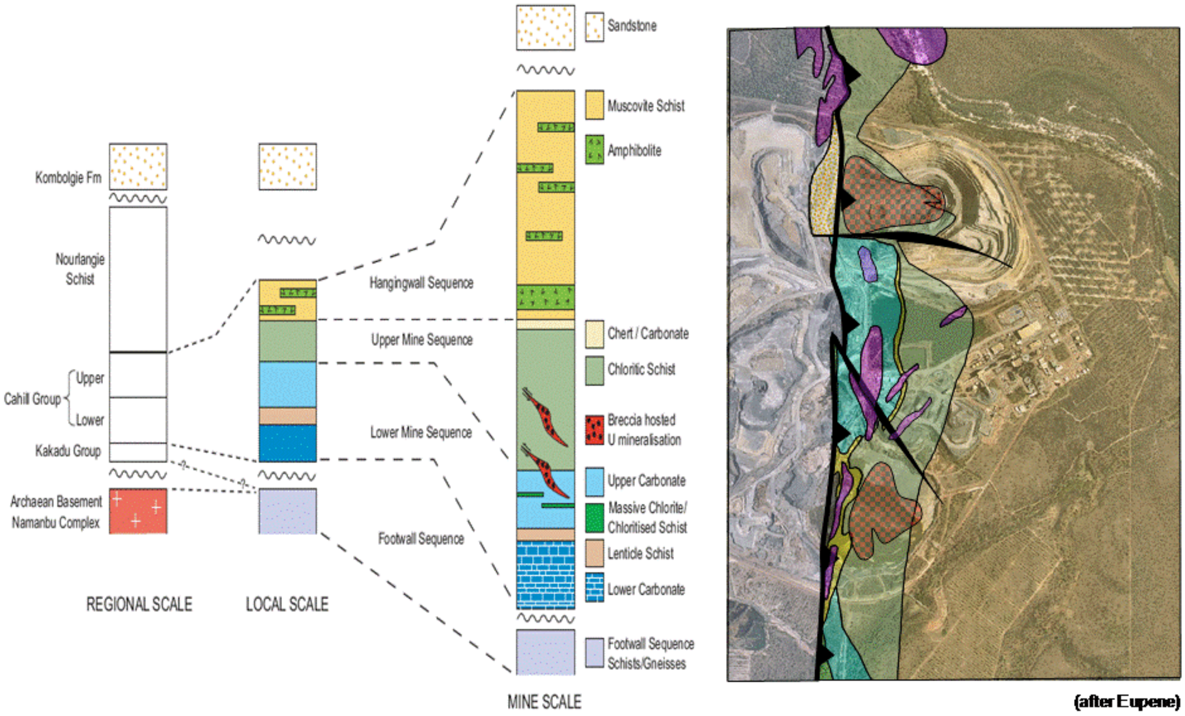


Figure 5-7: Stratigraphic sequence from regional to mine scale and corresponding geological map of the immediate area of the Ranger Mine orebodies

5.2.7 Groundwater and background constituents

The tropical, monsoon climate of the Northern Territory (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 rocks1F3 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 5-8 shows the annual groundwater level behaviour

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

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).

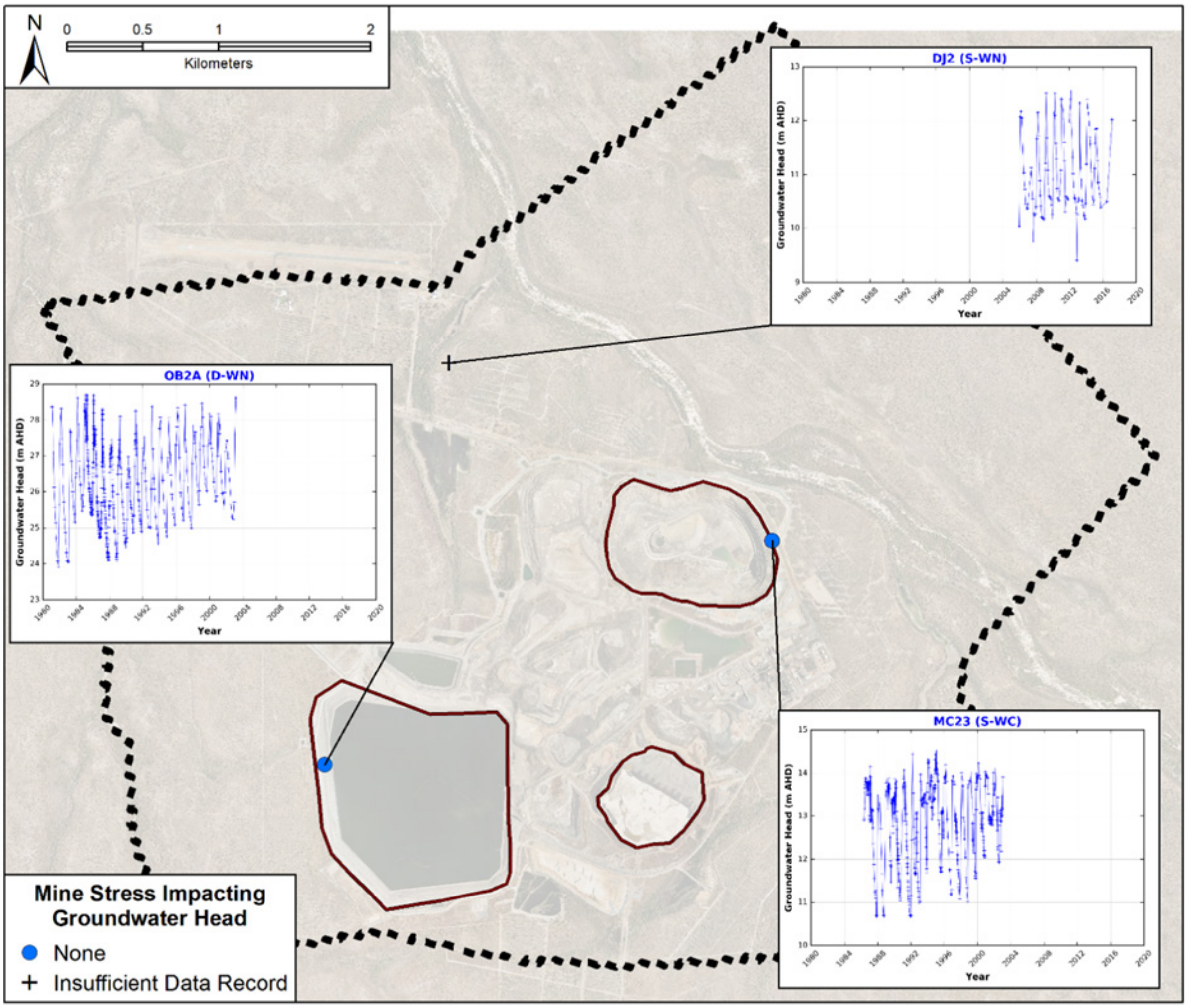


Figure 5-8 Hydrograph showing examples of seasonal groundwater head fluctuations (INTERA 2019a)

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. A breakdown of the Ranger Mine HLUs is shown in Table 5-5.

The HLUs were reviewed and updated as part of the Ranger Conceptual Model update (INTERA 2019a). The HLUs are being further reviewed and refined as part of the solute transport modelling with uncertainty analysis currently underway to support Key Knowledge Need (KKN) WS2.

The natural background hydrochemistry of groundwater of the RPA typically exhibits relatively low concentrations of total dissolved constituents. However, because of the slow passage (compared to surface water flow rates) of groundwater through the rocks, the longer contact time allows a greater degree of mineralisation of the bedrock to occur.

Baseline groundwater quality had been previously reported to ARRTC in November 2013 (ERA 2013) and November 2014 (ERA 2014c). The 2013 report described groundwater quality in six HLUs (aquifer components partitioned by hydraulic characteristics and rock type) for the five constituents of potential concern (COPCs) discussed at ARRTC in April 2012 (ERA 2012). The 2014 report described an additional COPC (radium-226), the geochemical behaviour of uranium and manganese in groundwater, the reactions of uranium and manganese with the fracture minerals that line aquifer wall-rocks and modelling work done to support the knowledge base of background concentrations of COPCs at the Ranger Mine.

In 2015, Esslemont reviewed the datasets with the geology team, which resulted in changes to the spatial assignment of groundwater to some HLUs (Esslemont 2015). Selected groundwater concentrations assigned to HLUs in November 2013 were recalculated, and the multivariate statistical analysis completed in November 2014 was revised. Following update of the Ranger conceptual mode (INTERA 2019), collection of a further 4 years of groundwater chemistry data and the increased list of COPCs to be assessed against closure criteria, the project to determine the background concentrations of COPCs in groundwater was undertaken again to inform KKN WS1.

Commencing in 2019, Environmental Resources Management (ERM) were engaged to establish a background data set for a broader suite of analytes in groundwater from HLUs identified in the Ranger Conceptual Model Update (INTERA 2019a). The evaluation was conducted with the premise that concentrations of COPCs in samples collected in potentially impacted areas comprise both mining-derived concentrations and background concentrations. This premise is used as a basis for ‘extracting’ an anthropogenic, site-specific background dataset from a dataset obtained from impacted areas at a site (USEPA 2014b). In the case that analyte concentrations in a sample derive only from background conditions (i.e. are not related to mining activities), the analyte is not considered to be a COPCs. Background threshold values (BTVs) were developed for the background concentration to facilitate use of the background datasets in decision making.

Table 5-5 Ranger Conceptual Model HLUs (INTERA 2019a)

HLUs	HLU Abbreviation
Alluvial HLUs	
Magela Creek sediments	MCS
other creek sediments	OCS
Djalkmarra sands	DS
Shallow Weathered HLUs	
shallow weathered Cahill	S-WC
deep weathered Cahill	D-WC
Zone C weathered carbonate (weathered Cahill subunit)	ZCWC
Pit 1 permeable zone (weathered Cahill subunit)	Pit1-P
depressurised UMS confining unit (weathered Cahill subunit)	D-UMS-C
shallow weathered Nanambu	S-WN
deep weathered Nanambu	D-WN
Deeper Bedrock HLUs	
shallow bedrock Cahill	S-BC
shallow bedrock Nanambu	S-BN
HWS	HWS
UMS	UMS
MBL zone (UMS subunit)	MBL
depressurised UMS (UMS subunit)	D-UMS
Zone C shallow bedrock (UMS subunit)	ZCSB
LMS	LMS
lower-K Deeps Water Producing Zone (DWPZ) (LMS subunit)	DWPZ-L
higher-K DWPZ (LMS subunit)	DWPZ-H
Nanambu Complex	Nam
Mine Backfill HLUs	
waste rock	NA
tailings	NA

Extraction of a background dataset from a larger site investigation dataset has support from various guidance documents (US Navy 2004; ITRC 2013; USEPA 2014b) and although no prescriptive approach is suggested, most guidance recommends a combination of a population partitioning approach followed by a weight of evidence evaluation. This is the approach that was implemented in this assessment.

Nearly a quarter of a million records from the Ranger site database were compiled and reviewed in the background assessment database to ensure that the data met the data quality and usability standards. Although some HLUs and analytes had limited spatial and/or temporal coverage, 64 HLU-analyte combinations across eight HLUs were able to undergo a full background evaluation. A robust and objective approach was taken to extract background values from the dataset. The dataset was reviewed for the number of reported results for each fraction. In all but one HLU, the dissolved fraction accounted for more than 75% of available metal data, with 9 HLUs consisting entirely of dissolved fraction metal data. Because of this, for aluminium, arsenic, beryllium, boron, cadmium, chromium, copper, iron, lead, nickel, radium, selenium, uranium, and vanadium only the dissolved fraction was retained for the background analysis. All of the available magnesium data was reported in total fraction, therefore the total fraction was used for this analyte.

In Phases 1 and 2, a data screening framework was developed to off-ramp HLUs and analytes that did not meet the minimum data requirements for the further background evaluation. Where supported, surrogate background values were developed for those HLUs and analytes with low detection frequencies, poor spatial coverage, and/or substantial data gaps. For HLUs and analytes with sufficient data, the dataset was progressed to a full background evaluation (Phase 3) that was conducted based on the following approach.

First, an iterative population partitioning approach was used to identify a breakpoint in the data using QQ plots (USEPA 2014a). This initial determination was made independently of site qualifying information. The breakpoint was then refined based on the data characteristics, in the context of the conceptual site model (CSM) and with consideration of site history, sources and known impacts. Refining the breakpoint relied on multiple lines of evidence including temporal trends in concentrations, covariance with known site sources (sulfate concentrations and SO4:Mg weight:weight ratios) and spatial patterns in impacts in the context of the CSM. Almost without exception, the final breakpoint was supported by at least one additional line of evidence; where support for the breakpoint was limited this was typically due to the dataset size and characteristics, such as concentrations approaching analytical limits. A schematic of the decision framework for data screening and the further background dataset evaluation is provided in Figure 5-9, Figure 5-10, and Figure 5-11. The background dataset was validated using multiple statistical validation methods that further strengthened the breakpoint determination by identifying additional lines of supporting evidence across COPCs and/or HLUs.

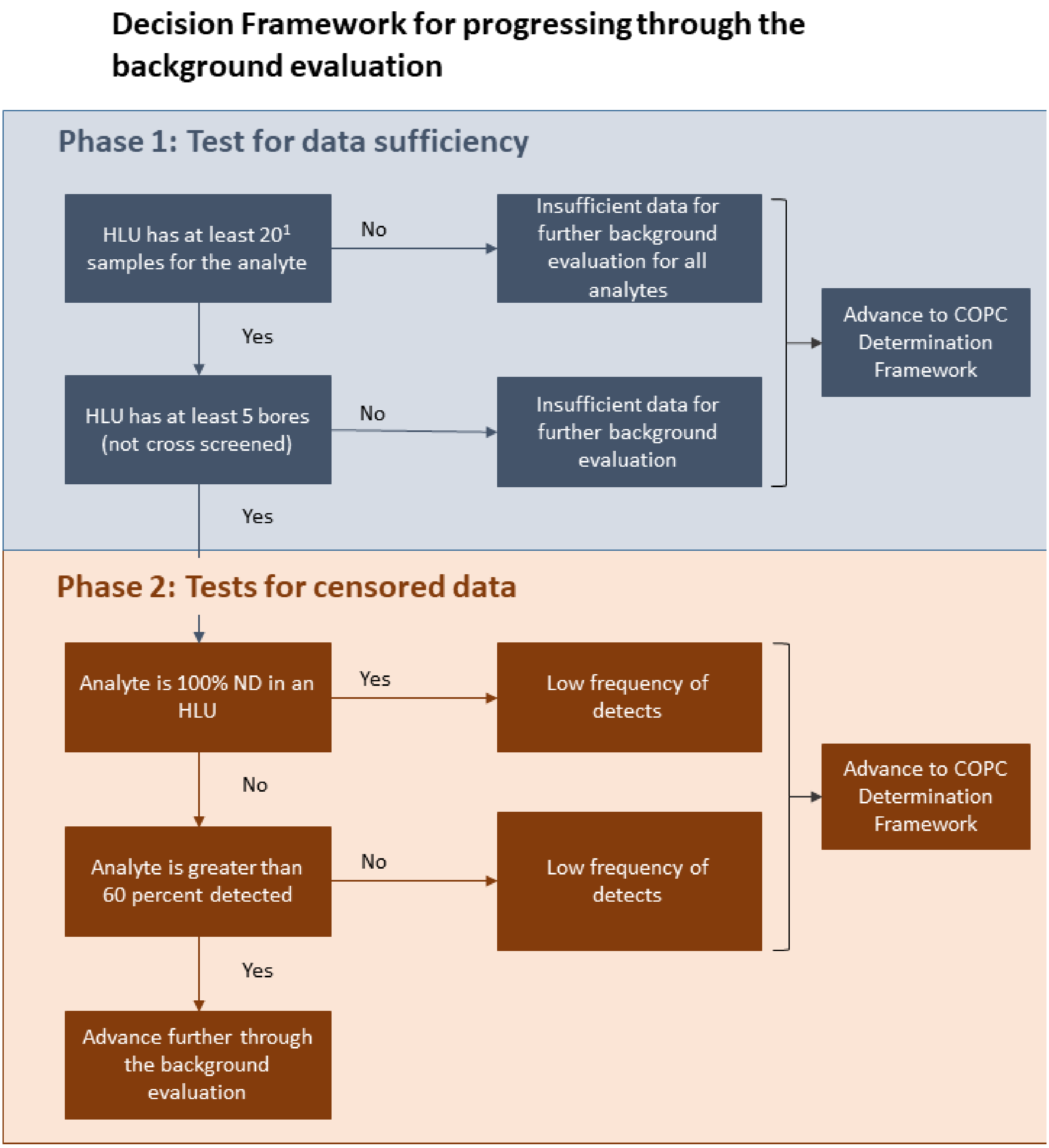
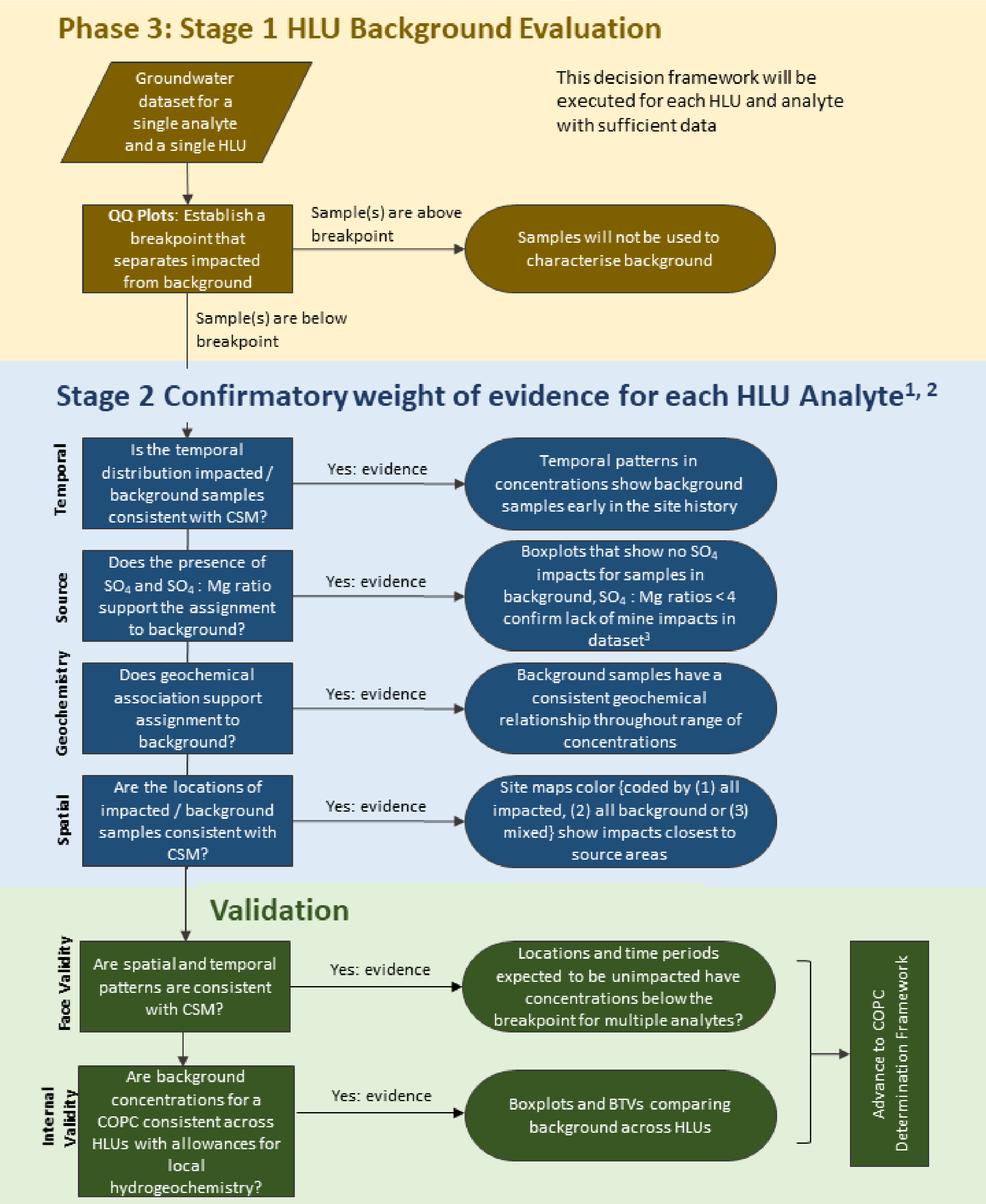


Figure 5-9 Background COPC decision framework for data screening (ERM 2020a)



Notes:
[1]Some iteration back to the QQ plot may be needed based on findings from confirmatory evaluation
[2]To aid with interpretation, data points in the visuals will be coded as impacted / background for subsequent evaluations
[3]SO_4 : Mg ratios ≥ 4 may be used as another sulfate-related line of evidence

Figure 5-10 Background COPC decision framework for weight of evidence background evaluation (ERM 2020a)

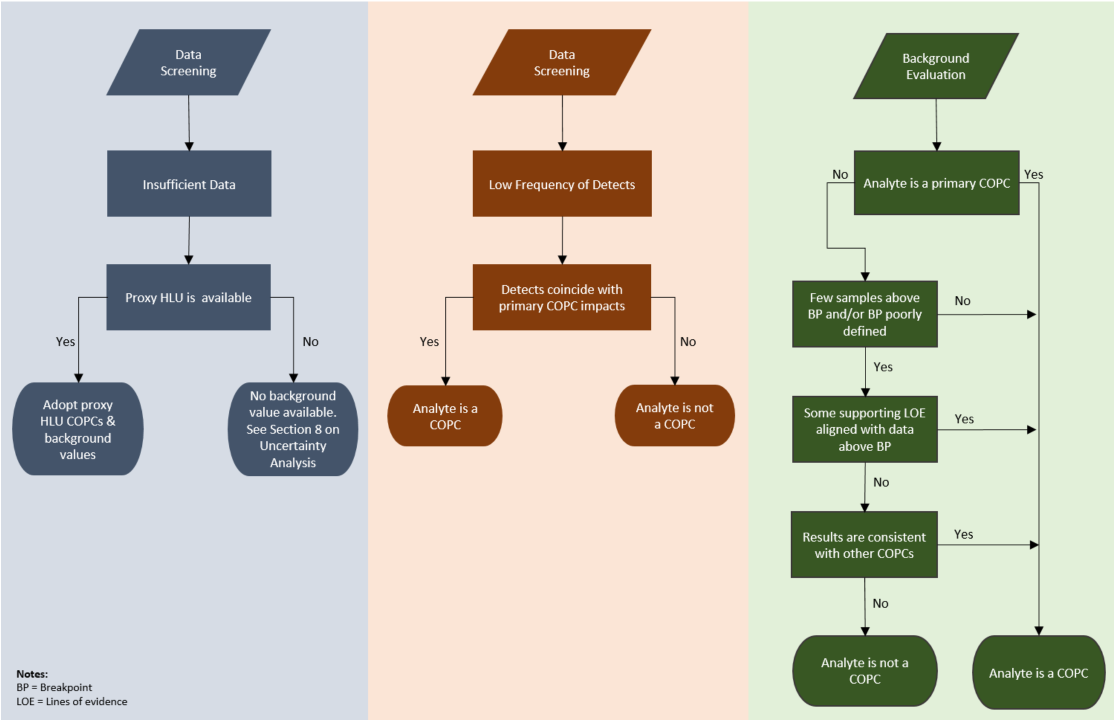


Figure 5-11 Background COPC decision framework for identifying COPC (ERM 2020a)

The initial dataset included a broader suite of analytes than had been considered previously, and the lines of evidence were used to refine the COPC list for each HLU based on evidence of impacts in the data. Primary COPCs were all retained, including uranium, radium, magnesium, manganese, and sulfate; however, the background radium dataset did not indicate that radium was a COPC in the Shallow Weathered Cahill, Shallow Bedrock Nanambu and the MBL Zone. Ammonia (NH_3-N), nitrate (NO_3-N), aluminium, arsenic, boron, nickel, and zinc were also retained as COPCs on an HLU-by-HLU basis. Several other metals did not show evidence of impacts and were ultimately removed from the COPC list. These included beryllium, cadmium, chromium, copper, lead, mercury, selenium and vanadium. The final COPC list by analyte and HLU is presented in Table 5-6.

BTVs were developed for each HLU and analyte for which there was data to support development of a BTV, even in the case that the analyte was not a COPC. The Pit 1 Permeable Zone HLU was determined to be entirely impacted at the available sampling locations and no BTVs were developed for this HLU. Calculated BTVs are presented in Table 5-6; background concentrations, which were adopted as BTVs for data with a low frequency of detects, are presented in Table 5-7. In this project 95/95 upper tolerance limits (UTLs) were used as BTVs for the background datasets. BTVs are advantageous because they are simple to implement and understand, they do not need to be recalculated over time, and point comparisons (single data points) can be made to the BTV. However, the application of BTVs can be problematic, because the more comparisons are made to the BTV, the more likely false positives become (i.e. the chance of falsely concluding that a sample or bore is impacted). Therefore statistical hypothesis testing is recommended to control for false positive rates in those cases where COPC concentrations are above the BTV.

Table 5-6 Background Threshold Value (BTV) from data rich HLUs from the background evaluation 95/95 Upper Tolerance Limit (ERM 2020c)

Analyte	Units	Shallow Bedrock Cahill	Deep Weathered Cahill	Shallow Weathered Cahill	Shallow Bedrock Nanambu	Deep Weathered Nanambu	Shallow Weathered Nanambu	MBL Zone (UMS subunit)
Aluminium	µg/L			27.6	14.4[a]	34.9	19.3	
Ammonia (NH_3-N)	mg/L				0.88	0.312	0.43	
Arsenic	µg/L				2.5	8	4.5	
Boron	µg/L				30	55	25	
Copper	µg/L			3.8		4	6.15	
Lead	µg/L			0.9			2.05	
Magnesium	mg/L	21.7	57.9	11.1	39.8	26.7	52.3	40.5
Manganese[b]	µg/L	190	87.5	483	1420	401	890	18
Nickel	µg/L				2.3	4.9	11.5	
Nitrates (NO_3-N)	mg/L		0.554	3.17				0.554
Radium	mBq/L	130	50	27.3	130	90	30	37.3
Sulfate	mg/L	1.5	4.3	1.88	2.5	7.6	1.6	1.6
Uranium	µg/L	7.74	21.9	3.03	5.76	5.7	3.37	1.92
Vanadium	µg/L					3		
Zinc	µg/L			13	3	16.5	11.5	

Table 5-7 Background COPC concentrations HLUs for analytes with low frequency of detects (ERM 2020c)

HLU	Analytes	Adopted Background Concentration	Basis for Selection
Deep Weathered Cahill	Ammonia	0.005 mg/L	Detection limit reported in all samples available.
Deep Weathered Nanambu	Beryllium	0.5 µg/L	Detection limit reported in all samples available.
	Cadmium	0.1 µg/L	Detection limit reported in all samples available.
	Chromium	0.5 µg/L	The lowest and most frequently detection limit reported from samples available.
	Lead	0.1 µg/L	Based on detectable lead concentrations in groundwater at bores located away from mine activities and considered to be background (22138_D and 23931_DEEP).

HLU	Analytes	Adopted Background Concentration	Basis for Selection
	Mercury	0.1 µg/L	100% of concentrations were reported below detection limit.
	Nitrates	0.022 mg/L	Detection limits ranged from 0.005 mg/L to 0.1mg/L. The selected background concentration was the most frequent detection limit reported and was also from the most recent analyses (after 2010).
	Selenium	1.0 µg/L	The lowest and most frequent detection limit reported from samples available.
MBL Zone (UMS subunit)	Ammonia	0.005 mg/L	The lowest and most frequent detection limit reported from samples available.
Pit 1 Permeable Zone	Ammonia	0.005 mg/L	Detection limit reported in all samples available. Other background concentrations not able to be assessed for this HLU.
Shallow Bedrock Cahill	Nitrates	0.022 mg/L	Detection limits ranged from 0.01 mg/L to 0.1 mg/L. The selected background concentration was the most frequent detection limit reported and was also from the most recent analyses (after 2010).
Shallow Bedrock Nanambu	Beryllium	0.5 µg/L	100% of concentrations were reported below detection limit.
	Cadmium	0.1 µg/L	100% of concentrations were reported below detection limit.
	Chromium	0.5 µg/L	100% of concentrations were reported below detection limit.
	Copper	0.05 µg/L	The lowest and most frequent detection limit reported from samples available.
	Lead	0.05 µg/L	The lowest and most frequent detection limit reported from samples available.
	Mercury	0.1 µg/L	100% of concentrations were reported below detection limit.
	Nitrate	0.022 mg/L	Detection limits ranged from 0.01 mg/L to 0.1 mg/L. The selected background concentration was the most frequent detection limit reported and was also from the most recent analyses (after 2010).
	Selenium	1 µg/L	100% of concentrations were reported below detection limit.
	Vanadium	0.5 µg/L	100% of concentrations were reported below detection limit.

HLU	Analytes	Adopted Background Concentration	Basis for Selection
Shallow Weathered Cahill	Ammonia	0.005 mg/L	100% of concentrations were reported below detection limit.
Shallow Weathered Nanambu	Beryllium	0.5 µg/L	The lowest and most frequent detection limit reported from samples available. .
	Cadmium	0.1 µg/L	Most frequent detection limit reported from samples available.
	Chromium	0.5 µg/L	Most frequent detection limit reported from samples available.
	Mercury	0.1 µg/L	Most frequent detection limit reported from samples available.
	Nitrates	0.022 mg/L	Detection limits ranged from 0.005 mg/L to 0.1 mg/L. The selected background concentration was the most frequent detection limit reported and was also from the most recent analyses (after 2010).
	Selenium	1 µg/L	Most frequent detection limit reported from samples available.
	Vanadium	0.5 µg/L	Most frequent detection limit reported from samples available.

This background evaluation 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. The results were supported by multiple forms of validation that help to create a high level of confidence in the conclusions.

The approach allowed the data to dictate the background concentrations and then supported this with multiple lines of evidence and site knowledge to develop BTVs and to identify COPCs for the HLUs at the site. The statistical methodology used to establish the background dataset and develop the supporting lines of evidence is well established and reproducible, 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.

5.2.8 Surface water

5.2.8.1 Hydrology

Surface water management will be a key focus of rehabilitation and closure, as it is one of the pathways for COPCs to enter the environment.

The Ranger Mine is located within the 1,600 km^2 of the Magela catchment and adjacent to Magela Creek (Figure 5-12). 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 Ranger Tailings Storage Facility (TSF) and from relatively undisturbed bushland to the west of Retention Pond 1 (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.

Moliere (2005) reviewed historical stream flow data for Gulungul Creek in order 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 5-13) [4] 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. Within the sub-catchments, backflow billabongs sit on the margins of Magela Creek creating complex localised hydrological relationships.

[4] Government agency gauging stations shown in Figure 5-13 correspond with stations listed on the NT Government, Natural Resource Maps website: https://nt.gov.au/environment/environment-data-maps/water-data

Figure 5-12: Regional extent of Magela catchment

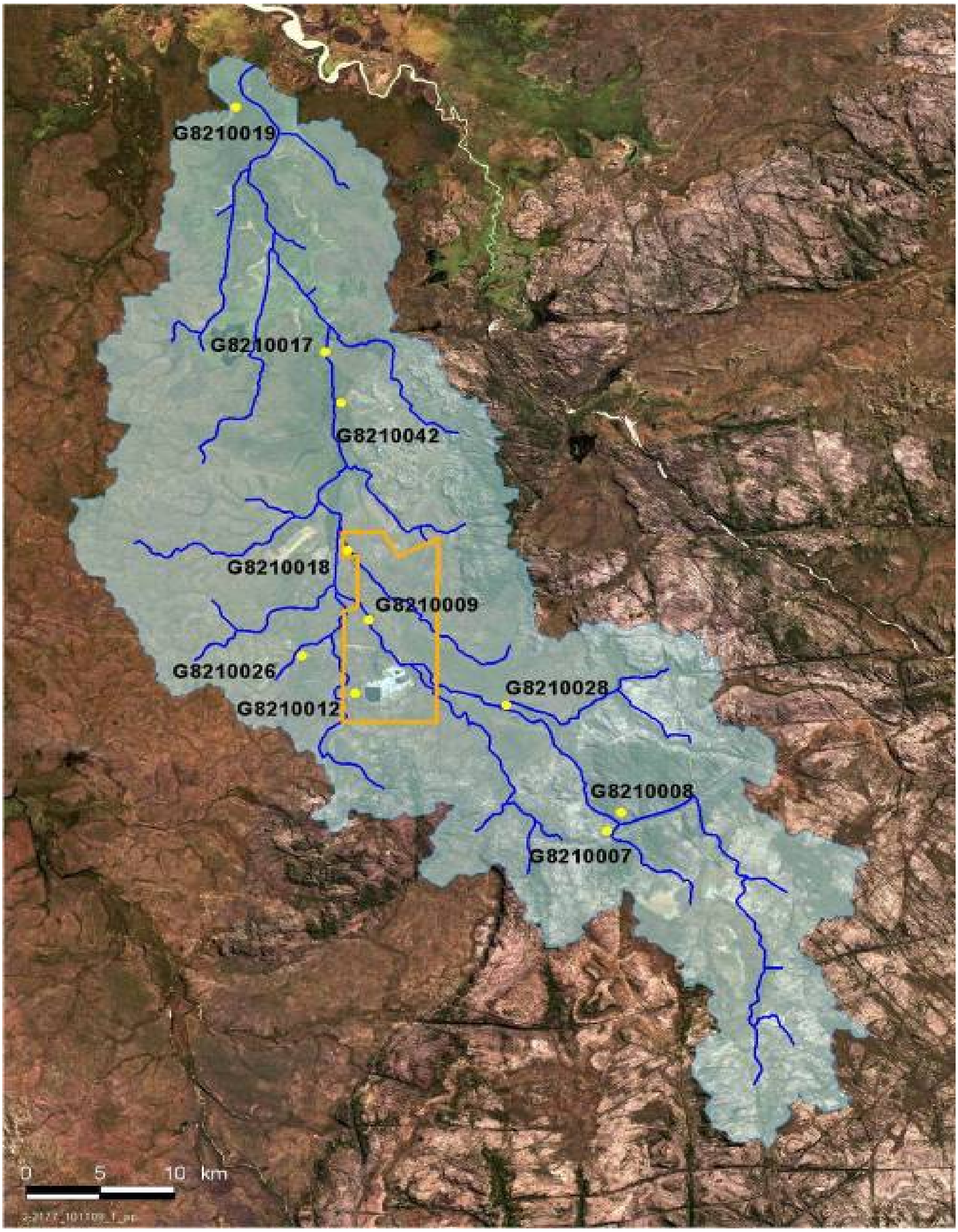


Figure 5-13: Magela catchment showing government agency gauging stations

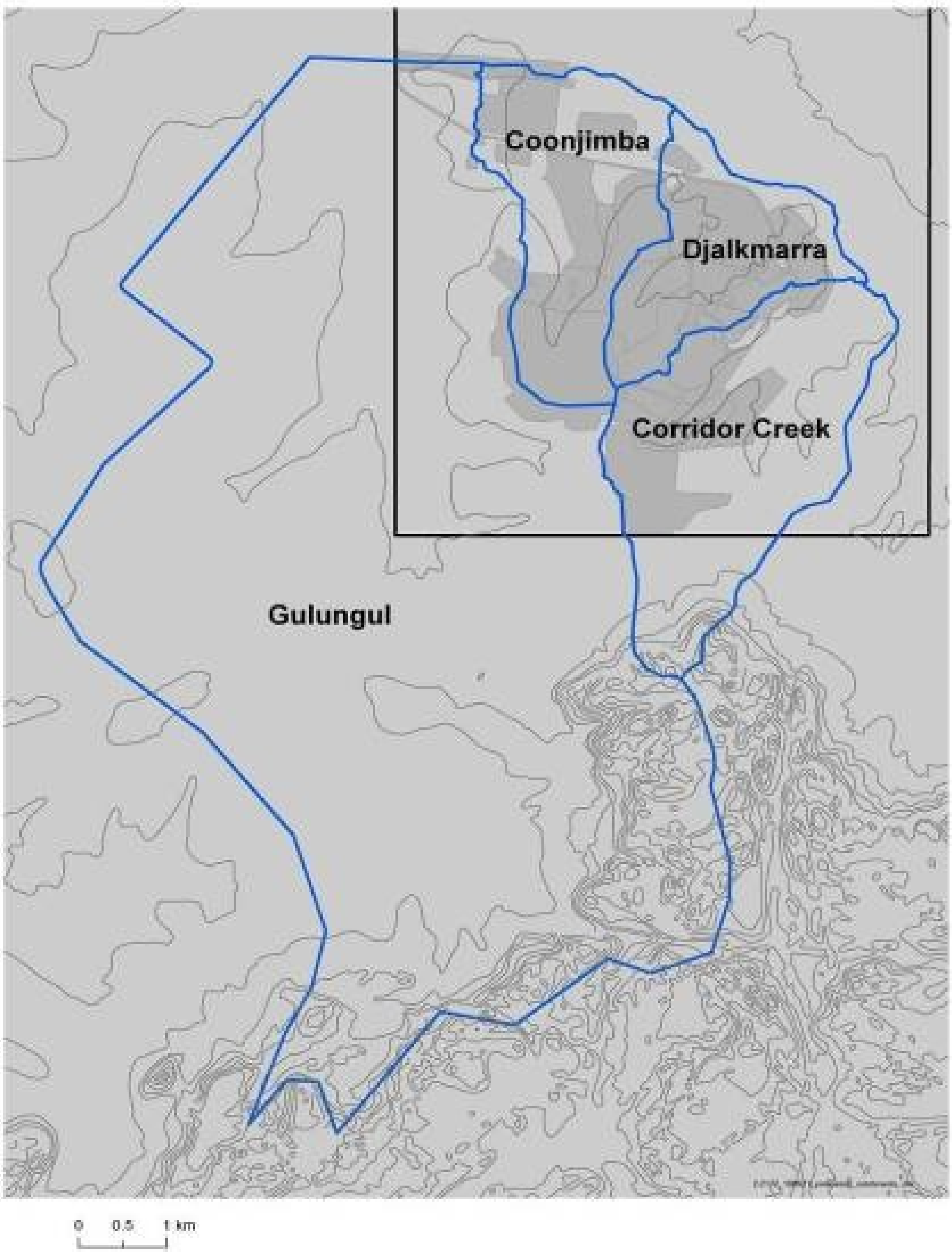


Figure 5-14 Pre-mining catchments in relation to the Ranger Mine

5.2.8.2 Water quality

Water quality monitoring has been ongoing at Ranger Mine and in the surrounding environment for several decades providing a significant volume of reference data for surface water quality within the creeks and billabongs. Several studies conducted before, or shortly after, mining commenced describe the background conditions in billabongs and creeks in the Magela Creek catchment (e.g. Hart and McGregor 1980, 1982, Walker & Tyler 1982, 1983, Office of the Supervising Scientist 2002, Hart *et al.* 1987a, Hart *et al.* 1987b, Hart *et al.* 1981, Hart *et al.* 1986b, Hart *et al.* 1986a).

Klessa (2000) derived baseline water quality data for Magela Creek against which change in water quality could be determined, based on:

- Ranger Mine water quality data base
- Northern Territory Department of Primary Industry and Resources (DPIR) check monitoring water quality database, and
- Northern Territory Water Resources Division (WRD).

The majority of water samples were taken upstream of Ranger Mine from site GS8210067. In addition, the DPIR data is independent of the Ranger Mine data. The WRD data from the downstream site GS009 collected before the 1976-77 wet season is pre-mining data. The Klessa (2000) baseline data (provided within Klessa (2005) analysed the Magela Creek monitoring data to produce a balance sheet over 4 wet seasons (1999 to 2003) to account for magnesium sulfate entering Magela Creek from the Ranger Minesite.

Upstream Magela Creek data (from 1993 to 2003) showed magnesium concentrations varied from approximately 1 mg/L at low flow to less than 0.1 mg/L flow rates that exceeded 100 m^3/s. Corresponding sulfate concentrations ranged from approximately 0.1 to 1 mg/L but did not show the same negative correlation with flow rate. EC showed that same trend as magnesium with EC decreasing with flow rates approximately 20 microSemens/cm to 5 microSemens/cm. At the end of the wet season, upstream of Ranger Mine, waters have elevated magnesium and EC. This implies a base-flow water source with higher ionic strength than the predominantly allogenic surface water flow observed earlier in the wet season.

Generally EC and magnesium variation follows the hydrological phases of flow, which is a decrease in concentration from start of wet season to a minimum near mid-wet season, followed by a subsequent increase to end of wet season. The EC and magnesium concentrations in surface water at the start and end of the wet season are similar. This observation by Klessa (2005) is consistent with the results of the ERA and SSB monitoring programs.

Table 5-8 was derived from Ranger and the DPIR datasets from sites GS028 and GS067 and WRD site GS009.The results in Klessa (2000) are compared to the 1992 – 2018 Magela Creek upstream reference site (MCUS) data, collected by the ERA (predominantly weekly) monitoring program (Table 5-8). The Klessa (2000) dataset contains MCUS data from 1991, which is considered to be affected by Georgetown Billabong (GTB) outflows (Hart *et al.* 1982). Some data from this location have high uranium in the early part of the year. However, the dataset contains greater than 200 data points and the statistics shown are percentiles rather than an average, so the influence of these points is considered to be small. Data from that time is not included in the MCUS 1992 – 2018 dataset.

A review conducted a decade after Klessa (2005) describes similar water quality and seasonal treands. INTERA (2016) describe Magela Creek surface water chemistry as being generally slightly acidic pH (~6.2) with very low electrical conductivity (EC) (~15 to 16 micro Siemens per centimetre; up to 30 micro Siemens per centimetre during low flow conditions), and low turbidity (7 Nephelometric Turbidity Unit) and metal concentrations, reflecting rainfall chemistry more closely than groundwater chemistry.

During the wet season, EC and concentrations of magnesium (Mg) and calcium (Ca) upstream of the Ranger Mine are highest during initial flows, lowest during high flows and increase during the recessional flow limb (late wet season, when stream flow is decreasing). Sulfate (SO_4) and manganese (Mn) concentrations are highest with the start of flow, but then decrease to steady levels; whereas turbidity is high during the accessional limb (early wet season, when stream flow is increasing), but decreases to a steady low during the recessional limb. Only pH appears to increase during the period of flow, although it is highly variable over the entire period. Uranium (U), total ammonia nitrogen (TAN) and radium-226 (^{226}Ra) remain essentially constant throughout the period of flow (INTERA 2016).

A comparison of the Magela Creek water chemistry upstream and downstream of the Ranger Mine indicates that generally:

- turbidity is lower downstream than upstream
- pH and Mg and SO4 concentrations are higher downstream than upstream
- Mn, U, Ca, 226Ra and TAN concentrations are similar downstream and upstream, with the following exceptions:
    - Mn concentrations are higher downstream than upstream during the recessional limb, and
    - U concentrations are very occasionally slightly higher downstream than upstream (INTERA 2016).

Table 5-8: Baseline values from Klessa (2000) and ERA Laboratory Information Management System (LIMS) database 1992-2018; results are for filtered fraction except for ^{226}Ra

Parameter	Unit	Source	*n*	Minimum	Percentiles		Maximum
					50th	80th	
pH	-	Klessa 2000	*366*	4.20	6.20	6.45	7.00
		MCUS 1992-2018	*880*	3.97	6.15	6.44	8.04
EC	(µS/cm)	Klessa 2000	*493*	5	16	21	75
		MCUS 1992-2018	*885*	3.4	13	16	47
Turbidity	(NTU)	Klessa 2000	*356*	0.5	5	9.9	82
		MCUS 1992-2018	*718*	<1	3	5	46
SO_4	(mg/L)	Klessa 2000	*232*	0.03	0.27	0.78	9.3
		MCUS 1992-2018	*805*	0.03	0.20	0.40	3.5
Mg	(mg/L)	Klessa 2000	*266*	0.05	0.64	0.88	8.1
		MCUS 1992-2018	*806*	0.05	0.55	0.80	1.7
Ca	(mg/L)	Klessa 2000	*214*	0.05	0.52	0.8	6
		MCUS 1992-2018	*682*	0.05	0.30	0.50	1.3
Na	(mg/L)	Klessa 2000	*150*	0.05	1.3	1.7	5.5
		MCUS 1992-2018	*379*	0.05	1.2	1.4	2.5
K	(mg/L)	Klessa 2000	*149*	0.05	0.22	0.4	1.8
		MCUS 1992-2018	*379*	0.05	0.12	0.20	1.00
Cl	(mg/L)	Klessa 2000	*125*	0.8	2.1	3	24
		MCUS 1992-2018	*324*	0.3	1.8	2.2	3.4
NO_3	(mg/L)	Klessa 2000	*122*	0.002	0.03	0.05	0.43
		MCUS 1992-2018	*163*	0.011	0.011	0.050	0.841
NH_3	(mg/L)	Klessa 2000	*76*	0.01	0.01	0.025	0.18
		MCUS 2013-2019	*179*	0.003	0.012	0.021	0.068
Cu	(µg/L)	Klessa 2000	*105*	0.1	0.6	1	3.49
		MCUS 1992-2018	*78*	0.0	1.00	1.00	3.49
Mn	(µg/L)	Klessa 2000	*224*	0.5	5.6		180
		MCUS 1992-2018	*807*	0.22	4.93	7.35	41.5
Pb	(µg/L)	Klessa 2000	*122*	0.01	0.5		22
		MCUS 1992-2018	54	0.020	0.025	0.124	0.530
U	(µg/L)	Klessa 2000	*260*	0.013	0.10	0.30	24.95
		MCUS 1992-2018	*853*	0.003	0.030	0.050	3.50
Zn	(µg/L)	Klessa 2000	*93*	0.5	2.5	13.0	81
		MCUS 1992-2018	88	0.25	1.00	1.72	141
^{226}Ra Total	(mBq/L)	Klessa 2000	*101*	0.6	3	18.0	43.2
		MCUS 1992-2017	137	0.5	1.94	3.94	58.4
Al	(µg/L)	Klessa 2000	NR	NR	NR	NR	NR
		MCUS 1992-2018	*43*	0.5	51.5	99.8	187
Fe	(µg/L)	Klessa 2000	NR	NR	NR	NR	NR
		MCUS 1992-2018	48	28	97	130	544

5.2.9 Radiation

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

5.2.9.1 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 5-9.

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).

5.2.9.2 Aquatic baseline radiation

The RPA contains three distinct regional HLU zones: alluvial, weathered and bedrock.The derivation of the background threshold values for uranium and radium is discussed in 5.2.7. The results for uranium and radium baseline groundwater concentrations are presented in Table 5-10. 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 5-11.

Table 5-9: 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 application area	0.10 ± 0.01	90 ± 20	0.13 ± 0.04
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			

Table 5-10 Estimated baseline groundwater radionuclide concentrations

Analyte	Units	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	130	90	30	37.3
Uranium	µg/L	7.74	21.9	3.03	5.76	5.7	3.37	1.92

Table 5-11: Magela Creek upstream radionuclide concentrations (2010 – 2014 average)

Magela Creek upstream	Total radium-226 (mBq L^{-1})	Total uranium (mBq L^{-1})
Average	2.1	0.70
Minimum	1.2	0.16
Maximum	4.0	2.6
Standard deviation	0.9	0.48

5.2.9.3 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 5-12 (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 5-12: 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)

5.2.10 Sediment

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) lists 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 Ranger Project Area (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 Retention Pond 1(RP1), Georgetown Billabong (GTB) and the RP1 and Corridor Creek constructed wetland filters (CCWLF) 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 > Corridor Creek 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 GAC to review surface water management and monitoring at Ranger. Hart and Taylor (2013) 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 onward

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[5].

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 99.7th percentiles of data from un-impacted sites (control and unimpacted 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 5-13.

Table 5-13 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)					

[5] 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.

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. The results are shown in Figure 5-15,Figure 5-16,Figure 5-17,Figure 5-18 and Figure 5-19.

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.

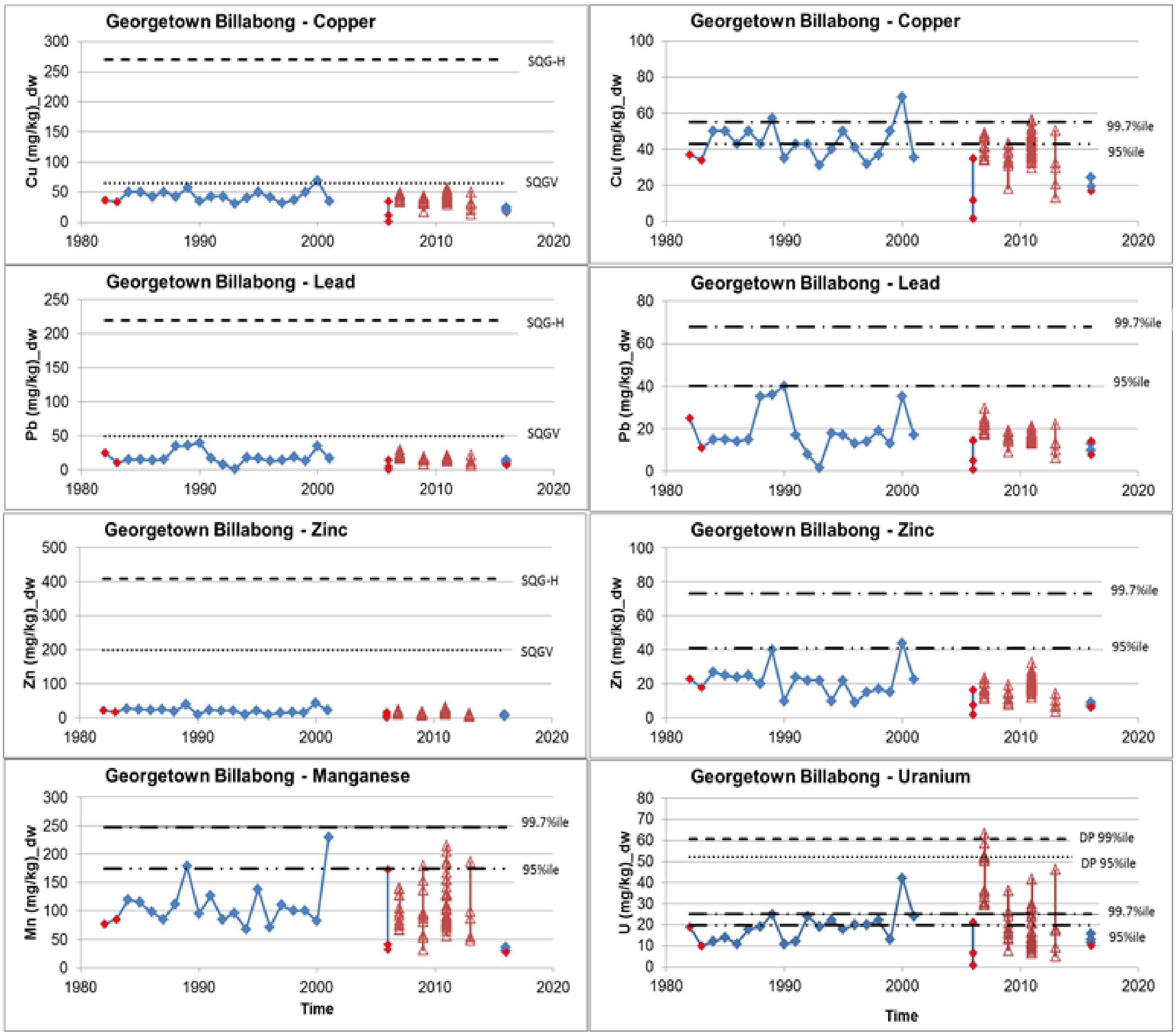


Figure 5-15: Control Charts of TPM concentrations in surface sediments of Georgetown Billabong. ◆ sub-clay (<63 µm) ERA samples, ◆ sub-sand (<2mm) ERA samples, △ sub-clay (<63 µm) SSB samples. Digests before 2006 were by reverse aqua regia and after 2006 were by nitric/perchloric acid.

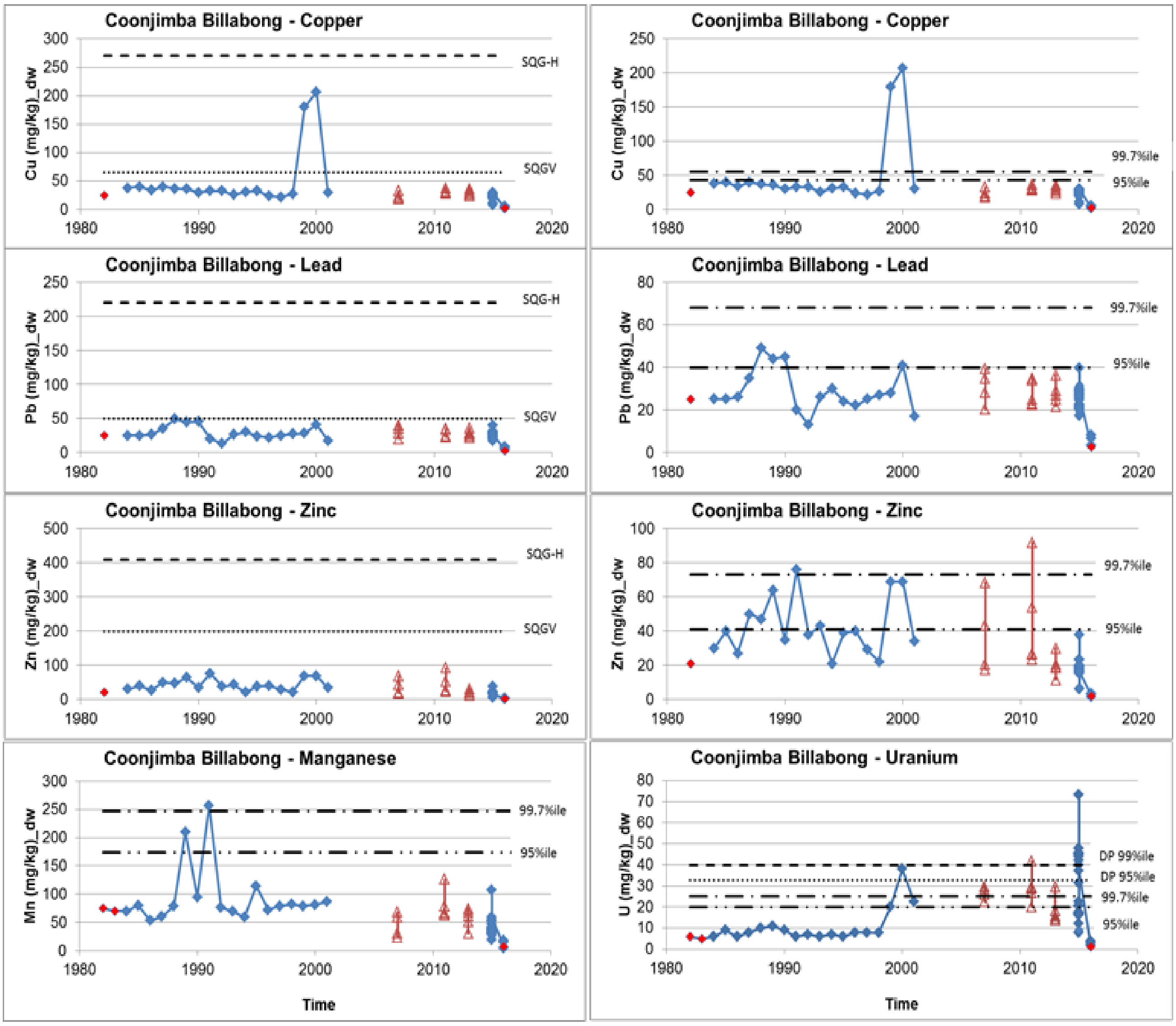


Figure 5-16: Control Charts of TPM concentrations in surface sediments of Coonjimba Billabong. ◆ sub-clay (<63 µm) ERA samples, ◆ sub-sand (<2mm) ERA samples, △ sub-clay (<63 µm) SSB samples. Digests before 2006 were by reverse aqua regia and after 2006 were by nitric/perchloric acid.

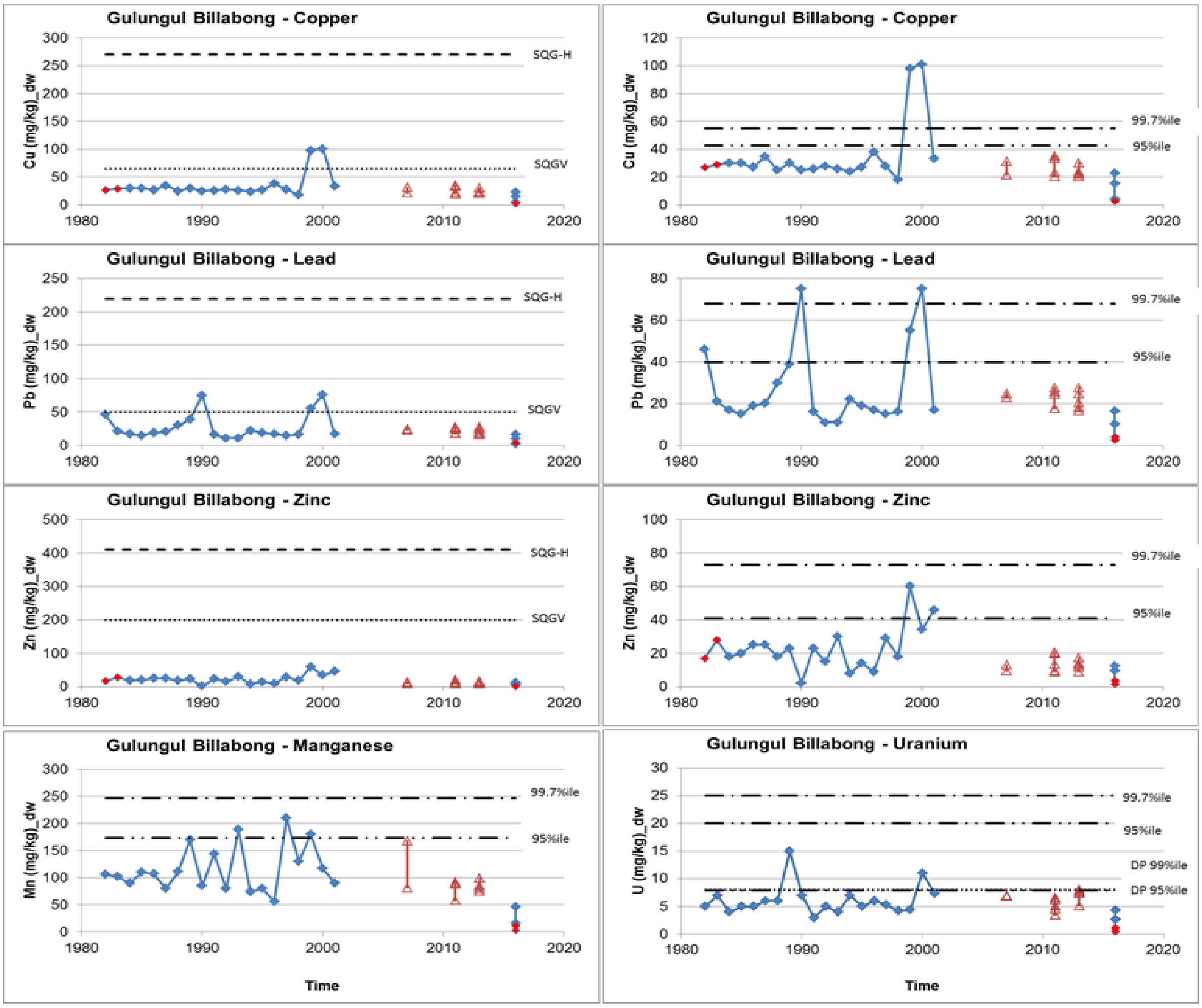


Figure 5-17: Control Charts of TPM concentrations in surface sediments of Gulungul Billabong. Symbols as for Figure 5-13. Digests before 2001 were by reverse aqua regia and after 2001 were by nitric/perchloric acid.

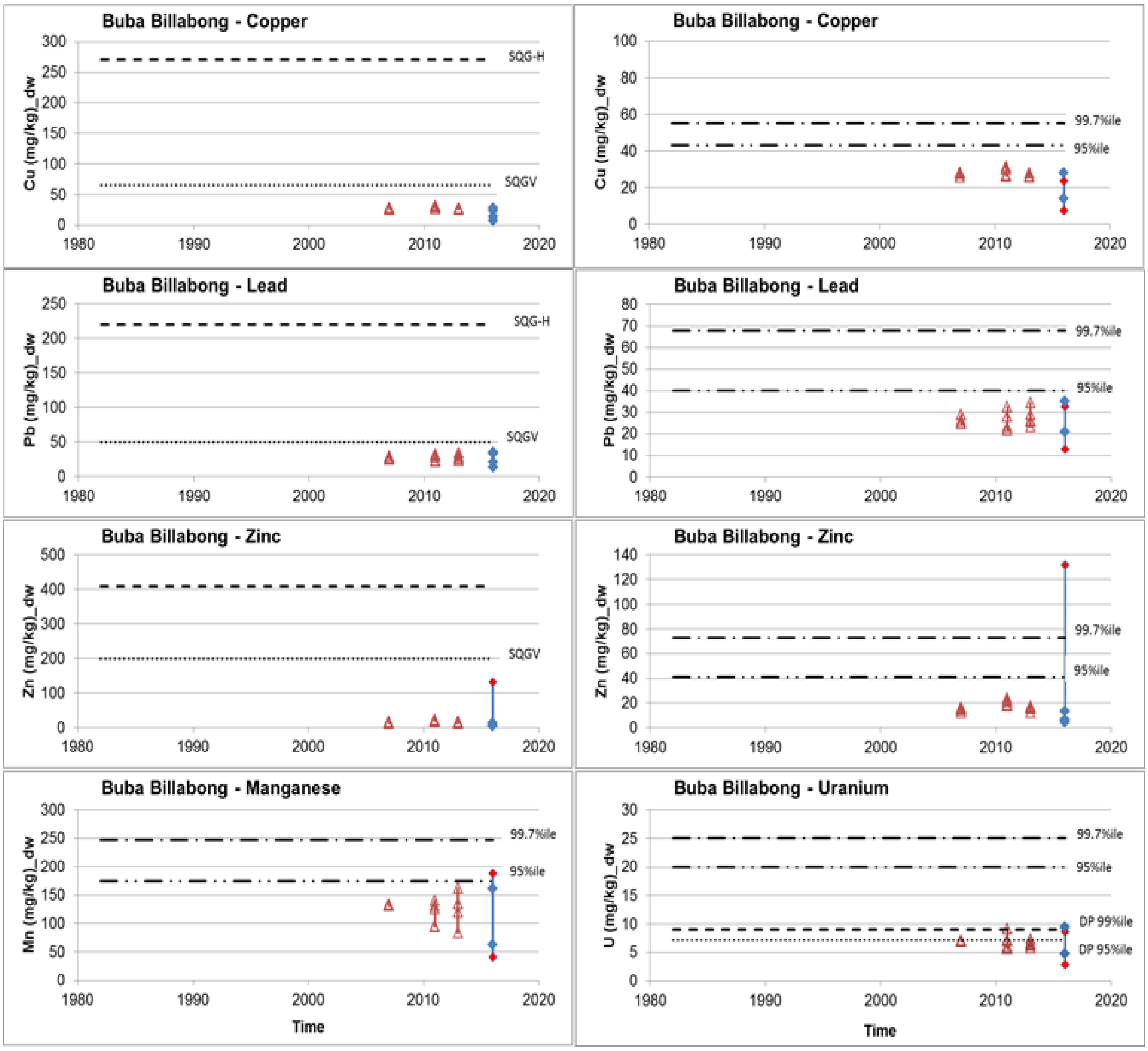


Figure 5-18 Control Charts of TPM concentrations in surface sediments of Gulungul and Buba billabongs. Symbols as for Figure 5-13. Digests before 2001 were by reverse aqua regia and after 2001 were by nitric/perchloric acid.

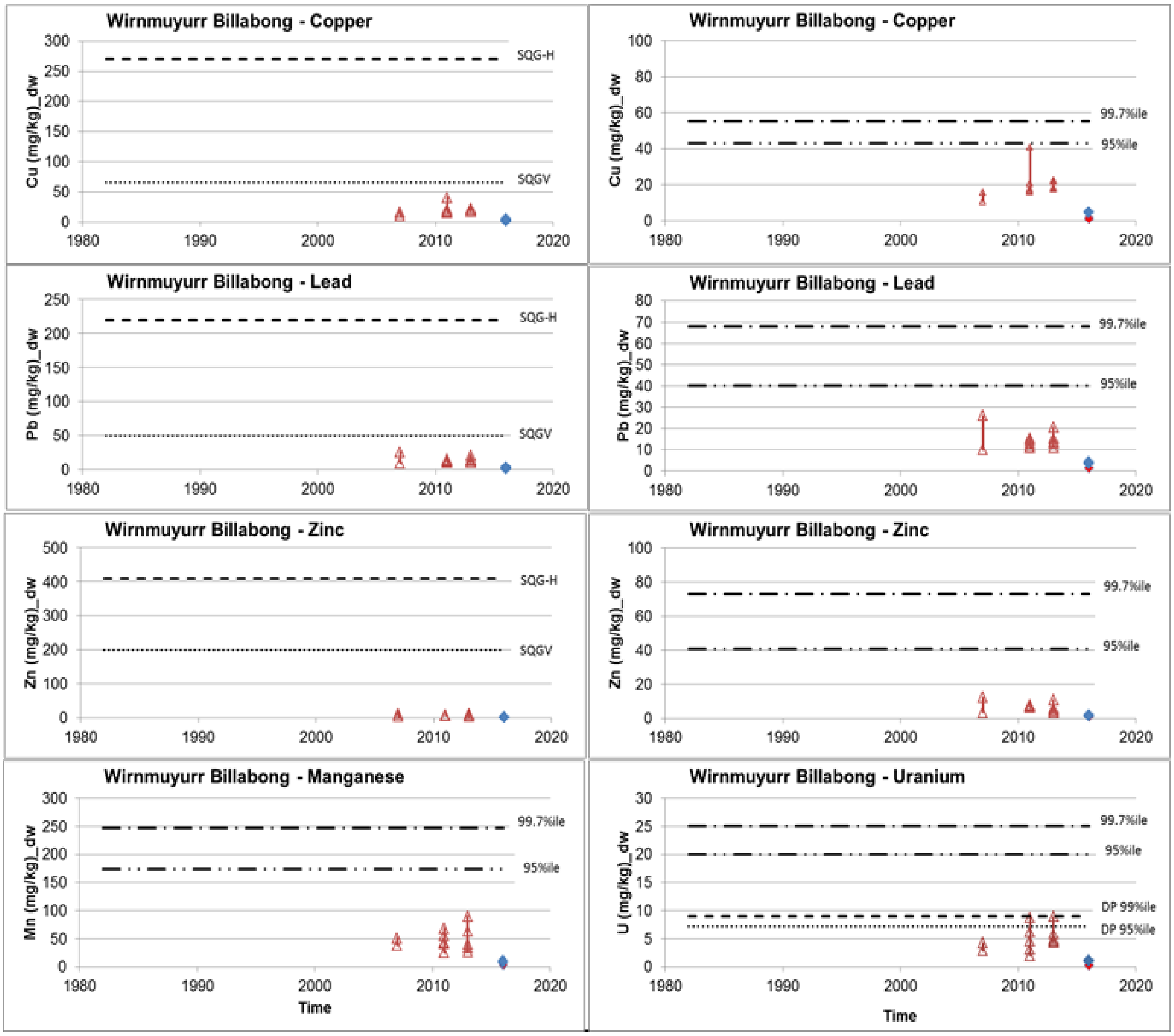


Figure 5-19 Control Charts of TPM concentrations in surface sediments of Wirnmuyurr billabong. Symbols as for Figure 5-13. Digests were by nitric/perchloric acid.

The next sediment sampling program is planned for 2020 and will focus on acid sulfate soil potential and confirming metal concentrations in the onsite waterbodies and creeks and the closest offsite billabong, Gulungul Billabong, refer to section 5.5.2.2.

5.3 Biological environment

5.3.1 Bioregions

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 km^2 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. Of those, a total of six plant species and 14 fauna species are threatened. During the wet season (November to March) approximately 90 percent of annual rainfall occurs in this tropical monsoonal bioregion (DEE 2005).

5.3.2 National parks and protected areas

The RPA is surrounded by Kakadu NP, which is an internationally recognised area of natural and cultural importance, and is inscribed on the United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Register. The RPA is also within 150 km of three other national parks: Warddeken Indigenous Protected Area (approximately 10 km east of the RPA and adjacent to the eastern boundary of Kakadu NP), Mary River National Park (115 km west of the RPA) and Nitmiluk (Katherine Gorge) National Park (approximately 123 km south of the RPA)

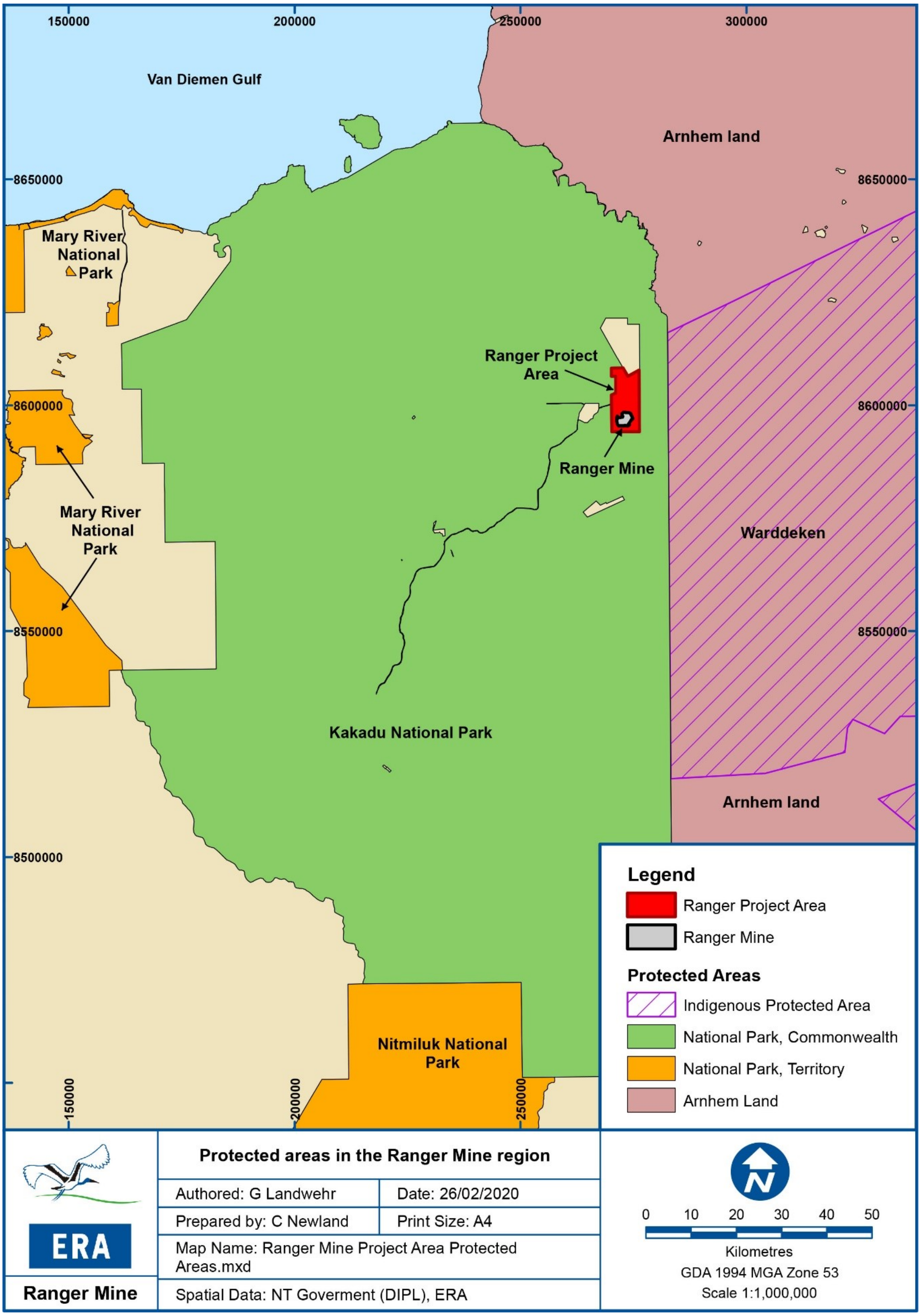


Figure 5-20 Protected areas in the Ranger Mine region

5.3.2.1 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.

5.3.2.2 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.

World Heritage listing 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.

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.

5.3.3 Terrestrial ecology

This section provides an overview of the terrestrial ecosystems of the RPA and surrounding region. Discussion on ecosystem establishment, including revegetation trials and seed provenance is provided in Appendix 5.1. This also includes a fine scale assessment, including plant species composition and relative abundance in the RPA, and surrounding natural analogue sites.

5.3.3.1 Vegetation communities

Schodde *et al*. (1987) described four vegetation types in the RPA dominated by eucalypt open forest and/or woodland (Figure 5 14). Similarly, Firth (2012) described the main vegetation/ habitat types on the RPA as comprising of woodland and open forest, mostly co-dominated by *E. tetrodonta* and/or *Eucalyptus (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 km2 in the NT alone (Hart & Jones 1984). The topography of the RPA is relatively simple and as with vegetation, mirrors that of the region as a whole.

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 5-14

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 other 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 perennials 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, Croton arnhemicus, 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 *Livistonia 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.

5.3.3.2 Flora species

Native flora species

There has been a substantial survey and monitoring of the terrestrial flora across the RPA over the past 15 years. In a 2013 survey of lowland riparian and woodland areas within the RPA, 292 flora species from 30 families were identified (Eco Logical Australia 2014). These species are common in surrounding Kakadu NP and did not include any threatened or rare species. Approximately 1,600 terrestrial and aquatic flora species have been recorded in Kakadu, including 15 species considered rare or threatened (Director of National Parks 2016). These conservation significant species have not been recorded within the RPA.

On the basis of previous studies integrated from previous studies near the RPA a total of 461 flora taxa from 80 families and 195 genera have been recorded and identified to a minimum of genus level if not species and subspecies (see Appendix B). The flora is representative of a range of underlying environments ranging from riparian, seasonally wetter lowlands and a range of forests and woodlands on the slopes and ridges. There are a few local restricted communities associated with extreme site conditions including outcrops and shallow soils. The lifeforms summarized in Appendix C have been extracted from the NT Flora database (Northern Territory, 2020), the WA Florabase (Western Australian Herbarium, 1998–) and key references such as Brock (2001) and provides observations on site preferences of the respective species in relation to underlying landforms, soils and soil moisture records.

Conservation significant species

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.

Table 5-14 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

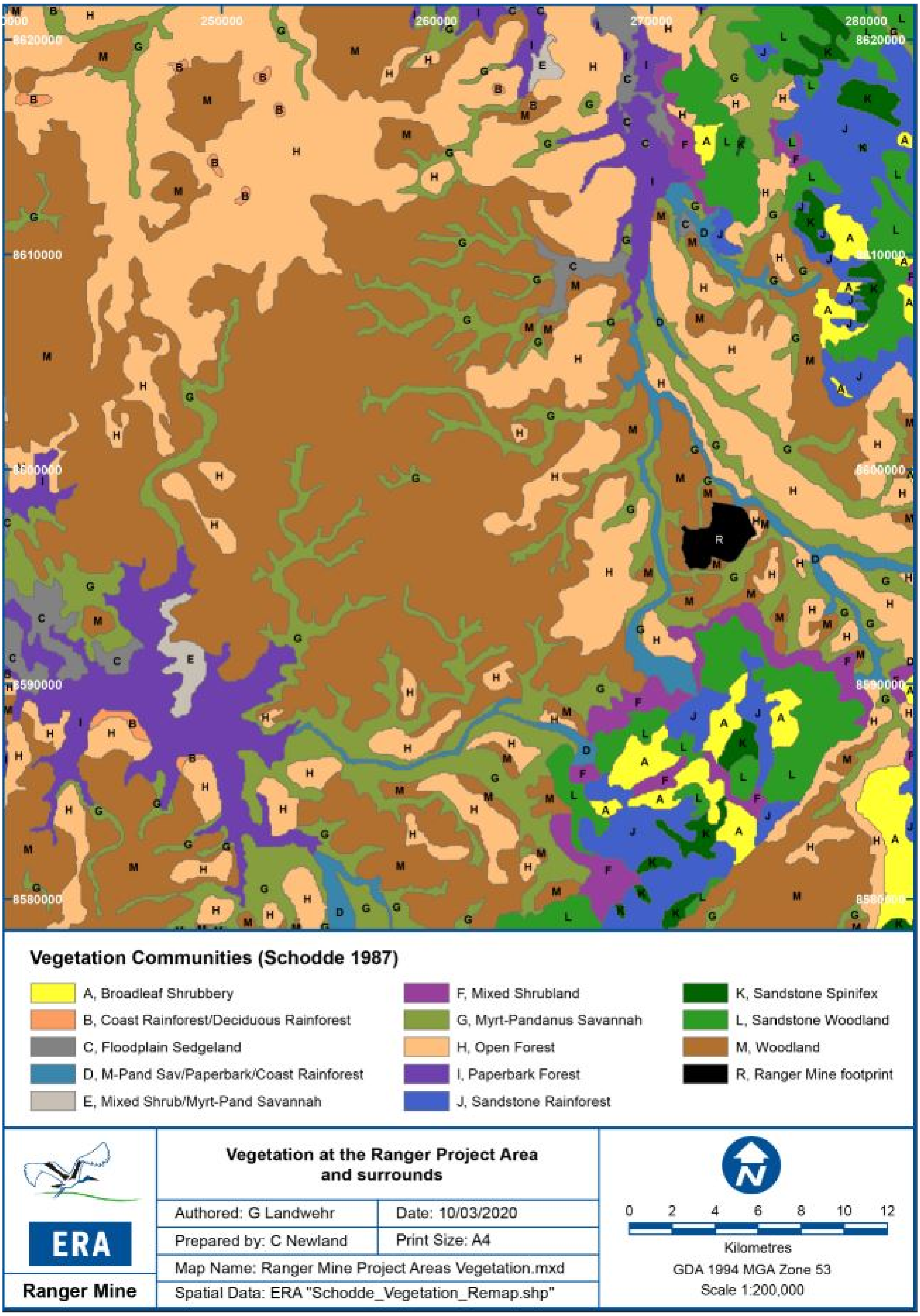


Figure 5-21 Vegetation of the RPA and surrounding Kakadu NP (Schodde *et al*. 1987)

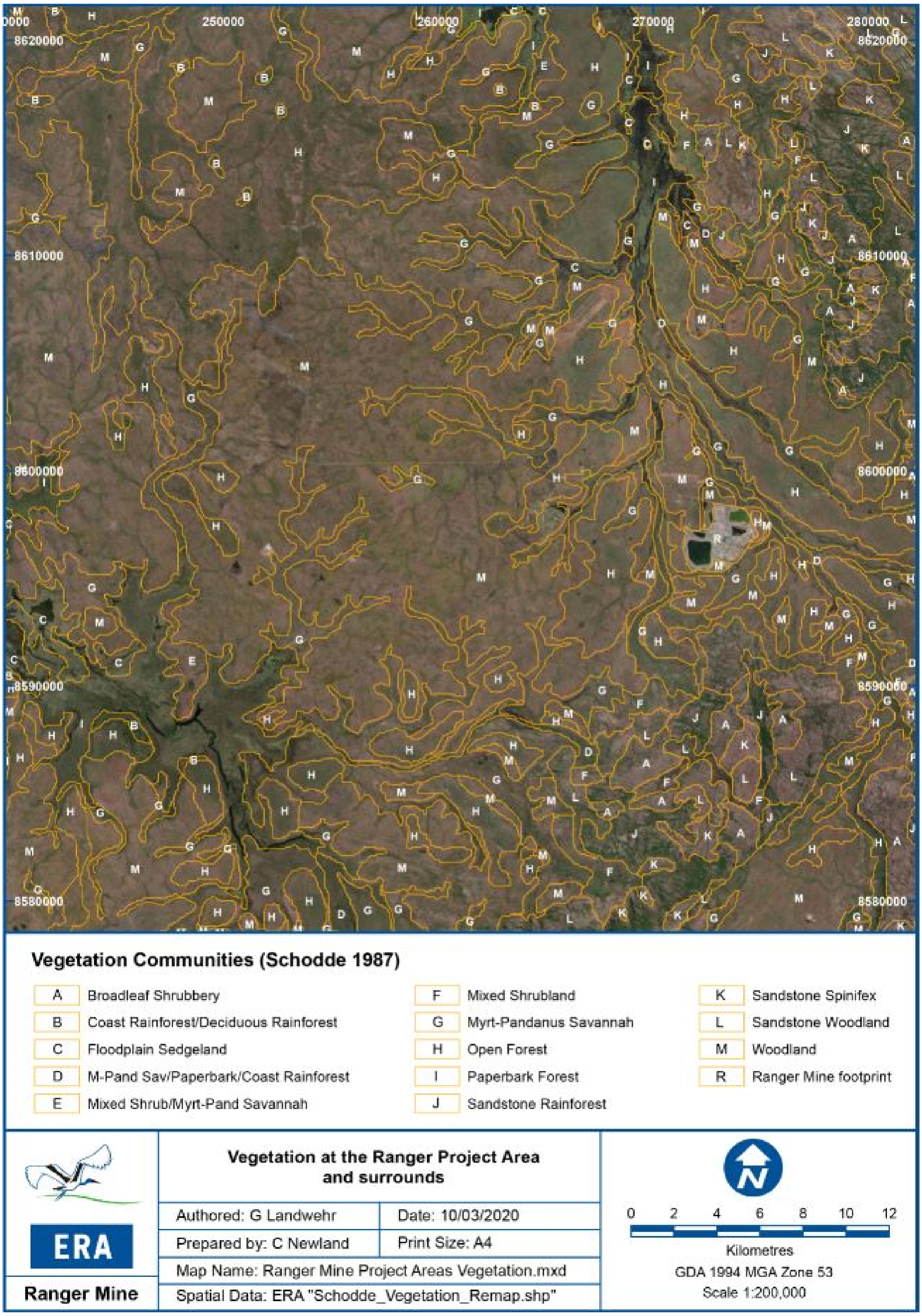


Figure 5-22 Vegetation types over aerial of the RPA and surrounding Kakadu NP

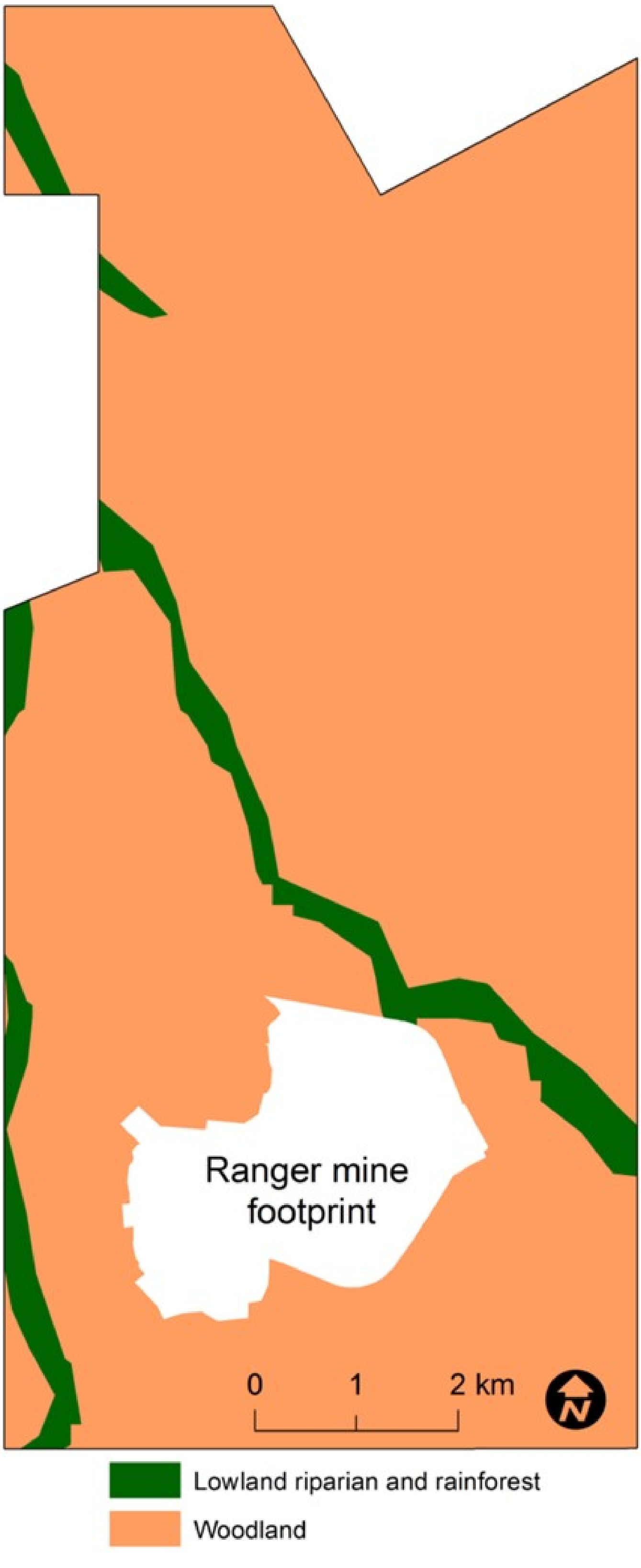


Figure 5-23 Vegetation habitat map of the RPA (based on Brady *et al.* 2007)

Weed species

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 *EPBC Act.* Gamba Grass (*Andropogon gayanus*) is the only WoNS previously recorded in the RPA with the recorded presence restricted to isolated plants on roadsides or in the vicinity of the Jabiru Airport. With successful weed control, there has been no plants nor viable seeds of this species detected for a number of years. 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 Minesite.

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 (Table 5-15). 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. The potential risk of weeds to closure success is further discussed within Section 7. Weed management strategies are discussed within Section 9.

An un-identified plant was observed, and a sample submitted to the NT Herbarium for identification 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, Philippines and PNG). Since identification the Ranger Project Area has been 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.

Table 5-15 Actively Managed Weeds in the 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

5.3.3.3 Vegetation ecology

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*. 1987) 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 EIS).

Vegetation dynamics and responses to disturbance

Disturbance events are the major agents of change in vegetation communities. The severity of their effects on plant community structure and composition depends upon (a) the type of disturbance, (b) its intensity, spatial extent and frequency of recurrence, and (c) the resistance and resilience of the affected plant community and its individual component species. Understanding how native vegetation responds to, and recovers from, disturbance is fundamental in designing ecologically-based revegetation programs.

Plants of forests and woodland communities of the wet dry tropics have been successful and survived because they have adapted to the disturbance events (eg fire, cyclone, El-Nino drought) that are characteristic of the region. The strategies adopted by the flora of the region fall into two broad categories, 'persistence' and 'opportunism'.

Persistence

All of the long-lived framework species rely on a 'persistence' strategy based upon the ability to resprout from lignotubers and root suckers (Lacey & Whelan 1976; Fensham & Bowman 1992). Although they produce and shed seed, seedling regeneration is considered rare in *Eucalyptus tetrodonta* and *E. miniata* (Fensham 1992). The chance of an individual seedling surviving by the end of the first dry season is extremely low, considering their slow growth and the combined pressures of a lack of water and the likelihood of fire. In their review of previous revegetation research at Ranger Mine, Reddell and Zimmermann (2002) noted that, of 5000 young seedlings of framework species observed in natural woodland plots, not one survived after 2 years. Other research in north Australian eucalypt savannas has found that seedlings of *Eucalyptus miniata* and *Acacia oncinocarpa* grown from seed were reduced by 75% and 65% respectively by the end of the first dry season, and this had further dropped to only 11% and 33% survival by the middle of the following dry season (Setterfield 2002). In contrast, woody resprouts of framework species are common components of the ground and shrub layers in these woodlands. Although often damaged or filled by the frequent low intensity fires that are characteristic of the management regime in the region, once they reach approximately 3m in height they become increasingly fire resistant and are able to 'break-out' from the fire-suppressed ground layer. To reach such a height, fire would need to be excluded from a woodland site for 3 to 5 years (Williams *et al* 2003a).

The success of the 'persistence' strategy over seed regeneration for long-lived species probably related to a number of factors including (a) the hostile environment of these woodlands (eg very infertile soils, extended annual dry periods, high fire frequency, high densities of very competitive grasses and forbs in the ground-layer) for establishment of the generally slow-growing seedling of long-lived plants, and (b) the marked competitive advantages for a root sprout of being able to access a well-established existing root system.

The persistence strategy allows long-lived species to capture and store resources, tolerate repeated low-intensity fire, and cope with other less frequent bit potentially more damaging disturbances (such as cyclones, El Nino events or high intensity wildfires). Given that the annual mortality rate of canopy trees in these woodlands is estimated to be around 1% (and up to 15% after particularly intense fires (Lonsdale & Braithwaite 1991; Williams *et al* 1999), current prescriptive fire management strategies which result in the continued suppression of woody sprouts in the ground layer could in the long-term have severe demographic consequences for the composition, structure and functioning of these plant communities.

Opportunism

The grasses and forbs that dominate the ground layer, together with some short-lived shrubs and trees (eg *Acacia holosericea* and *Grevillea pteridifolia*), rely largely on an 'opportunism' strategy for regeneration. This strategy is based on the ability to rapidly colonise a disturbed area and capture resources in the ground layer of the woodland that have been made 'available' by the disturbance event. Species with this strategy tend to produce large seed crops, some of which can form a soil seed back, and have high growth rates. The frequency and intensity of fire has a major effect on the composition of the opportunists which successfully capture a disturbed site (Andersen *et al* 1998; Fensham & Bowman 1992; Grant & Loneragan 2001; Lonsdale & Braithwaite 1991; Williams *et al* 1999; Williams *et al* 2003b). This strategy explains the significant year-to-year changes and the high spatial heterogeneity in the plant diversity in the ground layer of savanna woodlands.

The long-term dynamics of woodland vegetation in the wet-dry tropics results from the interaction between these two broad strategies. Framework species dominate the site and its resources and are very resistant and/or resilient to most natural disturbance events, including cyclones, El Nino drought and relatively intense fires. Recruitment of these species is predominantly by suckering from underground stems and they give the woodlands a high degree of long-term structural and functional stability. In contrast, 'opportunist' species form an extremely dynamic ground layer, changes in which are driven by frequent fire. Although contributing little to the overall stability of the plant community, this ground layer provides habitat and food resources for many of the native fauna. As a consequence, the predictability of the response of a woodland site to severe disturbance is linked directly to the size and dominance of the framework species (eg. Russell-Smith 1995; Williams *et al* 1999). Only when the soil profile is removed and the underground perenniating organs destroyed (eg in road cuttings, borrow pits, minesites), do the framework species lose their competitive advantage. In these situations, slow recolonisation by growth of suckers from adjacent undisturbed areas is likely the main regeneration strategy However, successful establishment of framework species from seed may occur in some of these highly disturbed areas, but only in situations where there are:

- high light conditions;
- some protected microsites for germination and early growth;
- minimal competition from aggressive, faster-growing species; and

- protection from fire for at least three to five years.

Despite the functional importance of framework species for the long-term sustainability and stability of the plant communities, they are not necessarily the major components of species diversity in these forest and woodlands. Annual and perennial grasses and forbs in the ground-layer often dominate total plant species diversity. However, these components can be very ephemeral in their nature, resulting in considerable year-to-year variation in both species diversity and composition, even at a single natural woodland site (e.g. Williams *et al* 2003b). 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 total species diversity and composition can be quite dynamic and variable in a manner that is largely unrelated to the overall functional performance of the plant community (which is controlled by the framework species).

5.3.3.4 Fire ecology

Fire is a major exogenous feature of Australian eucalypt-dominated ecosystems, especially subtropical savanna woodlands (e.g. Gill 1981; Bradstock *et al*. 2002). Removal of vegetation and litter by fire strongly influences nutrient cycling in savanna ecosystems of northern Australia (Cook 1994). The frequent occurrence of fire has driven the evolution and development of savanna woodland and has resulted in the fire-tolerance and reproductive adaptations that enable the range of plant and animal species found in these systems to persist.

In northern Australia, savanna forests and woodlands are often burnt due to traditional burning of country by indigenous peoples, prescribed burning for infrastructure protection and biodiversity conservation, and wildfires. Tropical savannas worldwide are intentionally burnt every 1 to 3 years (Andersen *et al*. 1998).

Intensity, frequency and timing 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 (*Andropogon gayanus*). Deliberately lit fires usually occur earlier in the dry season than wildfires, and therefore are generally less intense and less destructive to vegetation.

Two major research projects in the Northern Territory, 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.

The frequent dry-season fires often remove any accumulated litter or grass biomass. 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, and 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 litter layer by fire, microbial activity declines (Cook 1994).

Fire management

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 (*Sorghum intrans*). The subsequent curing of the vegetation during the long dry season (May to September) results in a highly flammable landscape, where fire is an annual event (Russell-Smith *et al*. 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).

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). The management approach in Kakadu NP has been to copy the indigenous burning regime by by undertaking early dry season burns which can be accomplished by using helicopter incendiary burning combined with on-ground burning (Edwards *et al*. 2003). Fire is estimated to occur over 55 percent of the park annually (Russell-Smith *et al*. 1997, Lehmann *et al*. 2008 and NAFI 2015) .

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) where trees and shrubs are replaced by annual grasses. The presence of grassy weeds such as Mission Grass (*Pennisetum polystachion*) and Gamba Grass (*Andropogon gayanus*) can exacerbate the effects of a grass-fire cycle (Rossiter *et al*. 2003)

Fire within the RPA is managed by ERA primarily for asset protection, and includes fuel reduction burns, excluding fire from certain areas and maintaining a network of graded firebreaks. Fuel reduction burns are usually undertaken in the early dry season to produce cooler fires with smaller burnt areas (patchy) and to remove fuel without damaging the over- or under- storey vegetation. Burns along the RPA boundary are typically coordinated with Parks Australia aerial burns in Kakadu NP and are designed to minimise the risk of unmanaged late dry season fires travelling into the RPA. The non-operational area of the RPA north of

Magela Creek is burned by Parks Australia (in co-operation with ERA) as part of annual burning programs.

5.3.3.5 Ecohydrology of natural tropical savanna ecosystems

Plant responses to water stress in the wet-dry tropics

A particularly strong influence on vegetation survival in the wet-dry topics is water availability. The survival of vegetation is dependent on the water balance in the dry season, especially towards the end of the dry season when the soil water stress is at its highest. Plants generally evolve to have adaptions suited to survival in their particular environment. In the seasonally wet-dry tropics, this includes strategies to survive what can be extremes of inundation or 'drought', or more-nuanced variations such as length of dry season, or timing of the wet season onset. Most plants have evolved physiological responses to cope with a broad (natural) range of scenarios. During the dry season plants resort to strategies of ever-decreasing water demand including stomatal closure, loss of leaves, and progressively developing a deeper root system.

A key adaptation is strategies to avoid a catastrophic cavitation of the water-conducting xylem system by balancing canopy water loss and root absorption. As soil moisture is reduced, trees reduce their water loss first by stomatal closure, then progress to sacrifice non-vital, peripheral organs (such as leaves, twigs, small branches to larger ones and above ground stems) to slow down water loss and soil water depletion and survive through the drought (Tyree and Sperry 1988). Vegetation, even the evergreen trees (such as *E. miniata* and *E. tetrodonta*), lose large amounts of leaves to reduce transpiration (water loss from tree canopy), to maintain a balance between root water uptake and canopy water loss (Thomas and Eamus 1999). As a result, although the amount of soil PAW is very low, it is sufficient for the survival of the trees.

Another key strategy to reduce water stress is to develop roots that can access plant available water as it retreats down the soil profile with the progress of the dry season. 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) and thereafter access water progressively deeper into 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 should not need to root any deeper than this. However, if water is more readily available below that depth, i.e. if a plant can spend less energy to access that water from depth than from an upper dry soil layer, then the root will go and reach that layer, as long as 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). It is well-known that plants have evolved in such a way that they can maintain the balance of water demand and supply to avoid such a catastrophic result (Tyree and Sperry 1988).

In the savanna woodlands typical of Kakadu NP (and the targets of the revegetation efforts at Ranger), by far the bulk of roots are present in the upper one metre of the substrate during the wet season, when growth rates are at a maximum (Janos *et al*. 2008; Hutley 2008). This is in part due to the ferricrete layer (duricrust) that occurs at about 1 to 1.5 m below the soil surface throughout the region (refer Figure 5-24) which limits root development further down but can allow penetration by deeper-tapping roots through macropores (Werner and Murphy 2001; Hutley 2008; Hutley *et al*. 2000). It has been observed that many important tropical savanna species in the NT Top End's soils are able to root to depth of 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 adapted to the Top-End seasonality (refer to Figure 5-25). One of the features is that during the wet season trees maximise growth and water uptake from shallow soil which is nutrient rich. During the dry season the shallow soil water is quickly depleted, and trees stops growing and access water from depth. Water is accessed from depth for trees to maintain photosynthesis and, under more severe conditions, maintain the viability of vital organs to survival the long dry season. Although the water uptake (use) is very low from depth and nutrients are very limited, sub-soil water storage is critical for the survival of the vegetation.

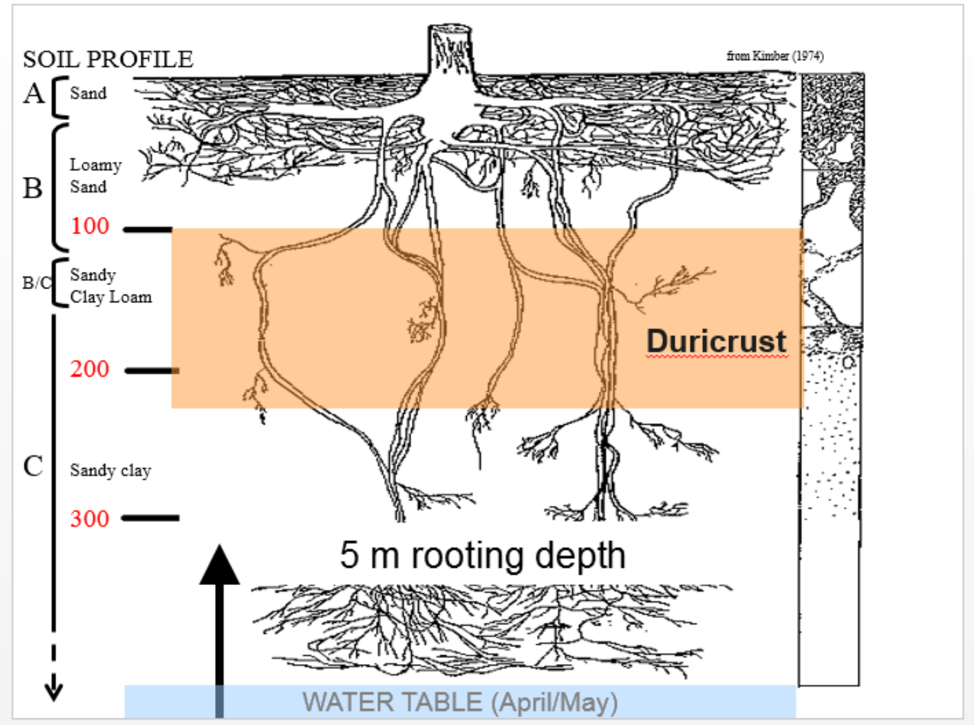


Figure 5-24 Rooting pattern of the savanna woodland trees in the Top-End (Source: Hutley 2008)

ERA

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 5-25 Key features of savanna vegetation water-use and carbon allocation strategies adapted to the Top-End seasonality ((Source: Hutley 2008)

In general, rates of plant growth and water demand decline as the wet season ends and the dry season progresses, and the fine root mass can be seen to diminish with the receding soil-water reserve (the cost to the plant of maintaining these fine roots during the dry season for 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) demonstrate that soil water was extracted from 5.5 to 5.8 m below the surface in the late dry season (Refer to Section 4.3.3). More information with regards to waste rock studies on the TLF can be found in Appendix 5.1.

Canopy cover dynamics

Long-term canopy cover (as measured by Leaf Area Index, LAI) of the woodlands was monitored at the four ecohydrological study sites at the Georgetown Creek Reference Area and show significant seasonal variability (refer to Figure 5-26). The LAI is highest during the wet season and lowest during the dry season. The seasonal reduction is mostly about 50%, but is higher in some dry years (Note: LAI methodology details can be found Lu *et al* 2019).

Site 21 has the densest canopy (highest LAI) among the sites, and also the highest LAI seasonal variation. At Site 21 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 also has the highest annual transpiration (data not shown). Site 21 has a species composition (dominant overstorey species are Eucalyptus tetrodonta and Eucalyptus miniata) and basal area (8 m^2 ha^{-1}) similar to other tropical savanna in northern Australia (Hutley *et al*. 2000).

Trees will shed more leaves and earlier during the driest period in the dry season if water is beyond reach of the roots, as observed at the reference sites 21 and 30. Site 30 sits on a drier site, it sheds more leaves, earlier, and more rapidly than trees at Site 21, as reflected in the seasonal dynamics of the LAI (shown in Figure 5-27). That means, in the worst-case scenario, if there was less PAW than the target, trees will still be able to survive through the dry season and regrow during the wet season.

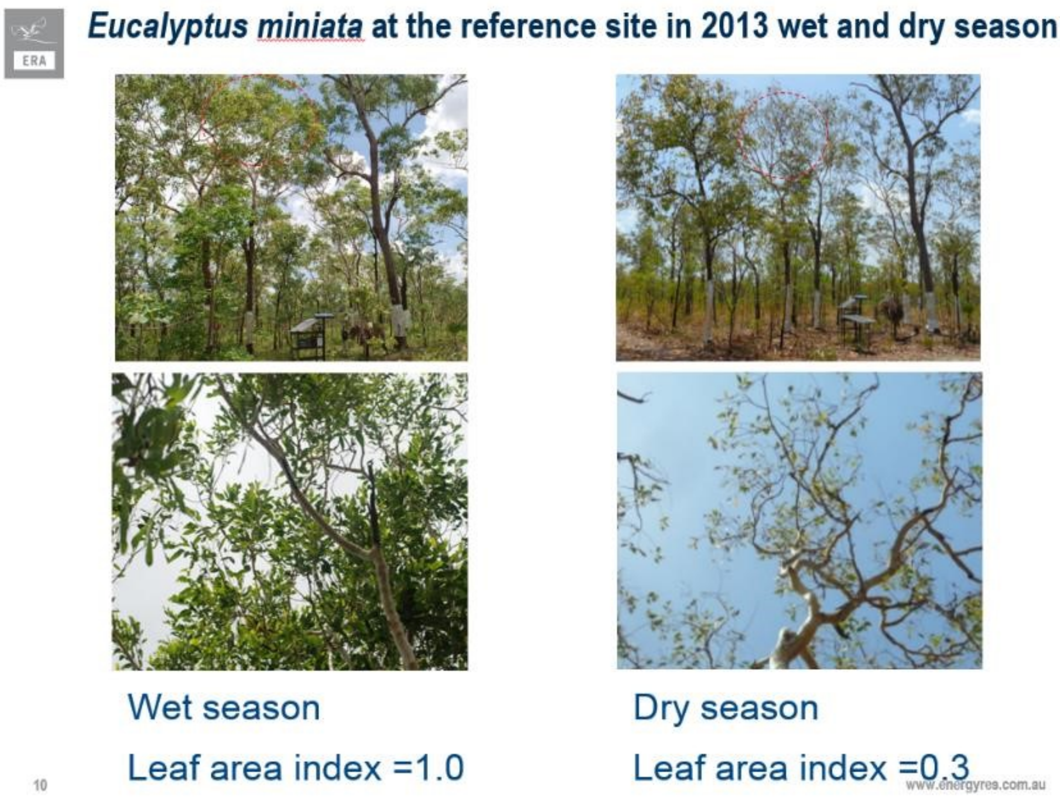


Figure 5-26 Seasonal change in leaf area index at the Georgetown Creek Reference Area (Source: Lu *et al*. 2018)

ERA

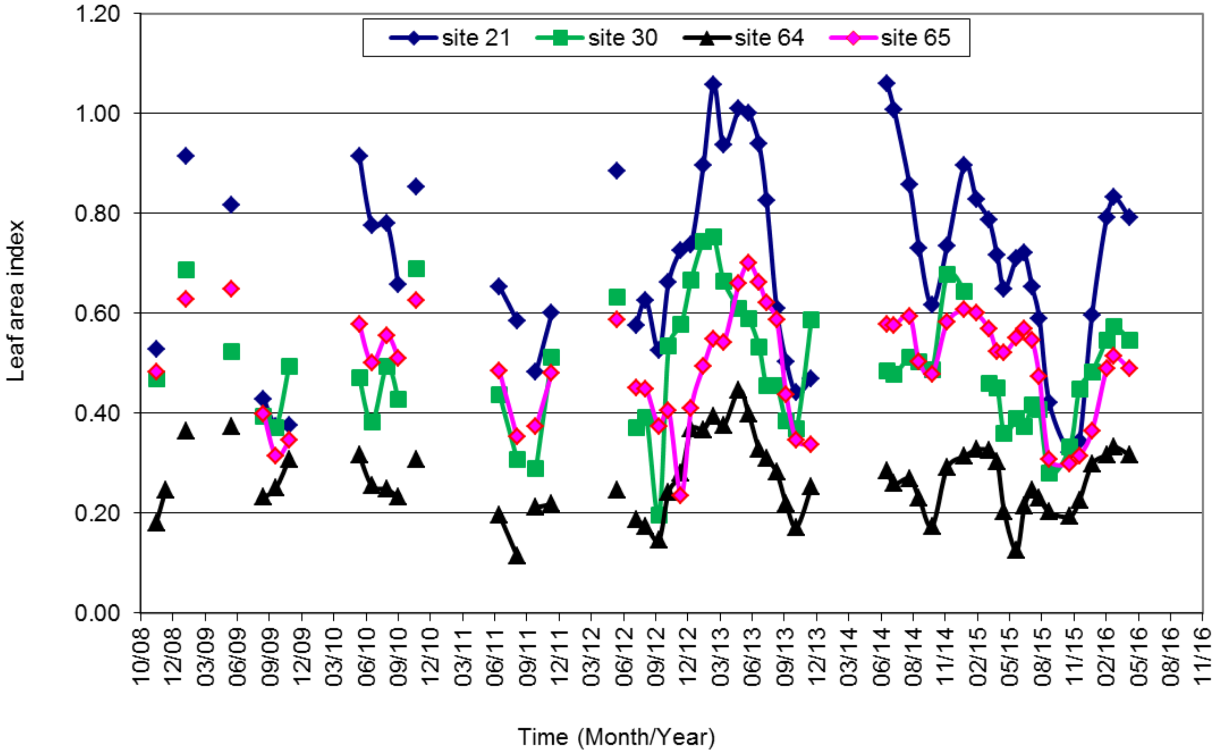


Figure 5-27 LAI dynamics at the four ecohydrological study sites

Total water requirements of the vegetation during dry season

Total water requirement for vegetation is usually measured by the evapotranspiration (ET), which in simple terms is the sum of over storey transpiration, under storey transpiration, and soil evaporation (Figure 5-28). Other closely related processes shown on Figure 5-28 are runoff and groundwater recharge.

In the Top End of the Northern Australia, during the dry season, the woodland vegetation water use is dominated by the overstorey and midstorey vegetation while the understorey dries off rapidly at the beginning of the dry season and its contribution to the ET is minimum and negligible compared to the tree/shrub water use (Hutley 2008, Hutley *et al*. 2000).

Stand transpiration, of the woodland near Ranger site was estimated based on tree stem xylem sap flow measurement at Site 21 of the Georgetown Creek Reference Area (Figure 5-29, refer to Lu *et al* 2019 for details on measurements of sap flow and stand transpiration). Tree water use is at its highest around the end of wet season and/or beginning of the dry season (April, May, June) when the soil water availability is high, the days are sunny, the air is dry (evaporative demand is high) and the LAI is high (refer to Figure 5-27). The transpiration decreases during the dry season as the soil dries up and LAI decreases (Figure 5-27), reaching a minimum at the end of the dry season right before a significant rainfall. During the early wet-season the transpiration increases as the soil water availability and canopy LAI increase, but the transpiration is not at its highest due to wet and raining days.

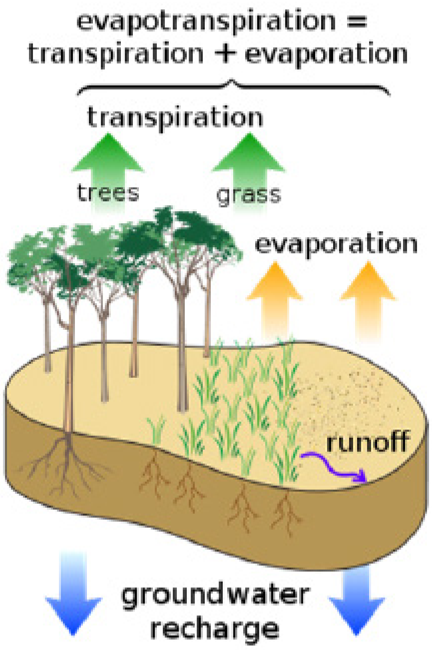


Figure 5-28 Evapotranspiration and its components

Figure 5-29 General view of an instrumented study site

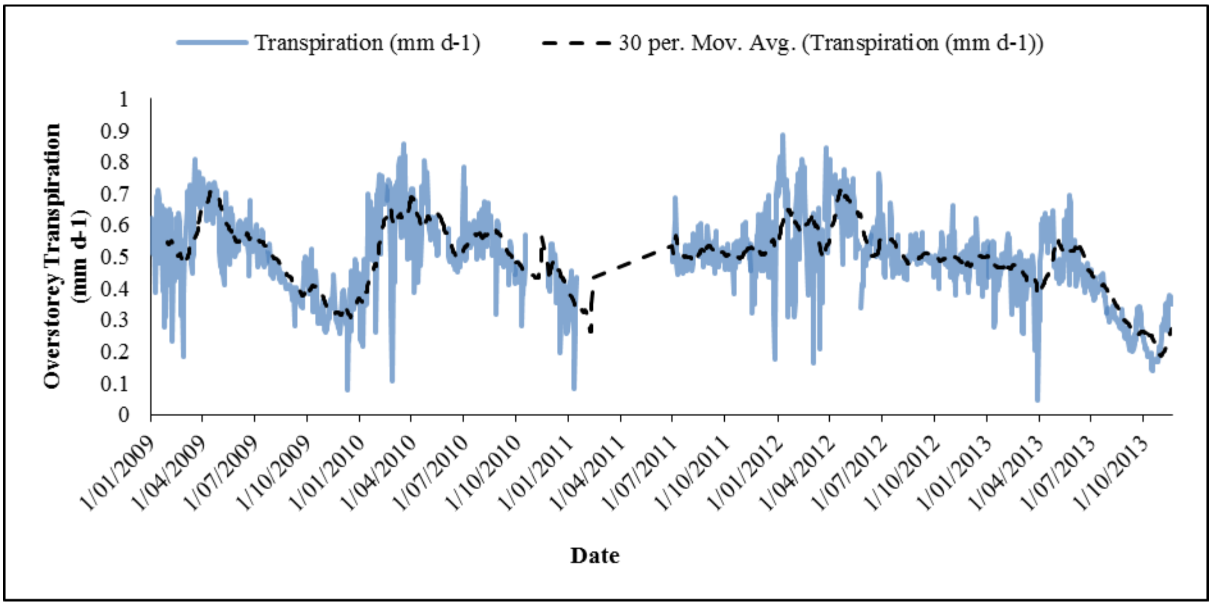


Figure 5-30 Annual dynamics of over storey tree transpiration at Site 21

Canopy cover (LAI) is directly and highly correlated with vegetation water use (Baumgartl *et al*. 2018). Site 21, with the highest LAI and therefore the highest vegetation water use, was selected as a reference site for modelling to compare dry season natural vegetation water requirement with the plant available water (PAW) supply in the final waste rock landform, because the site presents a conservative target for the vegetation water requirement (Baumgartl *et al*. 2018). To be on the more conservative side, an upper envelop of the average dry season transpiration of 0.5 mm day-1 was adopted for the WAVES modelling (refer to Appendix 5.1).

Groundwater table and soil water dynamics

At Site 21, the groundwater table level is very dynamic (Figure 5-31). During the wet season the water level reaches within 0.5 metres of the soil surface and during the dry season it drops below 10 metres below the soil surface. 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, so when the water level drops below 10 m, the transducer (logged) gives a maximal 10 m depth, but the manual dipper can still give the reading until the bottom of the borehole is dry. Groundwater and soil moisture measurement details can be found in Lu *et al* 2019).

This shallow groundwater system is also very transient during the wet season, with peaks subsiding rapidly after heavy rainfall stops. All these characteristics are typical of a groundwater system of a low hill with porous material in the shallow ground.

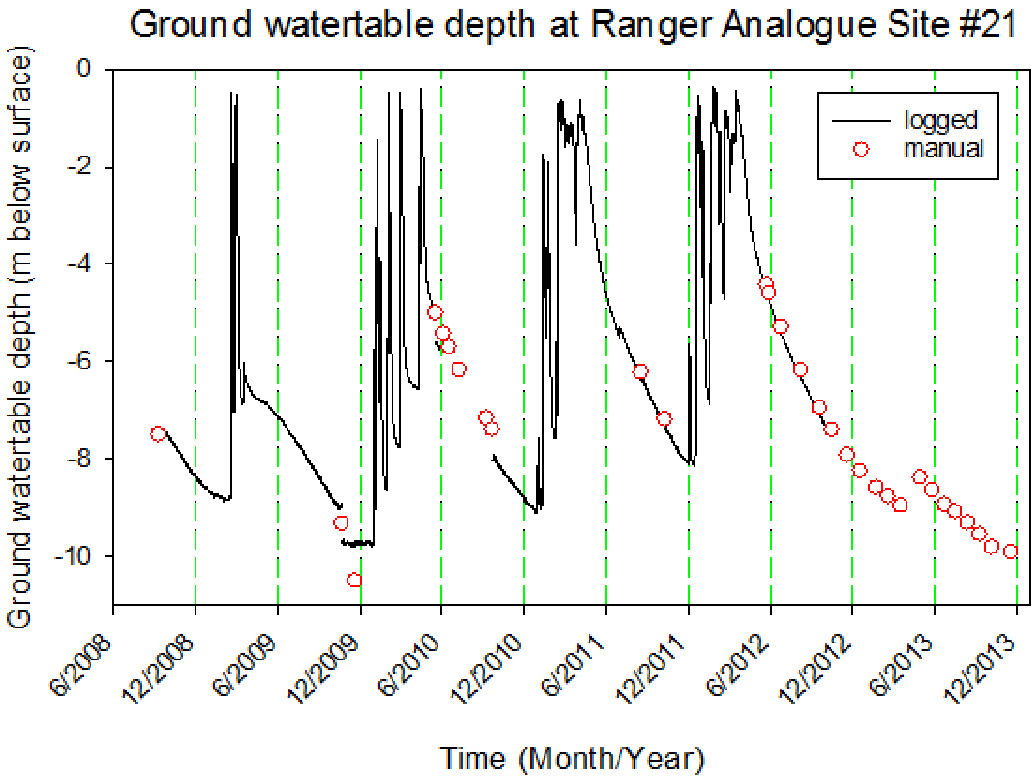


Figure 5-31 Temporal dynamics of the groundwater depth at Site 21

A comparison between the soil water dynamics (as shown by relative extractable water contents, REW) at different depths (0 to 5.5 metres below ground surface) and ground water table level (GWT) at Site 21 is shown on Figure 5-32. The data in Figure 5-32 clearly shows that maximum REW for the whole soil profile occurs during the late wet season. As the dry season progressed, soils dried quickly (within one month) near surface and in the shallow depths (at 0, 0.5 and 1 metres below ground surface). The 0-metre depth corresponds to a probe placed 0.05 metres below the ground surface (measuring soil water content from 0.05 to 0.35 metres below the ground surface). After the shallow soil dried, water was extracted from deeper levels, from 2 to 5.5 metres below ground surface progressively. By November 2012, extractable water from the whole 5.8-metre thick profile was nearly fully depleted (the deepest probe measures soil water from 5.5 to 5.8 metres below ground surface). However, the measurement of the sap flow clearly shows that the trees still maintained a substantial level of transpiration (Figure 5-30) during the same period which demonstrates that tree root systems exploited soil water from deeper soil.

The depth to the ground water table decreased progressively with, but ahead of, the rapid decrease of REW. The depth difference between the REW and the ground water table depth broadly corresponds to the capillary fringe height.

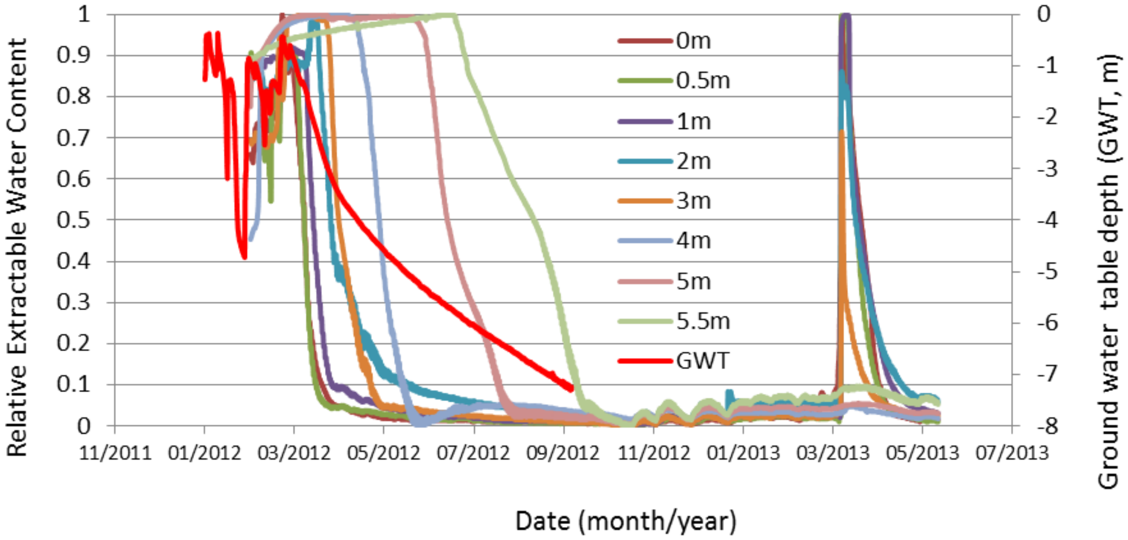


Figure 5-32 Relative extractable water contents measured at different depths and ground water table depth (GWT, in Red) at Site 21

Plant water uptake patterns can often be inferred from soil water depletion pattern (Knight 1999). From Figure 5-32 it is evident that as the dry season progressed, the extractable water was depleted progressively from the surface to deeper depths, reaching the depth 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. This is consistent with the finding of a study in Australia by Sharma *et al*. (1987) that a significant amount of soil water extraction under 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 5-32 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 the 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 that the dry season understorey ET and soil evaporation are negligible and were not directly measured at the Ranger reference site, they were simulated using a locally calibrated WAVES model to obtain the total dry season vegetation ET (Dawes *et al*. 1998, Zhang & Dawes 1998, Segura 2016).

Results of the total evapotranspiration (estimated stand transpiration of 0.5 mm.day^{-1} + simulated understorey ET and soil evaporation) of the reference site over the past 117 years are presented in Appendix 5.1 along with the PAW results for the waste rock landform.

5.3.3.6 Fauna species

Native fauna species

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 number of conservation significant species (including a large number of mostly bird species listed under various migratory agreements) have been recorded on the RPA during previous surveys (Table 5-16). The identified species include the conservation listed Northern Quoll *Dasyurus hallucatus* (Endangered1; Critically Endangered2) and the Partridge Pigeon *Geophaps smithii smithii* (Vulnerable1; Vulnerable2) listed under the 1 EPBC Act and 2TPWC Act (Firth 2012).

A desktop review of flora and fauna data held by ERA included 26 reports presenting the results of fauna surveys; three reports documenting aquatic flora and fauna survey work; seven documents that reviewed previous terrestrial and aquatic flora and fauna work; and relevant data bases of ERA Birdwatch events that occurred on the RPA from 2001 – 2011, inclusive (Firth 2012).

Since the 1990s, a significant decline in the abundance of ten species of small mammals in Kakadu, including the Northern Brown Bandicoot (*Isoodon macrourus*), Fawn Antechinus (*Antechinus bellus*), Common Brushtail Possum (*Trichosurus vulpecula*), the TPWC Act listed Pale Field-Rat (*Rattus tunneyi*) (conservation status vulnerable) and the Northern Quoll (*Dasyurus hallucatus*) (conservation status Critically Endangered), has been recorded. The decline has been attributed to a high fire frequency, feral cats and cane toads (Woinarski *et al.* 2010).

The Northern Quoll population has undergone dramatic declines in the Top End of the NT as a result of ingesting the toxic cane toad (*Rhinella marina*), and in many areas of the mainland, such as Kakadu NP, has become almost extinct. It has not been detected in several recent surveys on the RPA, indicating it is likely extinct on the RPA. The only EPBC Act listed fauna species still known to occur on the RPA with any certainty are the Partridge Pigeon (*Geophaps smithii smithii*), Fawn Antechinus (*Antechinus bellus*) and Black-footed tree-rat (*Mesembriomys gouldii*), the latter two only being recently conservation listed.

During the last fauna survey undertaken on the RPA in September 2013, at least[6] 127 species were recorded, comprising eight native amphibian species, 79 bird species, at least 17 native mammal species, 20 reptile species and three introduced species. Seven EPBC Act or TPWC Act listed species were recorded within the 220 ha survey area, situated towards the east of Pit 3 in the Magela Creek and former Magela land application areas (LAA), and in the vicinity of RP1 (Eco Logical Australia 2014).

[6] There were several bat species whose calls could not be positively identified.

Table 5-16: 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
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

Common name	Scientific name	EPBC Act (CTH) status	TPWC Act (NT) status	Preferred habitat
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

Common name	Scientific name	EPBC Act (CTH) status	TPWC Act (NT) status	Preferred habitat
Red-capped Plover	*Charadrius ruficapillus*	Marine	Not listed	Sandflats or mudflats at the margins of saline, brackish or freshwater wetlands
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

Introduced fauna species

Eleven feral fauna species have been recorded in the RPA and an additional eight species have been recorded in Kakadu NP (Table 5-17). 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 5-17: 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	Buffalo	*Bubalus bubalis*	Y	Y
Mammal	Cattle	*Bos taurus*		Y
Mammal	Cat	*Felis catus*	Y	Y
Mammal	Donkey	*Equus asinus*		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
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	Cockroach	*Periplaneta spp.*	Y	Y
Insect	European honey bee	*Apis mellifera*	Y	Y
Amphibian	Cane toad	*Rhinella marina*	Y	Y
Reptile	Flower-pot snake	*Ramphotyphlops braminus*	Y	Y
Reptile	House gecko	*Hemidactylus frenatus*	Y	Y

5.3.4 Aquatic ecosystem

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, ie Lowlands containing open woodlands and creeks, and Floodplains containing freshwater wetlands, creeks and billabongs.

The terrestrial flora and fauna of Kakadu NP descriptions provided above (section 5.3.3) discuss important water birds and semi-aquatic species (eg amphibians and reptiles).

On the RPA there are no listed or endangered macroinvertebrate or fish species, or aquatic fauna species, or any considered rare or restricted in distribution. Nor are there environments of special significance (such as significant breeding sites, seasonal habitats or wetlands areas). As discussed in section 5.3.3 several migratory bird species listed of international importance and the vulnerable Merten's water monitor have been recorded on the RPA.

5.3.4.1 Vegetation types

The lowland riparian and rainforest vegetation type, which represents denser vegetation of the lowlands, typically associated with streams, creeks and billabongs is described in section 5.3.3. This habitat type is represented throughout the Kakadu NP Ramsar site with about 1% occurring within the RPA.

There has been multiple reports of floodplain vegetation on the Magela Floodplain with varying numbers of classes being identified which suggest a high level of variability over time. Rainfall volumes and patterns affect inundation periods, water level, and soil moisture which along with fire affects community distributions seasonally and inter-annually (Whiteside and Bartolo 2014). Using remote sensing and a review of past reports, Whiteside and Bartolo (2014) identified twelve classes of typical vegetation on the Magela floodplain occurring in May 2010 (Table 5-18). Time-series mapping by the SSB will build on this dataset and classification providing further information on vegetation dynamics on the floodplain.

Table 5-18 Twelve classes of Magela floodplain vegetation described by Whiteside and Bartolo (2014)

<table>
<tr><th>Class name</th><th>Composition and occurrence</th><th>Area of cover on the floodplains in May 2010</th></tr>
<tr><td>Melaleuca woodland</td><td rowspan="2">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 reaches of the floodplain and around the perimeter.</td><td>10–50% woody cover; covering 5039 ha</td></tr>
<tr><td>Melaleuca open forest</td><td>open forest communities have 50–70% cover; covering 821.8 ha</td></tr>
<tr><td>Oryza grassland</td><td>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.</td><td>4040 ha</td></tr>
<tr><td>Hymenachne grassland</td><td>Dominated by Hymenachne acutigluma throughout the year. Other species that may occur include Oryza meridionalis, Nymphaea spp., and Pseudoraphis spinescens.</td><td>3639 ha</td></tr>
</table>

Class name	Composition and occurrence	Area of cover on the floodplains in May 2010
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	107.5 ha

Class name	Composition and occurrence	Area of cover on the floodplains in May 2010
	stretches of open water, the fern can be found on the leeward edge.	

BMT (2019) describe the patterns, components, key species and primary productivity of the aquatic ecosystems, of the RPA and surrounds as follows.

5.3.4.2 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 (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. Although in wetter years, substantial floodplain areas of the Magela Creek catchment can remain inundated 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 (predation, 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 because of their shallow nature and associated dry-season habitat and water-quality deterioration, (Humphrey *et al.* 2016). Furthermore, wet seasons of low rainfall, in conjunction with an extended dry season, can lead to many shallow lowland billabongs completely drying out (Humphrey *et al.* 2016). Similarly, creek channels and seasonally inundated floodplain environments also completely dry out during the dry season, and 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.

5.3.4.3 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) list a number of critical and supporting ecosystem components of the Kakadu NP Ramsar site. That work and Garde (2015) 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 listed in Table 5-19.

Table 5-19 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-invertebrate s
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	Significant breeding aggregations of magpie geese *Anseranas semipalmata* and comb-crested Jacana *Irediparra gallinacea*	Present – billabongs and floodplain	Water Birds

Category	Species, Conservation Listing and or cultural value	Presence on the RPA or downstream aquatic environment	Species Group
important populations in Kakadu based on Ramsar	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 *Ephippiorhynchus asiaticus*	Present – billabongs and floodplain	Water Birds
	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	Macrophyte s
	Mussels and freshwater prawns – food	Present – billabongs and floodplain	Aquatic Invertebrate s
	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.	Present – billabongs and floodplain	Reptiles

[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.

Category	Species, Conservation Listing and or cultural value	Presence on the RPA or downstream aquatic environment	Species Group
	See also *Carettochelys insculpta* above		
	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 5-19 are summarised (below) by BMT (2019).

5.3.4.4 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 less 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 5-20

Table 5-20 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 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

5.3.4.5 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. These refuges include permanent billabongs, and in the case of euryhaline[8] species such as barramundi, estuarine river channel environments.

[8] Species able to tolerate a wide range of salinity.

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 habitats were also commonly used spawning sites for numerous species, but only a small number breed 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 – e.g. barramundi, tarpon, eels.

5.3.4.6 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.

5.3.4.7 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 5-33 depicts a foodweb for aquatic ecosystems in the Magela Creek catchment. 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.

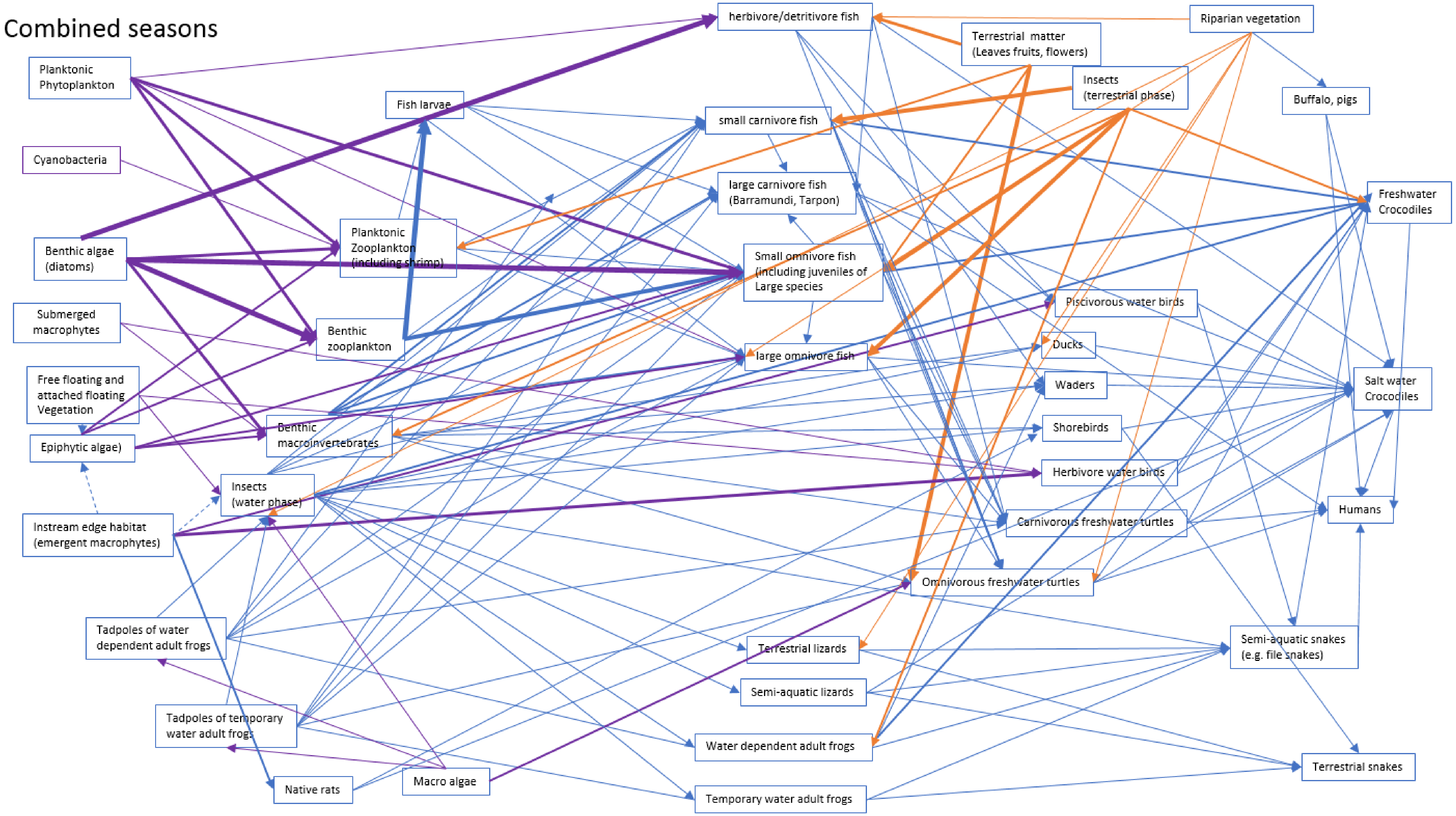


Figure 5-33 Food web for aquatic ecosystems in the Magela Creek catchment (from BMT 2019)

Notes: there are differences between seasons. In dry seasons the system is more closed. Wet seasons 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

5.3.5 Trial Landform

5.3.5.1 Radon exhalation

The TLF has provided a unique setting to investigate seasonal and long-term changes in radon exhalation, soil activity concentration and terrestrial gamma dose rate for the four surface and revegetation treatments, and dependency on cover type, weathering and compaction effects and developing vegetation. Radon exhalation from the four erosion plots (i.e. EP1, EP2, EP3 and EP4) has been measured over several years to investigate whether there were any temporal changes of radon exhalation, taking into account rainfall, weathering of the rock, erosion and compaction effects, and the effect of developing vegetation on the landform (Bollhöfer & Doering 2013).

Although average soil radioactivity was not markedly different across the four erosion plots (Figure 5-34), there was a difference in average radon flux densities for the two different surface treatments (waste rock and waste rock blended with lateritic material). In the dry season, typical average radon flux densities from the surface of the waste rock – laterite treatment were higher than radon flux densities from waste rock only, and decreased markedly in the wet (Bollhöfer & Doering, 2016). In contrast, there was no obvious seasonal trend observed for radon exhalation fluxes from waste rock only until years four and five after construction (Bollhöfer & Doering, 2016).

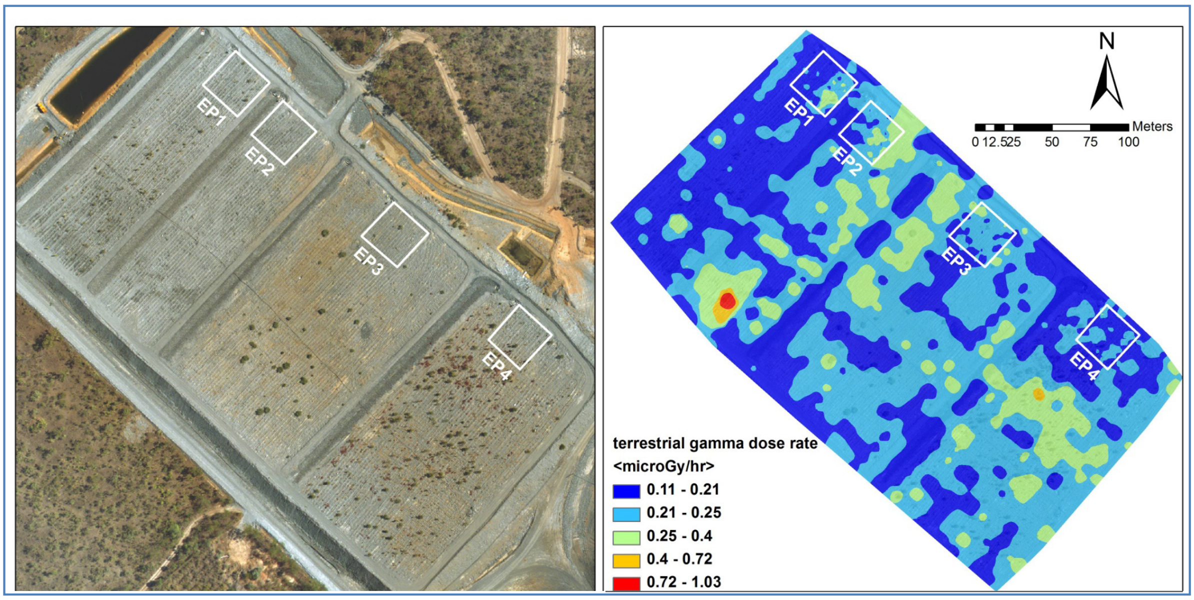


Figure 5-34: Trial landform and contour plot of the terrestrial gamma dose rates measured across the trial landform in June 2012 (Bollhöfer & Doering 2013; p 136)

Radon exhalation measurements recommenced in the second quarter of 2019 to confirm whether the dry season Radon exhalation flux densities have increased since 2014 (McMaster, 2020). Preliminary results indicate a stabilised Radon-222 exhalation flux density with no further increases in radon-222 exhalation (McMaster 2020).

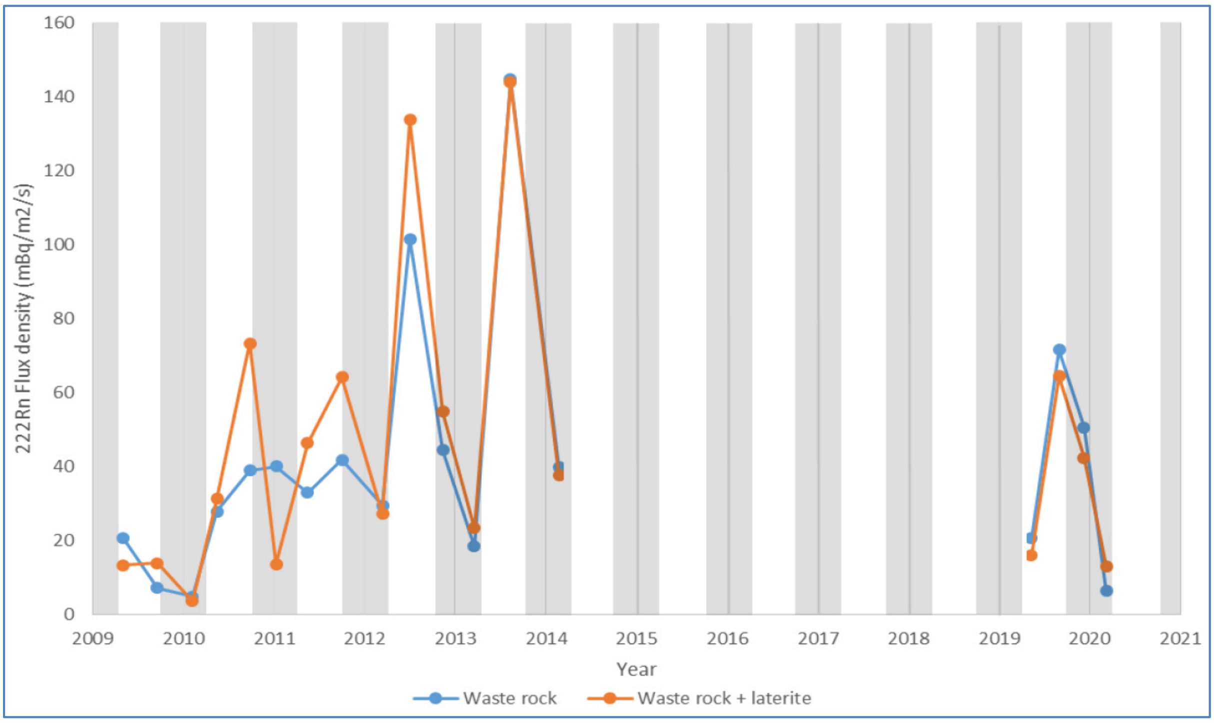


Figure 5-35 Geometric mean radon-222 exhalation flux at the TLF measured since 2009, grey regions indicate the wet season. (McMaster 2020)

Refer to Appendix 5.1 for other studies completed on the Trial Landform.

5.4 Technical knowledge base

The Ranger Mine has been the subject of extensive studies and monitoring programs over the past 38 years. The outcomes of these studies have been presented through various community and stakeholder consultation processes (e.g. ERA 2014b, Iles 2011, Johnston & Milnes 2007, McGovern 2006, Supervising Scientist 2016a) and in statutory reports such as the annual environment reports, mining management plans, Ranger Mine annual wet season reports and groundwater reports. The studies serve to:

- inform the overarching closure strategy and approach
- inform the development of closure criteria (Section 8)
- establish best practicable technology (BPT) and as low as reasonably achievable (ALARA) approaches and strategies for closure implementation that ensure the best environmental and achievable closure outcome for the Ranger minesite that attains compliance with ER requirements (Section 6)
- identify and rank closure risks to ensure the ongoing management of potentially high risks and an iterative approach to mine closure risk assessment (Section 7)
- inform the construction of a final landform (Section 9)
- provide baseline data against which to measure closure performance (Section 10)

- identify knowledge gaps and/or alternative options to past elements of the closure strategy thus ensuring that the most current and practical approaches to closure activities are implemented.

It is recognised that some projects have been finalised whilst others are ongoing. Further updates of the ongoing studies are provided in Section 5.5, Appendix 5.1 and in subsequent MCPs.

5.4.1 Tailings consolidation model

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 the Pit 1 and Pit 3 specific models.

The consolidation models have been supported by a number of other studies, including tailings characterisation and geotechnical investigations to predict the subsurface conditions for the final backfill design. 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
- the application of surcharges

The program models tailings deposition at user defined time steps. The current Pit 3 model is based on time steps of 0.1 days resulting in about 30,000 nodes for the deepest part of the pit.

The program also models 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.

5.4.1.1 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 annulus 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 5-36 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 5-37. 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.

5.4.1.2 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.

5.4.1.3 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.

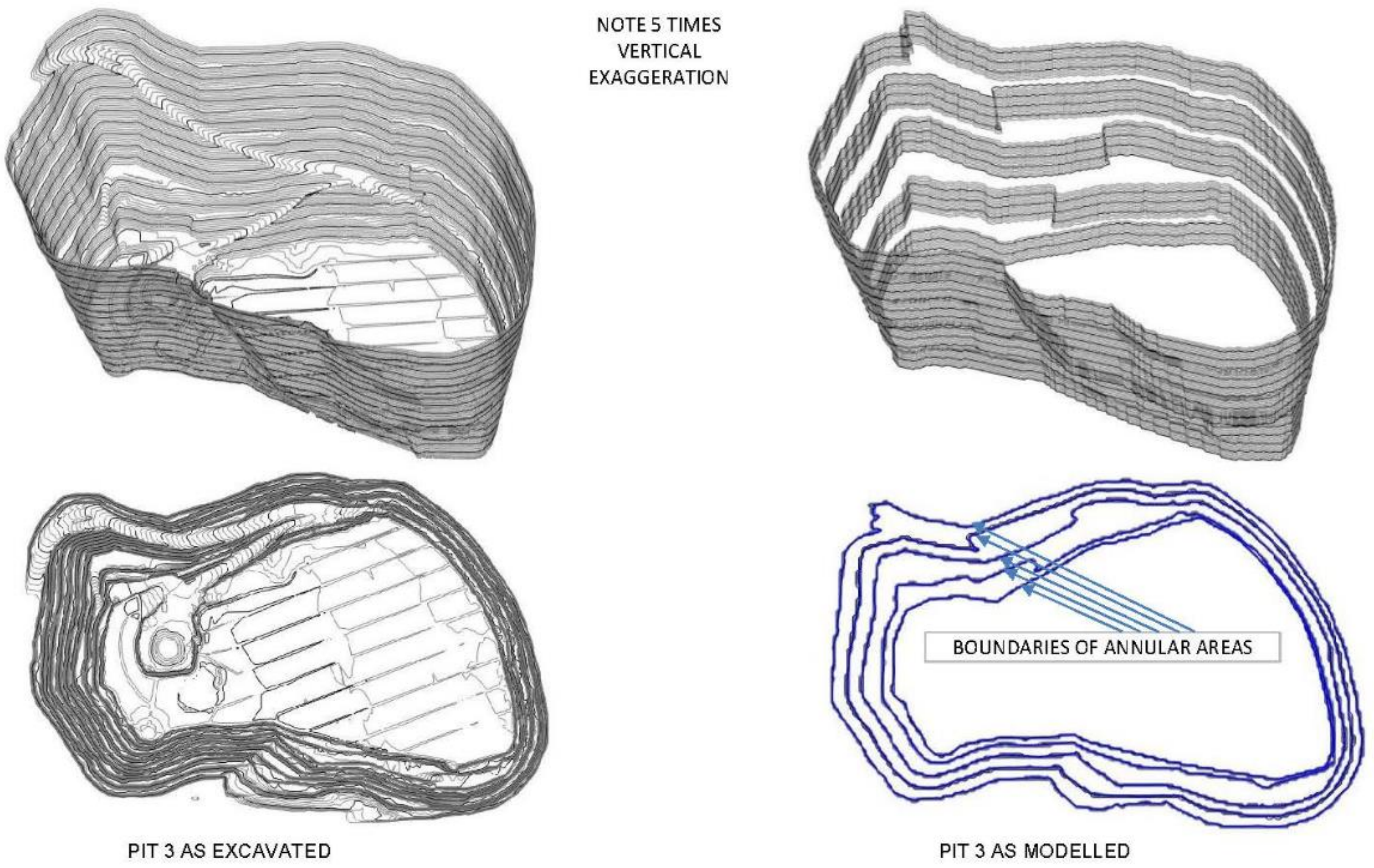


Figure 5-36: Pit 3 as excavated and as modelled

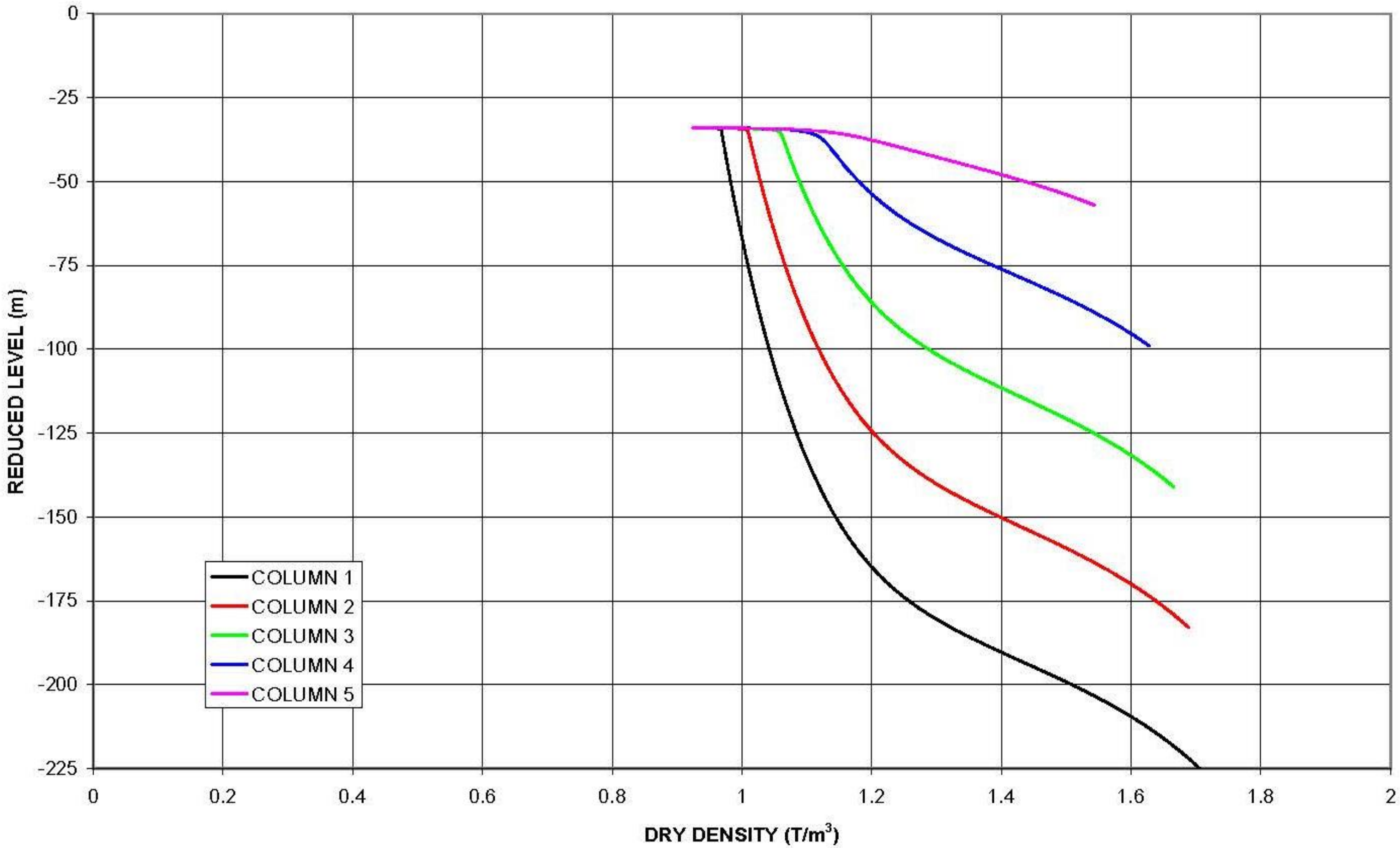


Figure 5-37: Pit 3 density profile - end of filling

5.4.1.4 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.

5.4.1.5 Pit 1 tailings consolidation

Tailings consolidation modelling in Pit 1 has been ongoing since 2003. The ATC Williams 2012 model predicted that the average final tailings level in Pit 1 would be 7 mRL with a minimum level of 0.5 mRL in the centre and approximately 12 mRL near the edges. The predicted final tailings level across the pit is shown in Figure 5-38.

The model was updated in 2015 by Fitton Tailings Consultants (Fitton). Prior to the placement of the pre-load in the fourth quarters of 2013 and 2014, 28 settlement monitoring plates and standpipes were installed across the pit and were raised concurrent with the initial bulk fill layers. The monitoring plates enable regular verification and updating of the consolidation model; the most recent validation of the model was conducted by Fitton (2017). Ongoing measurements of tailings settlement are undertaken on a monthly basis (Figure 5-40) and confirm the model is still valid.

The validation is based on the settlement data from the monitoring plates and earlier consolidation models and confirms the consolidation rate. This validation also estimated the volume of expressed process water over time (Figure 5-39). These results indicate that most process water (greater than 99 %) will be removed via the decant structures by January 2026.

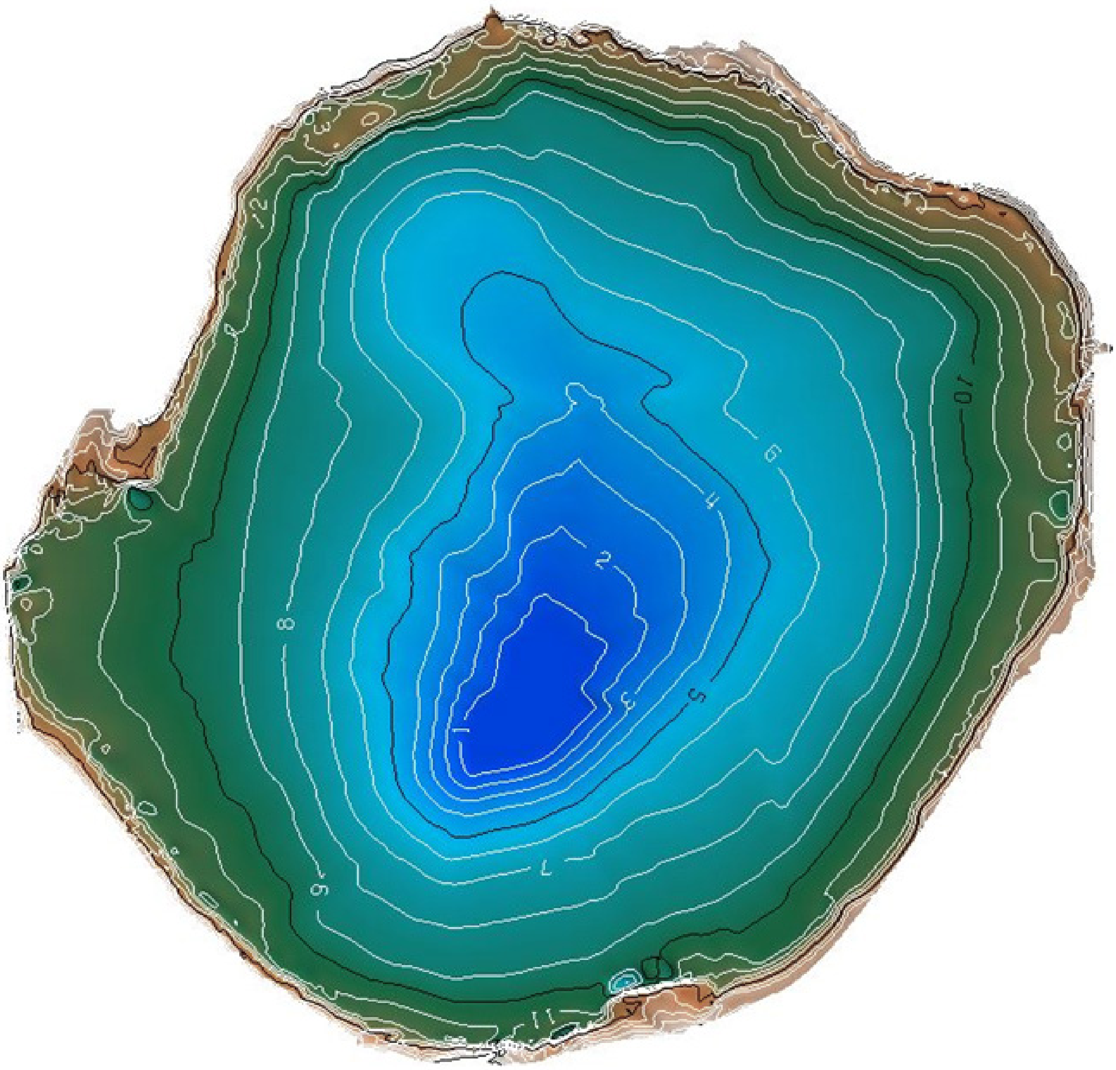


Figure 5-38: Predicted final tailings level (m) across Pit 1

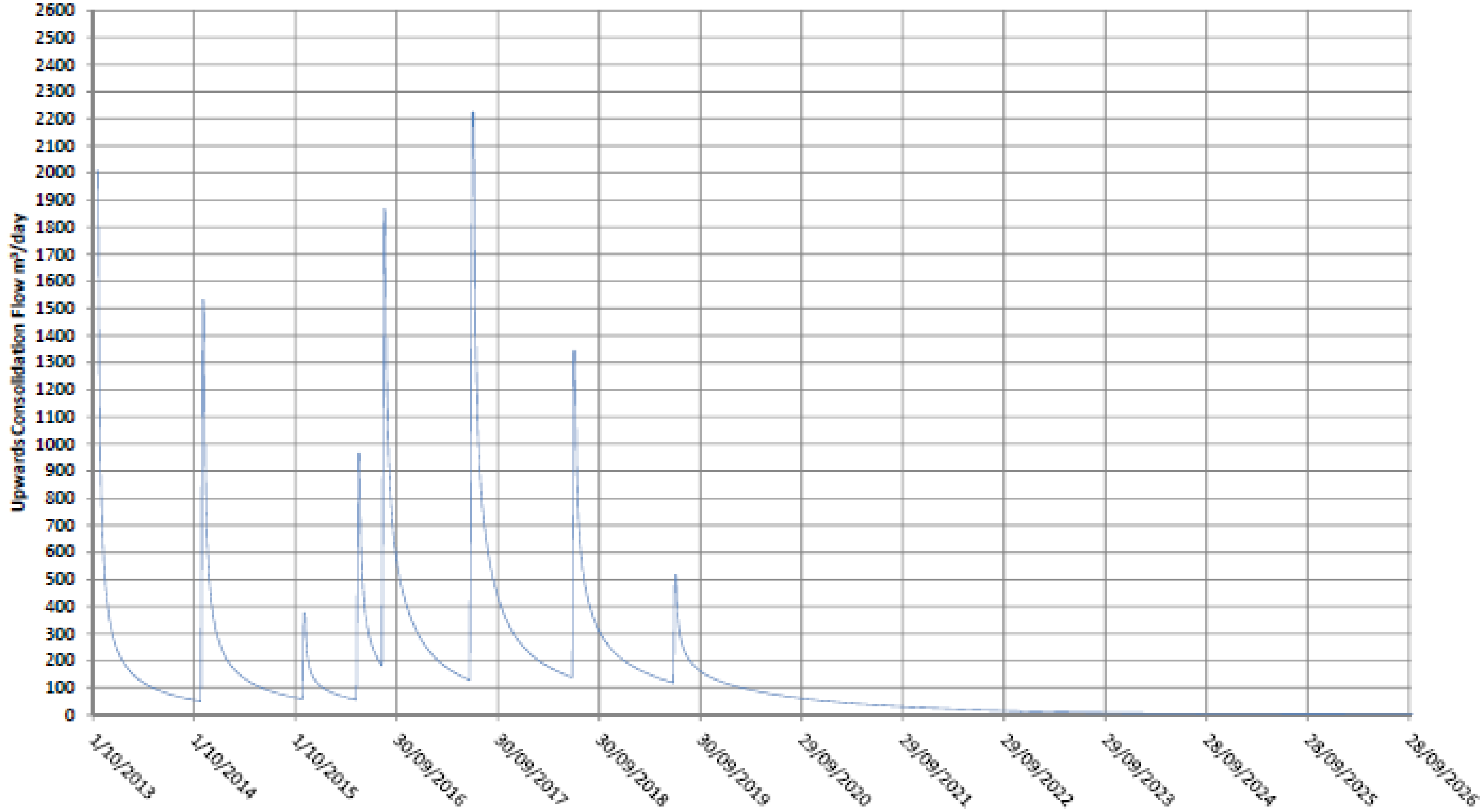


Figure 5-39: Predicted flow of process water from Pit 1 during consolidation (Fitton 2015, 2017; Figure 5)

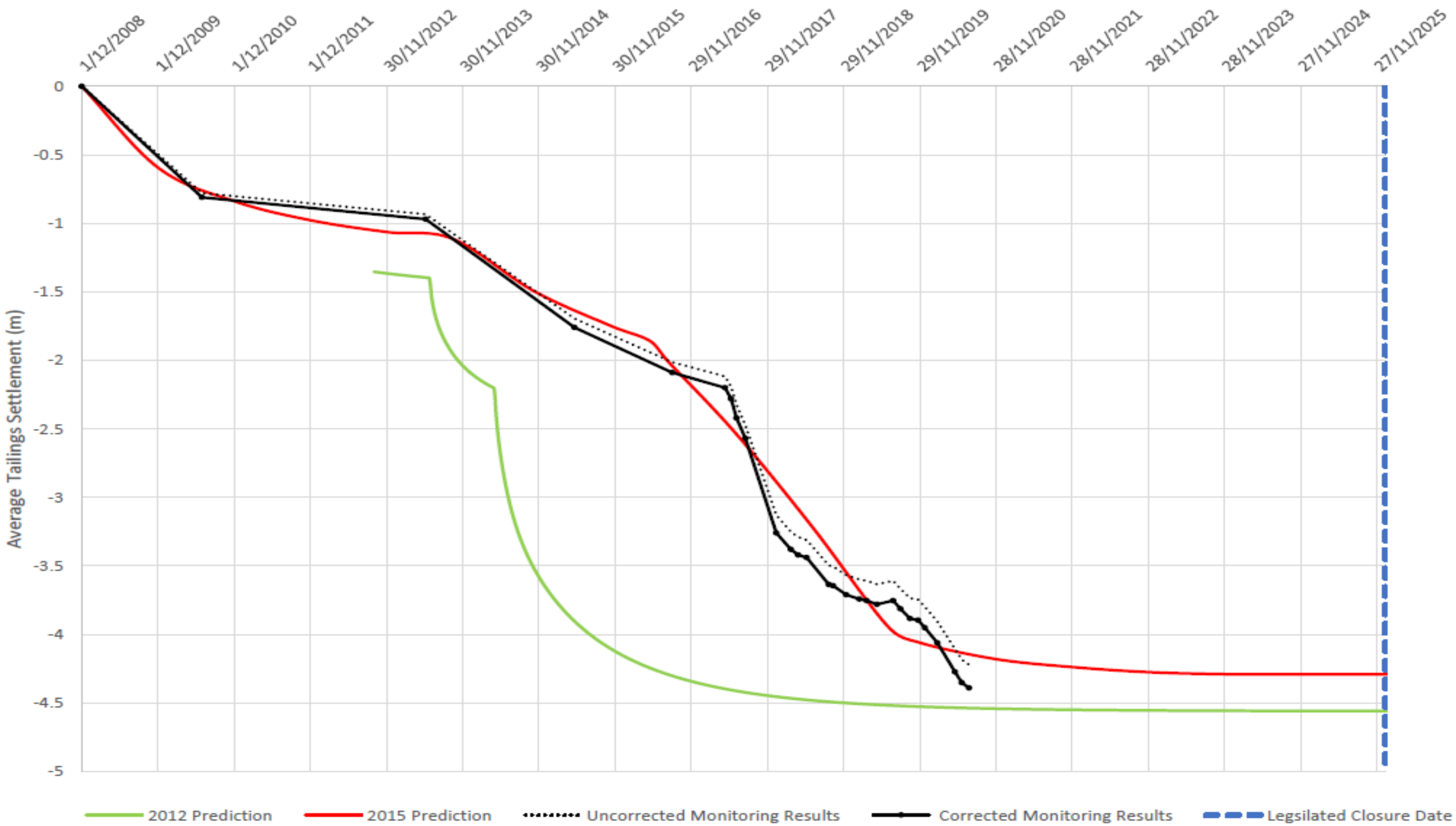


Figure 5-40: Predicted versus measured average tailings settlements in Pit 1

Available measurements relevant to flows in and out of the waste rock cap on top of Pit 1 have been used to construct a solute mass balance, using magnesium as the representative solute, and a water (volume) balance. Both balances have been conducted on a daily basis over a two year period, from 1 January 2017 to 31 December 2018. The solute balance indicates that the measured mass of solute recovered through the decant towers matches the mass of solute estimated to have been expressed from the tailings (Figure 5-41). Other sources of solute in the system are considered to be insignificant. The volume balance indicates that the decant structures are recovering additional volume from the waste rock cap, beyond that expected from catchment yield (rainfall less evaporation) and tailings consolidation flux. Both balances support the conclusion that all tailings consolidation flux is being recovered by the decant structures (Harvey 2019), an indication that the process water expressed by consolidation will be recovered for treatment before the end of rehabilitation activities in January 2026.

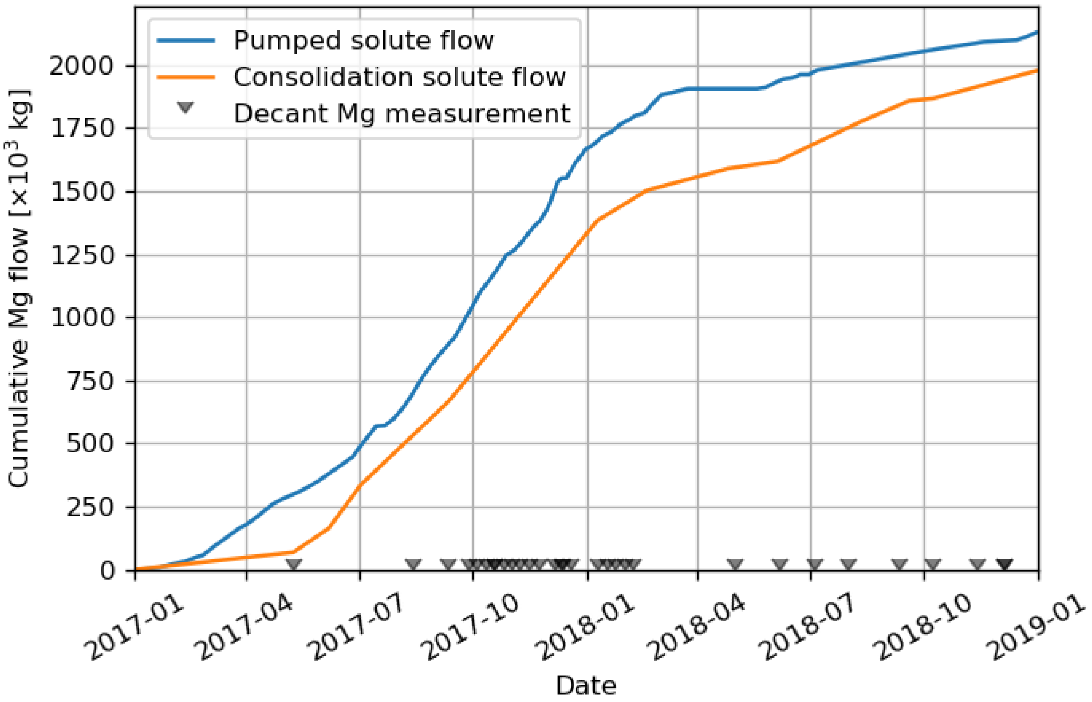


Figure 5-41: Cumulative magnesium flows

5.4.1.6 Pit 3 tailings consolidation

ERA made a submission to the Minesite Technical Committee (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 Consultant (2014) outlines 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 to understand the impact of tailings segregation, and estimate the tailings surface over the deposition and post deposition phases. Results of the consolidation models are provided in Table 5-21. These show that the majority of parameters are essentially the same. They achieve effective consolidation by December 2026, indicating that wick drains will be required to promote consolidation and achieve the January 2026 target. However, less wick area is now required across the surface of Pit 3, in order to achieve a similar consolidation result reported in 2014. Water expression, during deposition, for the May 2016 analysis is 30% greater than for the February 2014 analysis because the thickener was deleted from the former case, and the impact of the thickener is readily apparent. For the thickened case, there is 1.9 m^3 of water per tonne of solids less arriving in Pit 3. The difference between the dry density at deposition and the end of deposition is significantly less for the thickened case and thus the water expressed during the deposition phase is less. The consolidation model is currently being updated. The results will be included in the next MCP.

The consolidation model for Pit 3 was verified with the results from the cone penetration test (CPT) conducted in the Pit in the latter part of 2018 (Fitton 2019). It was noted that the measured excess pore pressure profiles closely agree with those predicted by the consolidation model. Figure 5-42 shows a typical comparison between the measured and predicted excess pore pressure profile.

Wick drains will be installed to promote the consolidation (Figure 5-43), similar to those which have been installed in Pit 1. A rock drainage layer will be installed on top of the tailings to act as an interception layer so that water expressed up through the tailings can be pumped out (Figure 5-43). Expression of tailings pore water with respect to local scale and regional scale ground water impacts is to be assessed within the groundwater solute transport modelling being 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. Figure 5-44 shows the flow of process water in Pit 3 estimated from the most recent model.

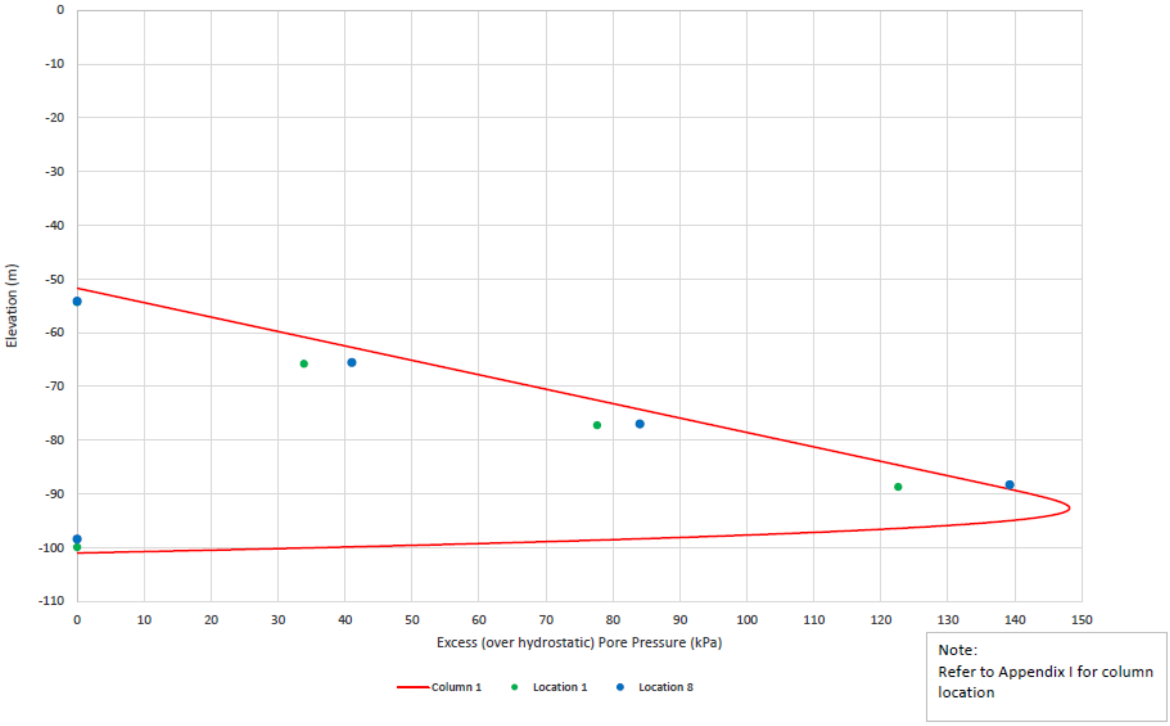


Figure 5-42: Measured versus predicted excess pore pressure profile

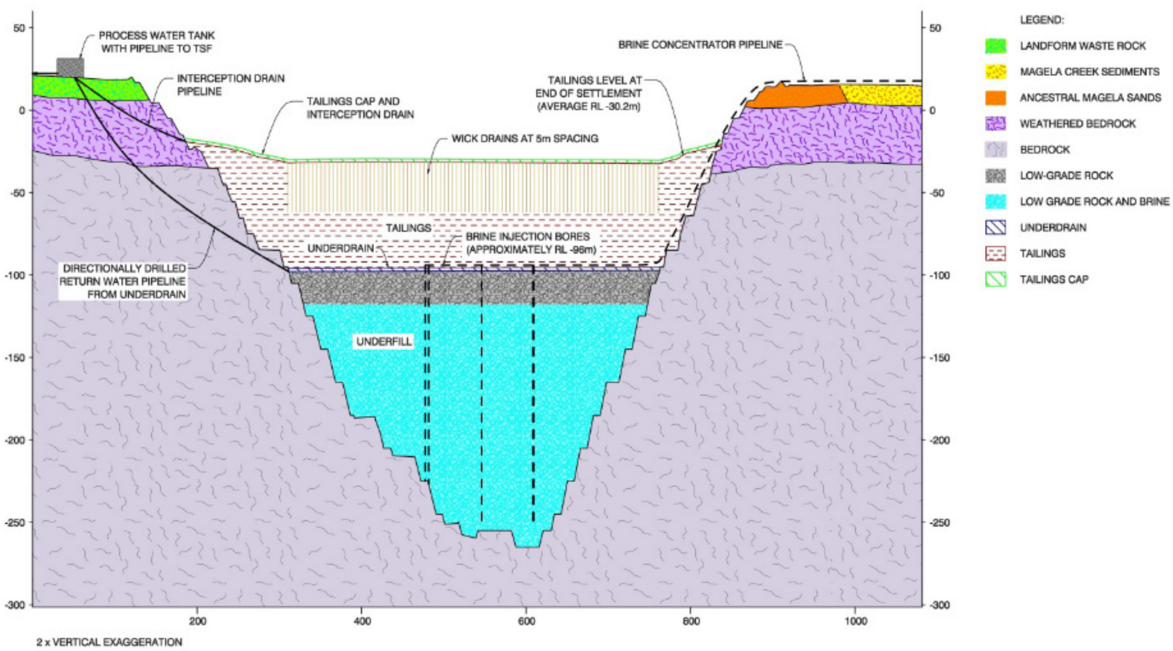


Figure 5-43: Indicative conceptual cross-section of Pit 3 at the end of consolidation, as at 2014 (INTERA 2014a)

Table 5-21: Consolidation model results, comparison of 2014 and 2018

	February 2014	May 2016	2018
Average base level (mRL)	-100	-99.7	-99.7
Underfill/drain volume (m^3)	15,298,380	15,658,180	15,658,180
Tonnes	41,781,246	40,345,324	40,345,324
Deposition duration (yr)	5.75	5.92	6.00
Thickening?	After year 1	No	No
Dry density - end of deposition (t/m^3)	1.42*	1.39	1.35
Dry density - end of consolidation (t/m^3)	1.68	1.66	1.63
Average level -end of deposition (m)	-21.30	-21.53	-20.00
Average level - end of consolidation (m)	-31.0	-31.3	-30.3
Average cover depth (m)	48.64	48.94	50.93
Cover volume (m^3)**	25,292,800	25,448,800	26,534,530
Water expressed - during deposition (m^3)	14,707,410	21,938,520	16,860,080
Water expressed - post deposition (m^3) ***	4,370,360	4,721,000	5,163,690
Wick area (m^2)	238,235	416,216	145,000
Water expressed by wicks (m^3)	2,334,780	2,125,840	430,439
Consolidation complete	May 2027	May 2027	May 2028
Consolidation practically complete****	February 2025	December 2024	June 2025

* 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 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

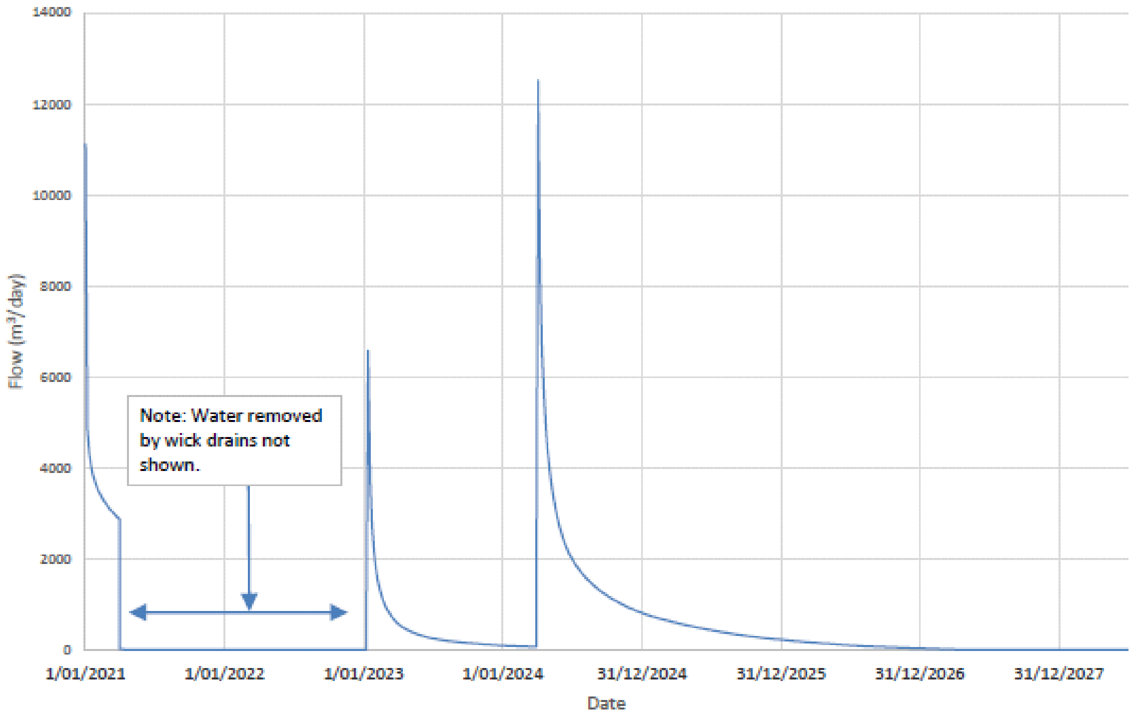


Figure 5-44: Predicted flow of process water from Pit 3 during consolidation

A new tailings deposition strategy has been developed for Pit 3 (Fitton 2019). This involves subaerial discharge from five spigots (DP1- DP5) from the eastern end as shown in Figure 5-45. and subaqueous discharge from two diffusers, from locations 1-15, on the western end as presented in Figure 5-46.. The adopted deposition method is based on the outcome from BPT workshop (GHD 2019). The tailings deposition into Pit 3, per the new strategy, will be monitored by conducting monthly bathymetric and six-monthly geophysical surveys, along with yearly CPTs. The results from these investigations (bathymetric, geophysical and CPTs) will be utilised to review and amend the deposition plan if required and review the consolidation model.

Refer to Section 9.3.2 for more information on current tailings deposition in Pit 3.

Figure 5-45: Mill tailings deposition locations

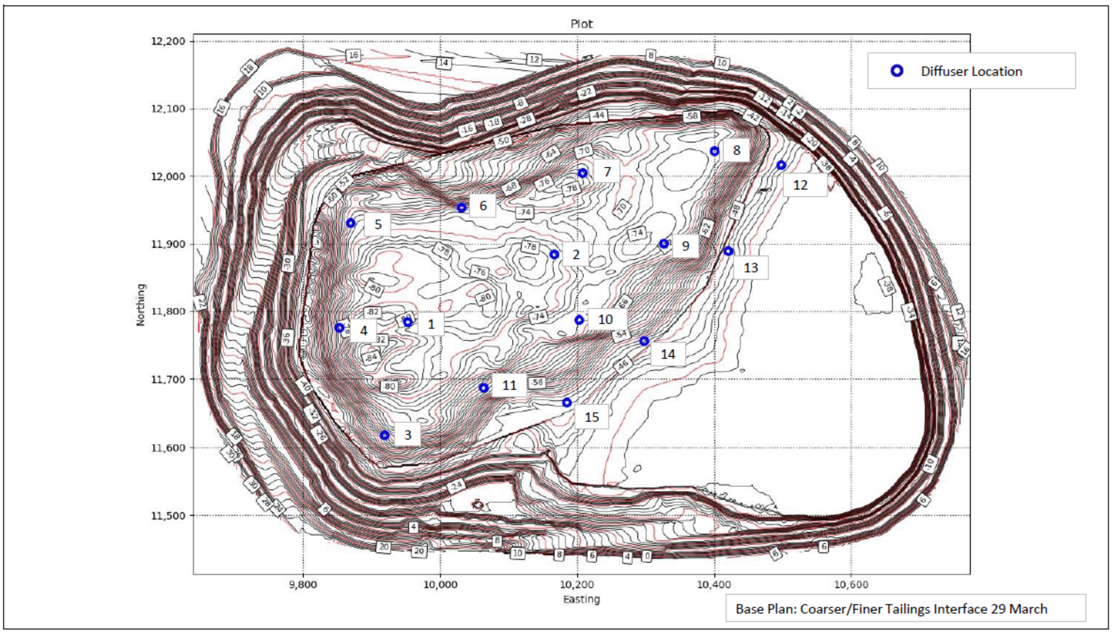


Figure 5-46: Diffuser locations

5.4.2 Tailings properties

Around 40 Mt of dry tailings from the mill and the TSF will be transferred to Pit 3 by January 2021. It was calculated that tailings would be deposited to a thickness of approximately 80 m and a volume of about 30.3 Mm^3. Section 9.3.2 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 currently underway. Studies included:

- TSF geophysical surveys (Fugro 2012 and 2018) (Figure 5-47)
- TSF magnetometer survey (Fugro 2012)
- Magnetic survey (Surrich 2019)
- TSF characterisation and CPT program (Shackleton 2013; in2Dredging 2020).

5.4.2.1 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. As of June 2019, 11.8 Mm^3 of tailings had been dredged to Pit 3. Typical survey results are presented in Figure 5-47.

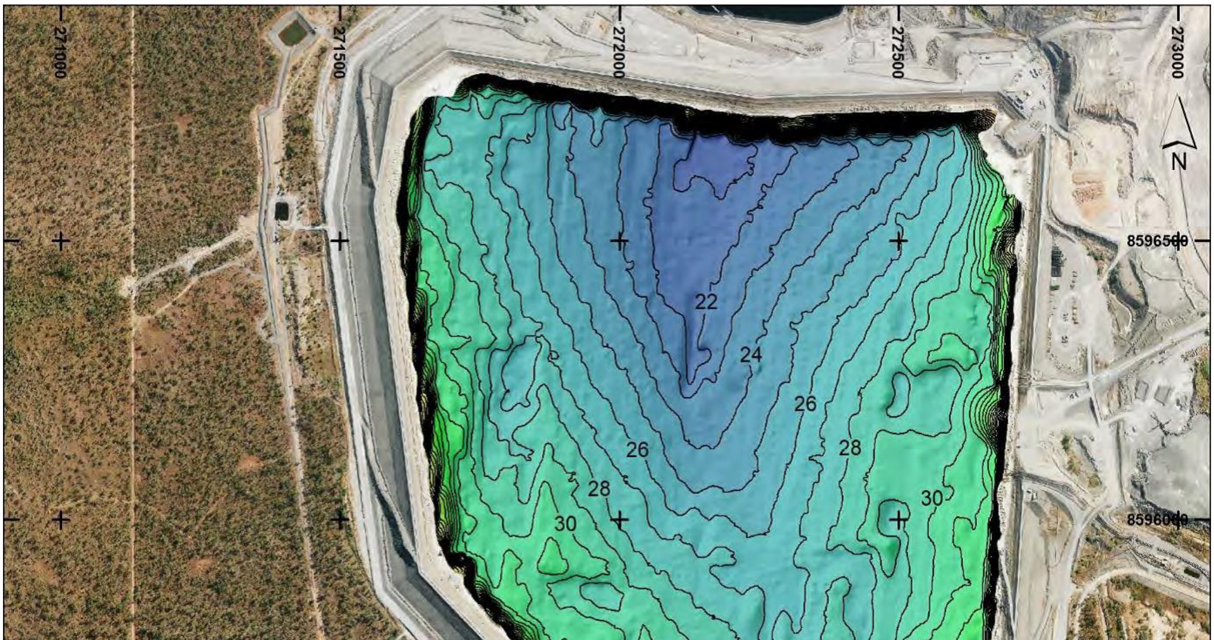


Figure 5-47: TSF topography (blue: low elevation; green: high elevation) (Fugro 2018)

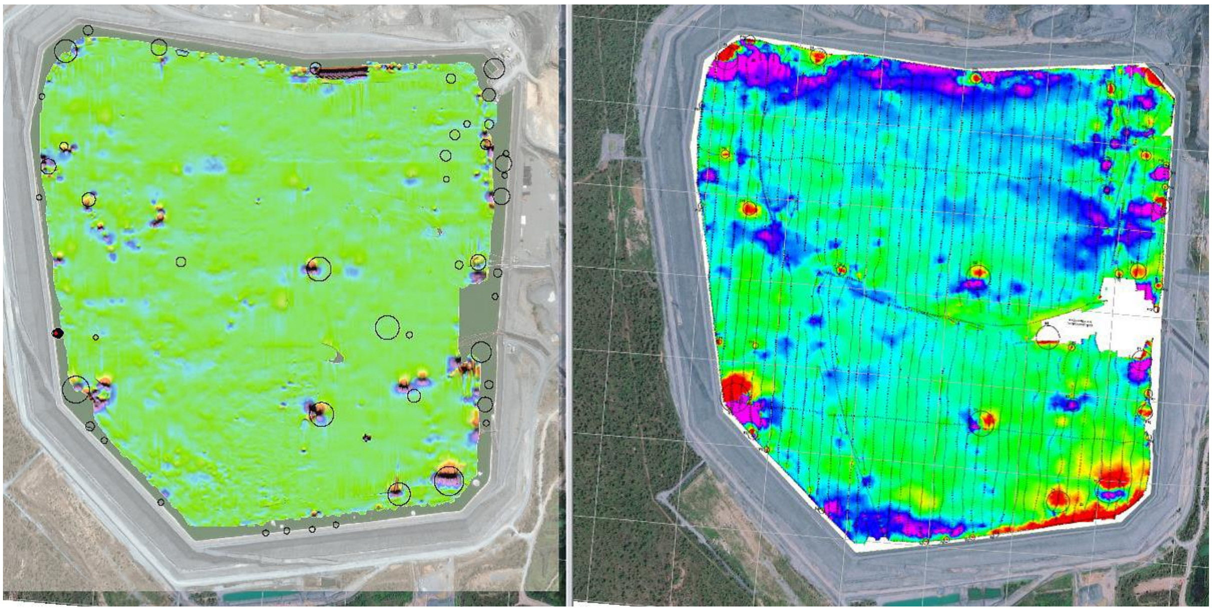


Figure 5-48: April 2019 Magnetic Anomaly Map (left frame) comparison with the 2012 Magnetic Anomaly Map (right frame)

Magnetometer 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 5-48. 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 diffuse, 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.

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). This study was undertaken during the integrated tailings, water and closure (ITWC) prefeasibility study (PFS); designed to gain a better understanding of the conditions within the TSF and 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.

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

1. 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 (Figure 5-49 blue)

2. 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 (Figure 5-49 brown) (Shackleton 2013; p 11).

The outcomes of the TSF geophysics 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 ATC Williams (2012). It involved CPTu, vane share test, 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).

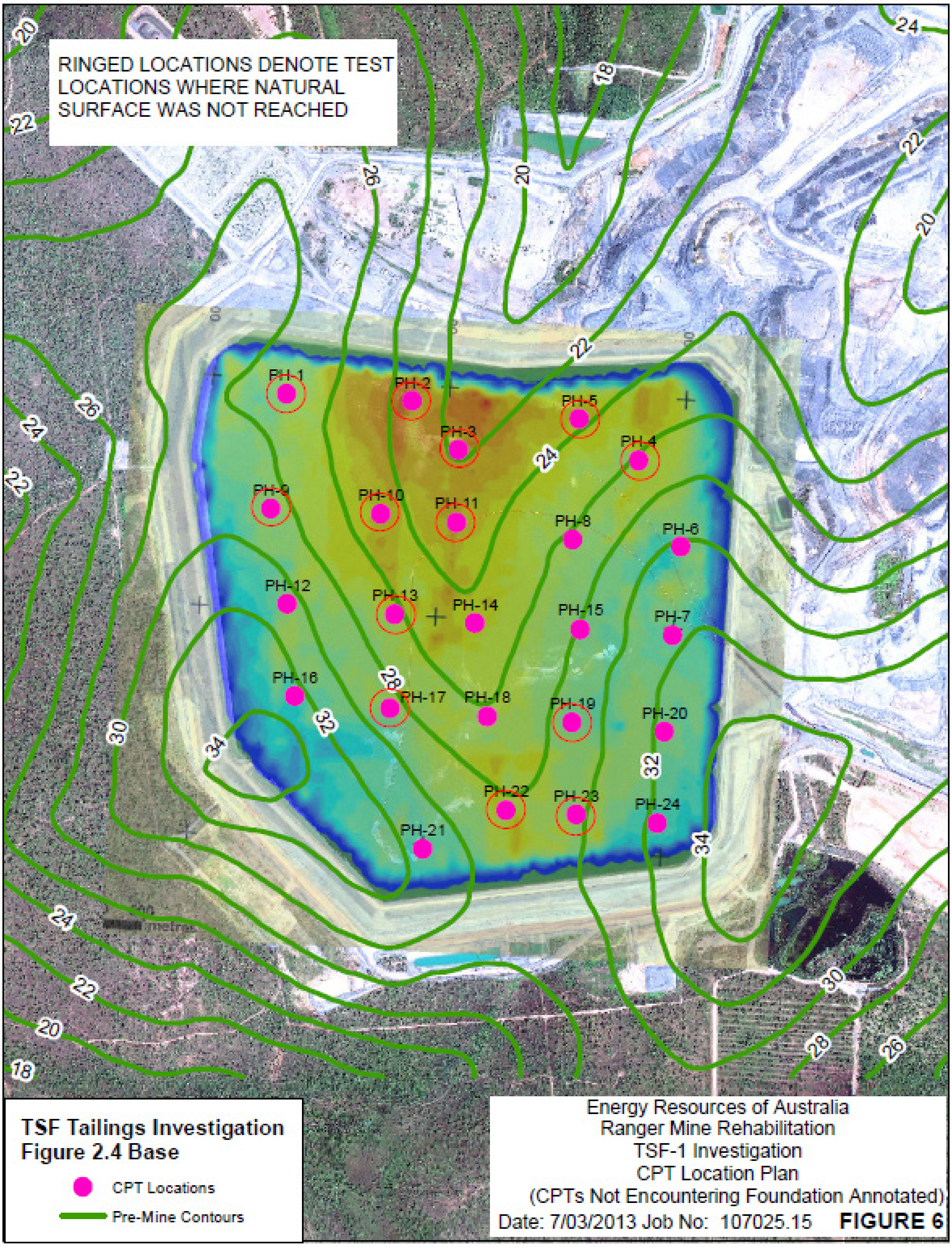


Figure 5-49: Cone penetration locations (Shackleton 2013)

5.4.2.2 Pit 3 geotechnical investigation

A geotechnical investigation was conducted in Pit 3 from October to November 2019 to verify the consolidation model (Fitton 2020b). It involved cone penetration test with pore pressure measurements (CPTu) at locations shown in Figure 5-50. A few tests locations from 2018 investigation were re-tested to understand how the fine tailings consolidation was occurring. Details of the CPTu is summarised in Table 5-22 Details of 2019 CPTu.

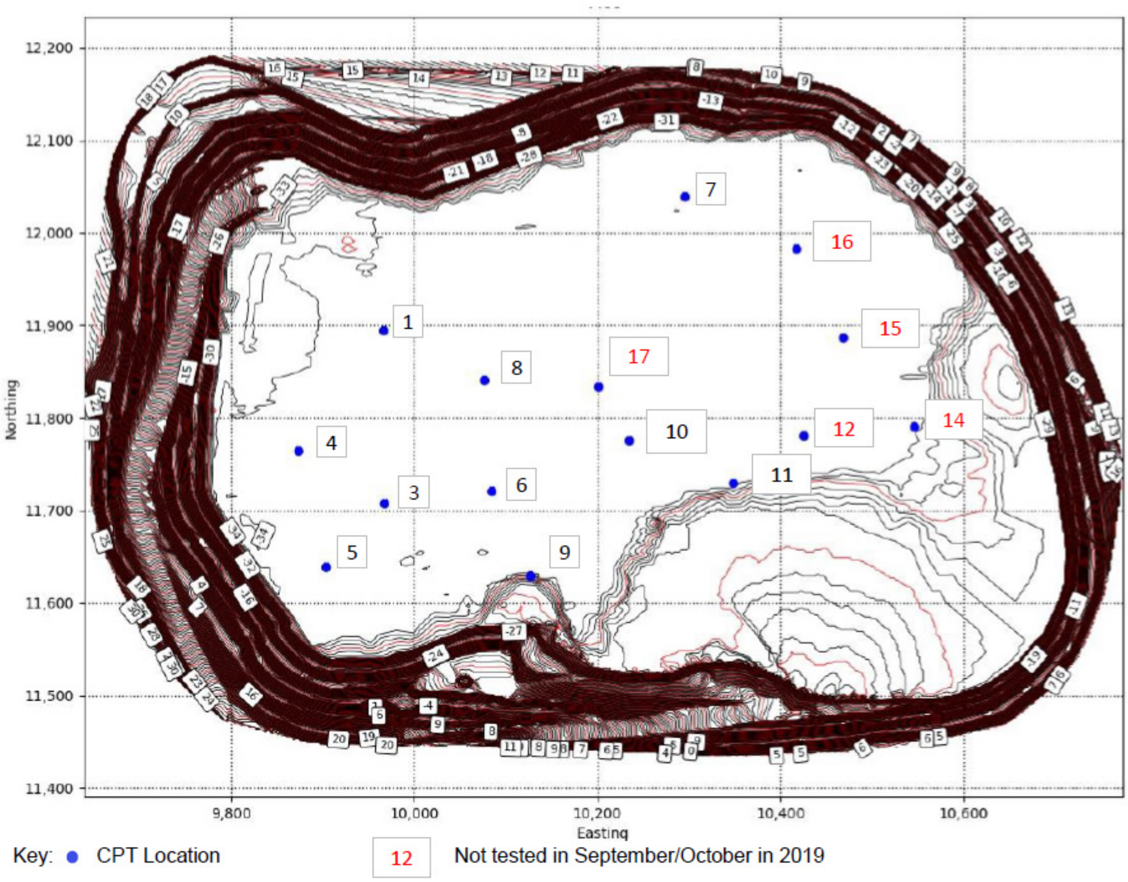
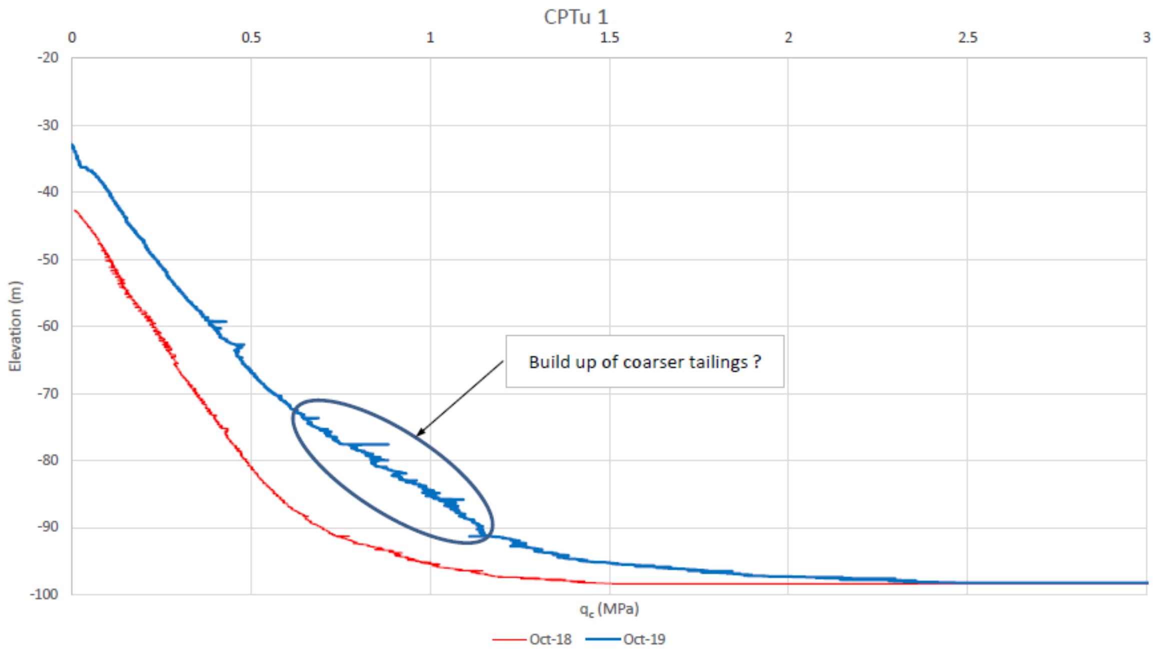


Figure 5-50 CPT Locations

Table 5-22 Details of 2019 CPTu

CPTu Location	Date of Test	Previously Tested (2018)	Recorded Water Depth (m)	Water Level RL (m)	Depth of Penetration (m)
1	4/11/2019	*	1.5	-32.82	65.5
3	30/10/2019	*	2.7	-32.60	68.8
4	2/11/2019		1.8	-32.68	61.1
5	31/10/2019		2.2	-32.51	50.0
6	17/10/2019	*	3.5	-32.81	51.1
7	11/10/2019		3.0	-32.63	40.2
8	7/11/2019	*	1.4	-32.80	67.4
9	16/10/2019	*	3.5	-32.83	51.8
10	8/11/2019	*	1.8	-32.77	38.1
11	6/11/2019	*	1.5	-32.83	34.7

The CPTu results indicated a clay like soil behaviour type at locations at 1, 3, 4, 5, 6, 7, 8 and 10, and a sand like soil behaviour type at locations 9 and 11. The cone resistance recorded at 1, 3, 6, 8, 9, 10, and 11 from the 2019 investigation is greater than that of 2018, 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. A typical cone resistance comparison profile is shown in Figure 5-51



q_c Uncorrected cone resistance

Figure 5-51 Typical 2018/2019 cone resistance comparison

One of the outputs from the consolidation model is the fine/coarse tailings boundary, which was determined with the cone resistance and compared with the predicted interface (Figure 5-52). The predicted and the measured boundaries are in close agreement.

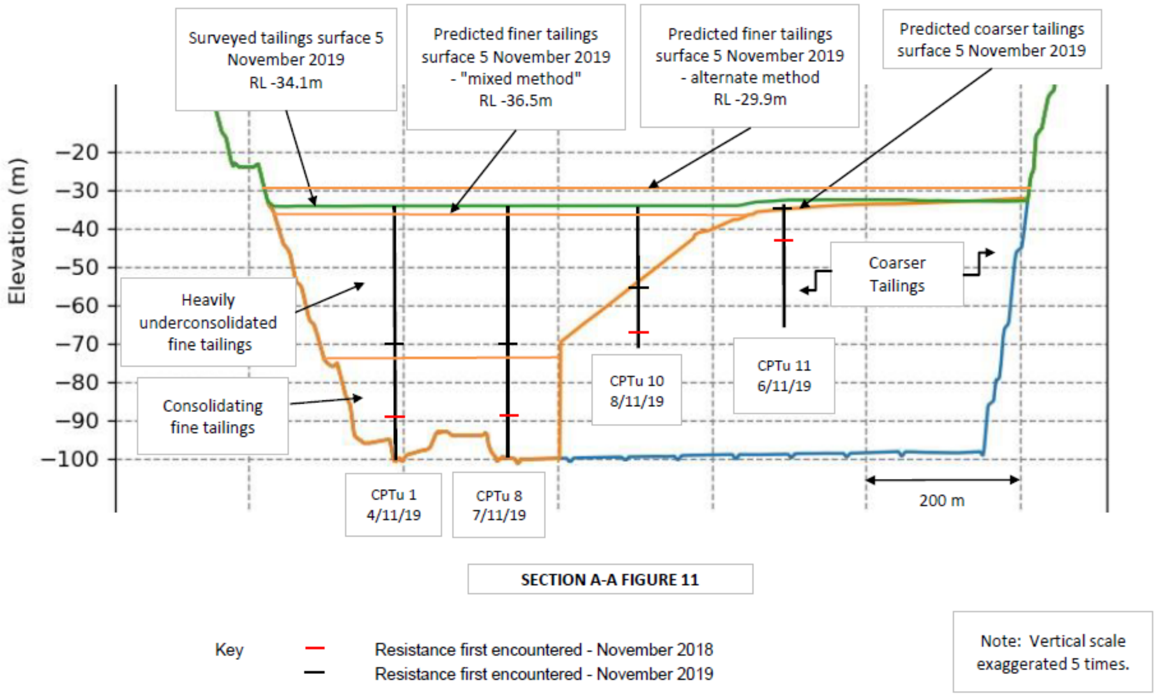


Figure 5-52 Predicted versus measured fine/coarse tailings interface

It is planned to undertake another geotechnical investigation in Pit 3, from September to November 2020, to verify the consolidation model and provide tailings parameters for the capping design. The investigation will comprise cone penetration test with pore pressure measurements, pore pressure dissipation test, vane shear test, tailings sampling and laboratory testing. After completion of tailings deposition into Pit 3, the tailings consolidation model will be updated then utilised for the settlement monitoring during Pit 3 capping and bulk backfill period.

5.4.2.3 Pit 3 geophysical surveys

A geophysical survey was conducted in December 2019 by Fugro Australia Marine Pty Ltd (Fugro), in Pit 3 to determine the distribution of tailings and their quantity within the pit. The survey used echo sounding to locate the tailings surface and Boomer and Chirp sub-bottom seismic profiling to investigate the tailings. The volumes of tailings and water in pit, established from the survey, are summarised in Table 5-23 and their surfaces presented in Figure 5-53.

Table 5-23 Summary of Geophysical survey

No.	Volume	Quantity [mm³]	Comment
1	Water	0.55	The top of the water (i.e. the water level) is taken from the limit of the bathymetric survey and interpolated up to -31.067 m AHD (average water level) on the DTM of the pit shell. The volume of water represents the difference between the Water Surface (dark blue) and Top of Tailings surface (light blue) (or Total Tailings)
2	Total Tailings	24.19	The Total Tailings volume is provided by the difference between the Base of Tailings surface* (pink) and the Top of Tailings surface (light blue)
3	Total Pit Fill	24.74	The total pit fill volume is the sum of the water and total tailings volumes
4	Delta Total Pit Fill Difference between April 2019 and December 2019	3.13	The difference between the total pit fill between the April and December 2019. The total pit fill volume in April 2019 survey was 21.61 mm³ It is noted that the difference in water volumes between April and December 2019 surveys is 1.72 mm³ and the difference in Total Tailings volumes is 4.85 mm³
*Note it is assumed the tailings include the filter layer or underdrain surface			

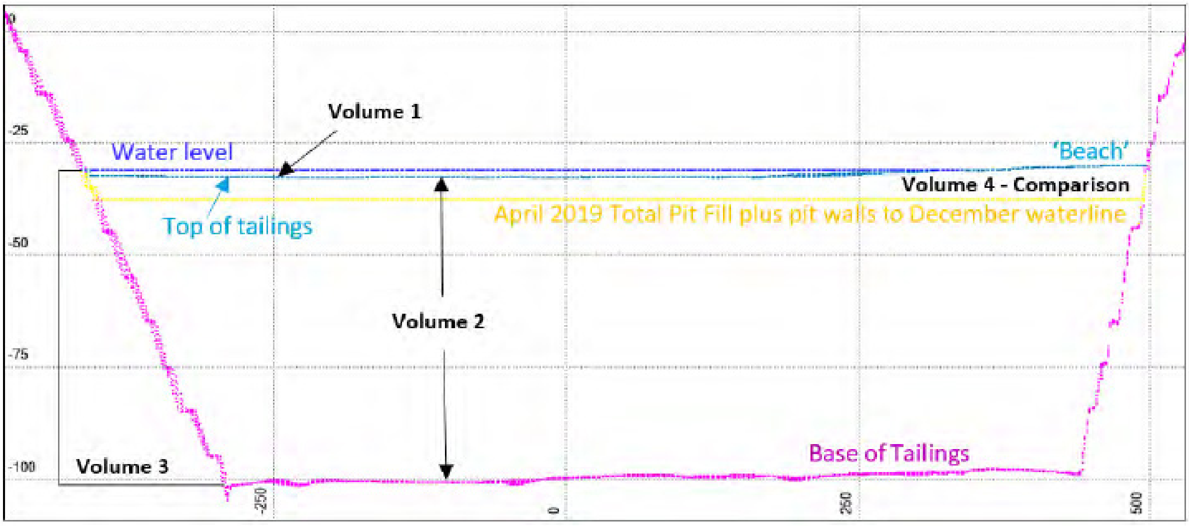


Figure 5-53 Cross section of tailings and water within the Pit

The volume of water, total tailings and total pit fill, estimated during the investigation, is 0.55 Mm3, 24.19 Mm3 and 24.74 Mm3, respectively. The total pit fill increased by 3.13 Mm3 since the previous survey in April 2019. It should be noted that the results from the geophysical surveys are usually used to augment the CPTu data, especially the fine/coarse tailings interface and mass ratio, to verify the consolidation model. The 2019 survey could not determine the fine/coarse tailings boundary due to the low depth of water (< 2m), in the pit, during the survey. It is understood that at least 7 m depth of water is required to establish the fine/coarse tailings interface. As this water depth is not likely to be achieved to the end of operations (January 2021), ERA has explored alternative methods to the geophysical survey,

ERA

including the use of the “SmartDiver” and “Eorca” equipment, to establish the fine/coarse tailings boundary. Recent site water balance modelling suggests that there is a potential to achieve a minimum of 5 m water depth in the Pit in April 2021, and hence the potential to conduct the final geophysical survey. Results from this survey will be utilised in the final tailings consolidation model update and proposed wick installation in Pit 3.

5.4.3 Groundwater modelling

5.4.3.1 Ranger Conceptual Model

The Ranger Conceptual Model (RCM) was initially developed by INTERA in 2016. In 2018 ERA requested that INTERA undertake a review and update conceptual and numerical models for groundwater flow for use in assessment of potential impacts from post-closure conditions at the mine in accordance with requirements in the Ranger Authorisation. INTERA completed the update to the Ranger Conceptual Model in March 2019.

The update to the Ranger Conceptual model included:

- incorporation of recent information gained since completion of the previous RCM in 2016
- increase of the domain of the site wide model to encompass all source material and post-receptors
- calibration of all hydraulic properties using all appropriate observed data from the pre-mining period through to present
- inclusion of the full range of mining related stresses on the groundwater system

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 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 5-54.

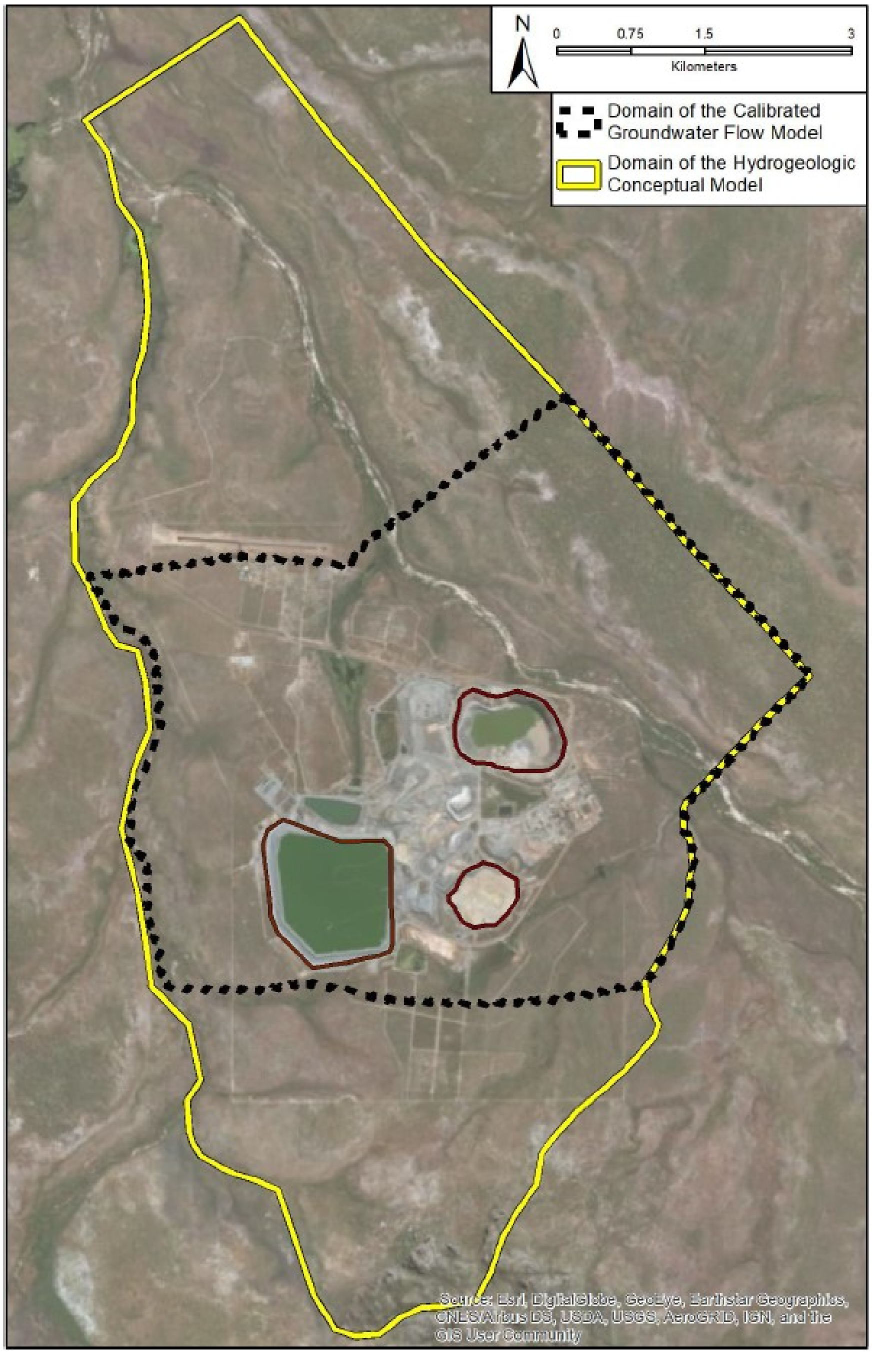


Figure 5-54 Spatial domain of the hydrogeological Ranger Mine conceptual model relative to the domain of the calibrated groundwater flow model.

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. HLUs are hydrogeologic units or volumes defined on the basis of similar geologic and groundwater flow and transport characteristics. 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 extensive data sets from bores, geologic mapping, and hydraulic testing were used to modify existing HLUs and add new HLUs (Table 5-24). New estimates of recharge and ET were calculated using observed seasonal changes in groundwater heads at shallow bores distributed across the Ranger minesite.

Table 5-24 Summary of differences in name/geometry between the updated HLUs and previous HLUs in INTERA (2014a, b, c; 2016)

Updated HLU	**Corresponding Previous HLU**	**Difference in Name/Geometry**
Shallow HLUs		
Magela Creek sediments	Magela Creek sediments near ancestral sands/other Magela Creek sediments	combined into a single HLU; larger extent to HCM boundaries; slight modifications to width in some areas; no change to thickness
other creek sediments	other creek sediments	addition of sediments for Djalkmarra, Coonjimba and Gulungul creeks; larger extent to HCM boundaries; slight modifications to width of Corridor Creek and its tributary; no change to thickness
Djalkmarra sands	Ancestral Magela Sands	new name; larger extent; no change to thickness
shallow weathered Cahill	shallow weathered rock	larger extent to HCM boundaries; separation of shallow weathered Cahill and shallow weathered Nanambu into two different HLUs; no change in thickness
deep weathered Cahill	deep weathered rock	weathered rock/fresh bedrock contact totally revised; larger extent to HCM boundaries; separation of deep weathered Cahill and deep weathered Nanambu into two different HLUs; thickness increased in some areas and decreased in some areas
Zone C weathered carbonate	LMS carbonate between Pit 1 and Pit 3	wider near Pit 3 margin; shorter extent between pits; thicker
Pit 1 permeable zone	Pit 1 permeable zone	similar extent; slightly thinner
depressurised UMS confining unit	NA	new HLU

Updated HLU	Corresponding Previous HLU	Difference in Name/Geometry
shallow weathered Nanambu	shallow weathered rock	larger extent to HCM boundaries; separation of shallow weathered Cahill and shallow weathered Nanambu into two different HLUs; no change in thickness
deep weathered Nanambu	deep weathered rock	weathered rock/fresh bedrock contact totally revised; larger extent to HCM boundaries; separation of deep weathered Cahill and deep weathered Nanambu into two different HLUs; generally thicker
Deep HLUs		
shallow bedrock Cahill	undifferentiated bedrock	larger extent to HCM boundaries; separation of shallow bedrock Cahill and shallow bedrock Nanambu into two different HLUs; thicker
shallow bedrock Nanambu	undifferentiated bedrock	larger extent to HCM boundaries; separation of shallow bedrock Cahill and shallow bedrock Nanambu into two different HLUs; thicker
HWS	HWS	modified HWS/UMS contact; larger extent to HCM boundaries
UMS	UMS	modified HWS/UMS and UMS/LMS contacts; larger extent to HCM boundaries
MBL zone	MBL Zone near Pit 1	new name; larger extent; dips with UMS rather than being flat; thicker
depressurised UMS	UMS carbonate north of Pit 3	new name; larger extent; deeper; thicker
Zone C shallow bedrock	NA	new HLU
LMS	LMS	modified UMS/LMS and LMS/Nanambu contacts; larger extent to HCM boundaries
lower-K DWPZ	DWPZ	subdivision of previous DWPZ; overall DWPZ extent slightly larger
higher-K DWPZ	DWPZ	subdivision of previous DWPZ; overall DWPZ extent slightly larger
Nanambu Complex	Nanambu Complex	modified LMS/Nanambu contact; larger extent to HCM boundaries
Mine Backfill HLUs		
waste rock underfill	Pit 3 underfill	no change
tailings	Pit 1 and Pit 3 tailings	no change

The calibrated groundwater flow model incorporates the major stresses applied to the Ranger Mine groundwater flow system at Pit 1, Pit 3, and the TSF. 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 important HLUs from shallow to deep. The calibrated model covers about 29 km^2 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 groundwater flow model 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 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 reveal that the model simulates groundwater flow with small average error relative to measurement errors and captures temporal groundwater head variations. 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.

Table 5-25 Calibration statistics for the transient groundwater flow model

HLU(s)	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	***8,536***	***-0.02***	***1.42***	***2.11***	***0***	***26.49***	***81.8***	***3***	***2***
Shallow HLUs									
All	5,560	-0.24	1.21	1.73	0	16.27	44.99	4	3
Magela Creek sediments	0								
other creek sediments	0								
Djalkmarra sands	84	0.31	1.28	1.78	0.01	5.97	9.56	19	13
shallow weathered Cahill	184	0.04	0.93	1.35	0.01	5.85	10.35	13	9
deep weathered Cahill	920	-0.15	1.34	2.02	0	16.27	33.82	6	4
Zone C weathered carbonate	144	-0.53	1.68	2.35	0.01	8.39	21.83	11	8
Pit 1 permeable zone	293	-1.38	1.61	1.99	0.02	4.77	7.71	26	21
depressurised UMS confining unit	0								
shallow weathered Nanambu	1,661	0.08	0.81	1.1	0	4.15	27.72	4	3
deep weathered Nanambu	2,274	-0.38	1.4	1.91	0	8.58	25.85	7	5
Deep HLUs									
All	**2,976**	**0.4**	**1.82**	**2.68**	**0**	**26.49**	**81.8**	**3**	**2**
shallow bedrock Cahill	410	-2.06	2.4	2.98	0.01	10.82	23	13	10
shallow bedrock Nanambu	1,473	0.71	1.54	2.19	0	10.25	22.29	10	7
HWS	0								
UMS	0								

HLU(s)	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 (%)
MBL Zone	844	0.14	1.2	1.55	0	6.31	23.25	7	5
depressurised UMS	196	4.36	5.33	6.55	0.01	26.49	61.65	11	9
Zone C shallow bedrock	43	0.21	1.57	2.46	0.07	7.68	30.31	8	5
LMS	10				0.55	4.03	5.25		
lower-K DWPZ	0								
higher-K DWPZ	0								
Nanambu Complex	0								

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 plots 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. 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.

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 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.

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 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 calibrated flow model. 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.

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.

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 me*et al*l indicators for the Level 3 confidence level (highest confidence level) after completion of the planned peer review by an independent hydrogeologist with modelling experience.

The updated Ranger Conceptual Model report was provided to the SSB. The SSB sought expert advice from Dr Glenn Harrington of Innovative Groundwater Solutions to determine whether the models are fit for purpose and appropriate for informing future interconnected models. The model was found to be a significant improvement over past models and majority of questions or comments identified by the SSB were resolved during consultation process with ERA (SSB 2019). The outstanding concerns relate to development of a formal uncertainty analysis. INTERA has commenced this analysis and it will be detailed in future versions of the MCP and the MTC Pit 3 closure application.

Further to the review undertaken by Dr Harrington and the SSB, ERA commissioned Brian Barnett, one of the key authors of the Australian Groundwater Modelling Guidelines (Barnett *et al*. 2012), to undertake an independent technical review of the Ranger Conceptual Model to ensure compliance and consistency with the Australian Groundwater Modelling Guidelines. The Ranger Conceptual Model was found to be undertaken in a thorough, considered and professional manner and that the model meets appropriate industry standards (Barnett 2019). A number of relatively minor issues were identified, that in the author's opinion, both individually and cumulatively do not amount to significant or fatal flaws in the work. These issues have all been addressed by INTERA in the final report. Additionally the author concluded that the modelling to date is in line with a fit-for-purpose conclusion provided the additional modelling tasks required to complete the investigation are undertaken in an appropriate manner.

Figure 5-55 is a graphical high-level representation of the various models developed and used to demonstrate the transport and fate of contaminants within the context of the whole of site conceptual model. The figure also shows the links between the whole of site conceptual model and the various numerical models developed to date.

Ranger Mine conceptual and model solute transport areas of interest/concern

Individual mine workings or features are areas of interest/concern for COPC sources and migration within and from the Ranger Minesite. These include Pit 3, Pit 1, the TSF, the processing plant area, LAAs, the existing R3D workings, and the final landform waste rock. Smaller-scale conceptual models were developed for each of these.

Conceptual models for the areas of interest/concern examined the operational and decommissioning period and the post-closure period. Steps for developing the area of interest/concern conceptual models included describing the setting, identifying the source(s) and COPCs, and identifying the transport pathways and receptors, including soil, groundwater, and surface water.

COPC sources in the areas of interest/concern can be divided into mine wastes and releases from mining activities. Mine wastes comprise waste rock, tailings, pit tailings flux (PTF), and brine. Waste rock is a potential COPC source for Pit 1, Pit 3, R3D, TSF and the final landform constructed with waste rock. Tailings are a potential COPC source for Pit 1, Pit 3 and the TSF. PTF is a potential source in Pit 1, and brine may be a source for Pit 3. COPC releases from mining activities comprise LAA irrigation and dust release and fluid spills or leaks in the processing plant area.

Conservative and reactive COPCs were evaluated for each of the different conceptual models. These included, for example, magnesium (Mg), uranium (U), manganese (Mn), radium-226 (^{226}Ra), total ammonia as nitrogen (TAN), nitrate as nitrogen (NO_3-N), total phosphorus (total-P) and polonium (^{210}Po), as well as others specific to a few areas of concern/interest.

Mg is a COPC because of its potential toxicity to the Magela Creek biota. Based on the previous ERA work and new calculations presented herein, estimates of Mg loading to Magela Creek were discussed for four areas of concern/interest: Pit 1, Pit 3, R3D, and landform waste rock. For the period 1999 to 2003 and 2005 to 2012, the natural Mg solute loading in Magela Creek upstream of the Ranger Mine varied between 75 and 181 tonnes per year, with an average of 135 tonnes per year, whereas the mine-derived loading varied between 72 and 375 tonnes per year, with an average of 178 tonnes per year. The estimated Mg loadings from the areas of concern/interest were compared to these historical natural and mine-derived Mg loadings, shown in Figure 5-56. Loading from waste rock is the largest potential source, and is discussed below under landform waste rock.

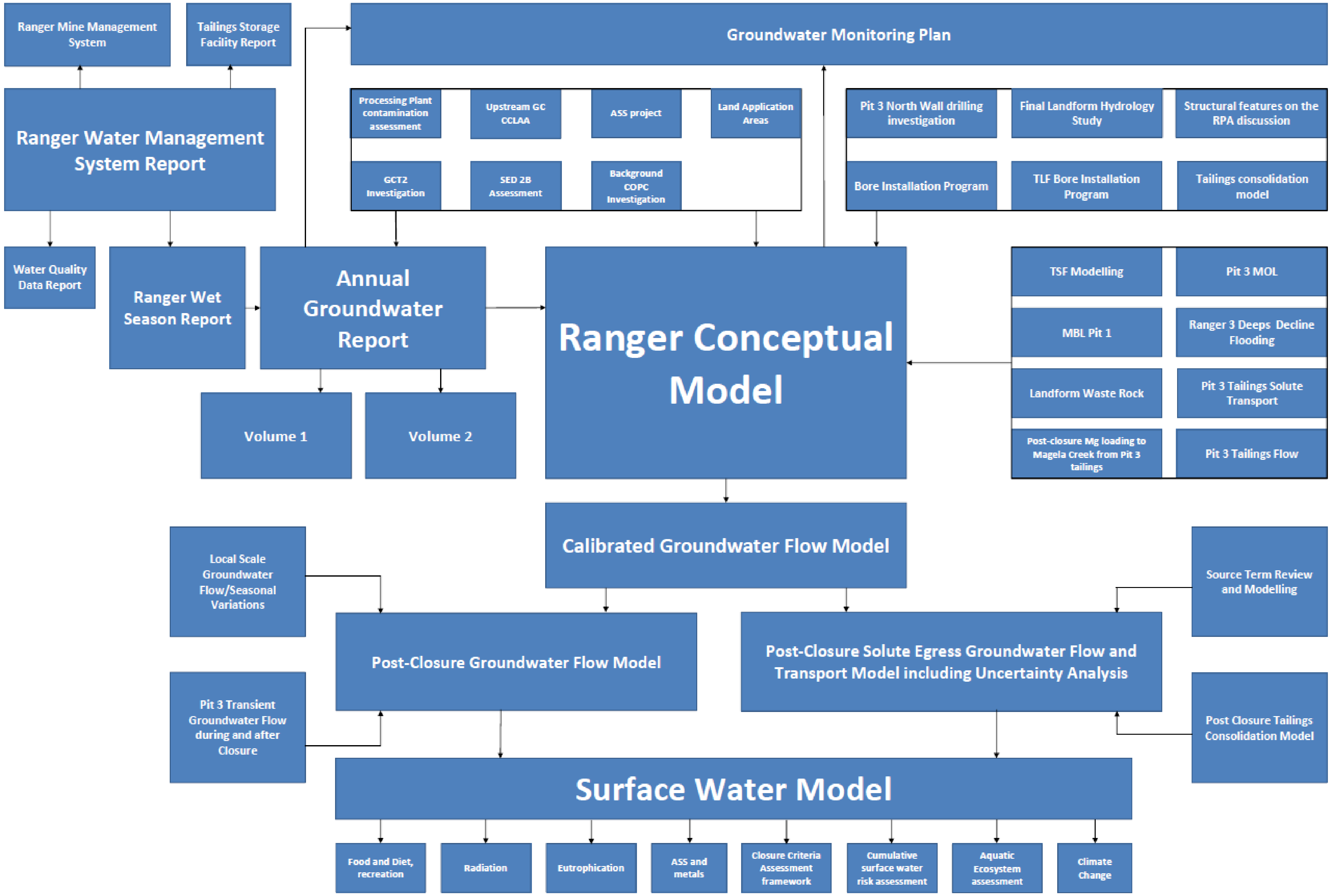


Figure 5-55 Indicative flowchart showing various numerical and solute transport model development for the RPA

Only the TSF, processing plant area and LAAs released COPCs into groundwater, surface water, soil or some combination in the Ranger Mine area during the mining operational and decommissioning period. None of the other areas of interest/concern released COPCs into the Ranger Mine environment during this period. R3D, Pit 1, and Pit 3 act as hydraulic sinks, allowing inward groundwater flow only (Figure 5-57). Evaluations of solute egress during the post-closure period are discussed below for each of these areas of interest/concern.

Discussion in the subsequent sections is based on 2 complementary but discrete packages of work. Discussion on hydrogeological conceptualisations is based on the updated INTERA 2019 Ranger Conceptual Model update as detailed in Section 5.4.3.1 whilst discussion on solute transport and impacts is based on the 2016 Ranger Mine groundwater modelling. Solute transport modelling based on the updated Ranger Conceptual Model is scheduled to commence in early 2020 following completion of a number of supporting models,and will be included in future revisions of the MCP and Pit 3 closure application.

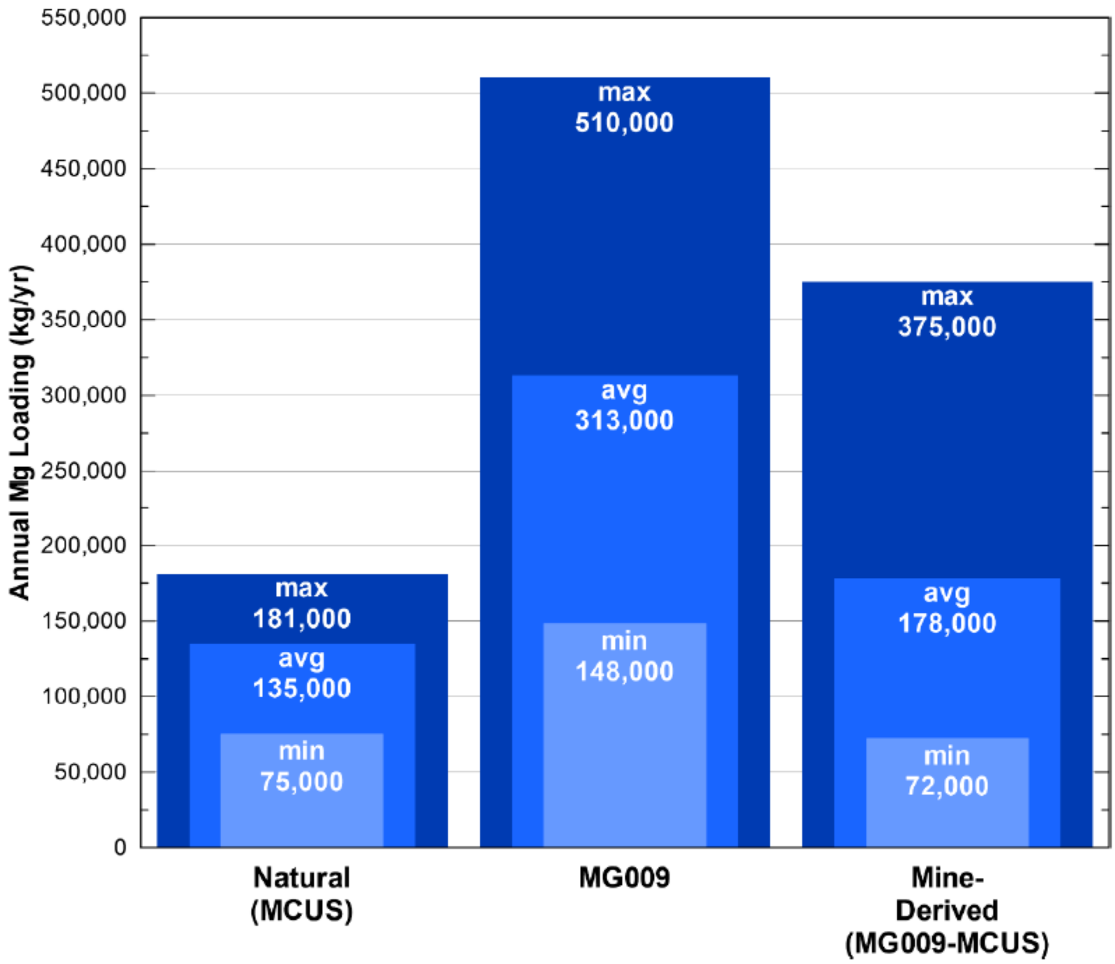


Figure 5-56: Mg solute loads at monitoring stations MCUS and MG009 and derived from the mine (INTERA 2016)

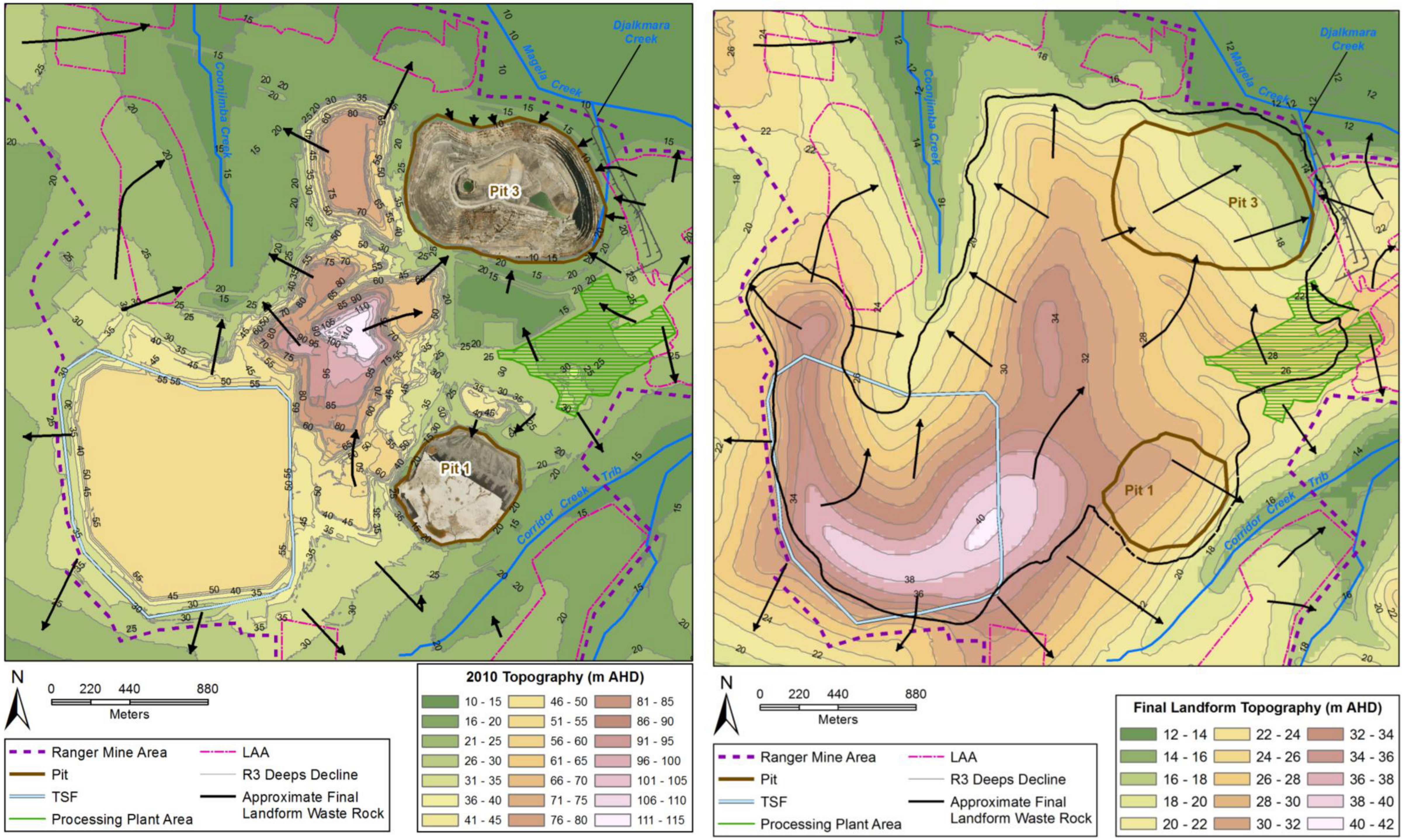


Figure 5-57: Operational groundwater flow (left) compared to post-closure groundwater flow (right) (INTERA 2016)

Ranger Conceptual Model: Pit 3

Located on the Ranger 3 orebody, Pit 3 is the largest mine pit and the nearest to Magela Creek. Conceptual models have been developed for Pit 3 since even before the start of excavation. Except for the sitewide CM by Salama and Foley (1997), each of the other CMs were developed to support modelling of groundwater flow and solute transport.

The key features and processes for pre-mining and during mining for the Pit 3 vicinity include the following:

- Magela Creek is located downgradient of the pit vicinity so groundwater flowed from the pit area to Magela Creek prior to excavation. The minimum distance between the pit and Magela Creek is about 150 m.
- Prior to excavation, the pit outline encompassed both a local topographic high in the west and a local topographic low in the Djalkmarra Creek drainage to the east and south. At the sitewide scale, groundwater flow prior to pit excavation would have been from south to north across the pit vicinity. In the near vicinity of the pit, however, groundwater would flow from the local topographic high north and northeast to Magela Creek, east and southeast to Djalkmarra Creek, and west to Coonjimba Creek. Both the local topographic high and the central portion of the Djalkmarra Creek drainage were replaced by the pit void.
- The pit area straddles the contacts between the LMS, UMS, and HWS hydrolithologic units. Hydraulic conductivity in this area is typically very low (less than or equal to 10-4 m/d), but higher values have been found in shallow weathered rock, the LMS carbonate on the south perimeter of the pit, and the UMS carbonate at the north perimeter or the pit.
- Several faults intersect the pit shell, including the two strands of the Djalkmarra Fault and the Amphibolite Fault. Straddle-packer testing of the strands of the Djalkmarra Fault indicated relatively low hydraulic conductivity of between 10-6 and 10-3 m/d
- Beginning in 2005, more than 400 depressurisation bores were drilled around the perimeter of the pit at depths between the elevations of 8 and -150 m AHD. The purpose of these bores, which had lengths up to 150 m, was to increase pit shell stability by dewatering the surrounding hydrolithologic units.
- Pit dewatering and the depressurisation bores created a hydraulic sink at Pit 3 during the mining period.
- Dewatering of the R3D decline has also led to depressurisation of the deep bedrock hydrolithologic units near Pit 3.
- When open-cut mining was completed in November 2012, the bottom elevation of the deepest part of the pit was about -255 m AHD.

The key features and processes for Pit 3 during and after decommissioning for consideration in groundwater conceptual model include the following:

- Placement of 30 million tonnes of low-grade rock underfill from the bottom of the pit to an elevation of -100 m AHD began in December 2012 and was completed in 2015. An engineered underdrain consisting of a nominal 2-m waste rock layer was constructed at the top of this underfill. The purpose of the underdrain is to remove water expressed downwards by the overlying tailings during consolidation and to remove entrained groundwater displaced upwards from the underfill by the brine injection process

- Deposition of tailings from the milling of ore stockpiles into Pit 3 commenced in 2015 and will cease in January 2021 when ore processing also stops. Transfer of tailings from the TSF by dredge operations began in 2015 and is planned to continue until 2020 at which time the tailings will have reached a maximum elevation of -15 m AHD in Pit 3. By the end of decommissioning in 2026, reduction in the tailings level due to consolidation is expected to reach an average level of -30 m AHD.

- Approximately 2.0E09 litres (L) of brine will be emplaced in the lower 150 m of the Pit 3 underfill up to a final maximum elevation of approximately -118 m AHD. Produced by passing supernatant from the TSF through the brine concentrator, injection of the brine through a bore network into the underfill at elevations between -250 and -210 m AHD began in the 2015 to 2016 time frame. Brine injection is expected to continue through.

- If necessary, tailings consolidation will be enhanced through the installation of wick drains. A rock drainage layer will be installed on top of the tailings to act as an interception layer for removal of expressed tailings water. Following installation of the wick drains and interception layer, and subject to further evaluations, the interception layer may be capped with a low-permeability layer or cap.

- The tailings, drainage layer, and low-permeability cap, if installed, will be covered by waste rock backfill, a second low-permeability cap, and a layer of growth media. The waste rock and growth media will be emplaced to match the final landform design, which moves and truncates the re-created Djalkmarra Creek drainage to the eastern edge of Pit 3 and truncates it

- Until Pit 3 backfilling is completed and the hydraulic heads in the shallow waste rock backfill increase to levels higher than those in the hydrolithologic units located between Pit 3 and Magela Creek, the pit will continue to act as a hydraulic sink preventing groundwater in the waste rock and tailings from flowing away from the pit.

- Once hydraulic heads in Pit 3 increase to levels higher than those in and near Magela Creek, groundwater will begin to flow from the pit, carrying solutes from the backfill into the ancestral Magela sands and weathered and unweathered hydrolithologic units between Pit 3 and Magela Creek.

- Eventually, the Ranger Mine post-closure groundwater flow system in the vicinity of Pit 3 will reach the topographically driven south-to-north flow expected for the final landform. Groundwater from Pit 3 will then discharge into Magela Creek when it is flowing. When flow in Magela Creek ceases, groundwater is expected to continue to flow within the sediments of the creek bed. The rate of solute migration from the pit to the creek will decrease when creek water levels rise more quickly than nearby groundwater hydraulic heads. In the beginning of each wet season, this rapid rise in creek water levels can cause surface water to infiltrate into the subsurface, temporarily minimising solute migration into the creek. This can occur over a relatively large area when the creek flood waters exceed 14 m AHD. Groundwater and solutes will eventually discharge to the creek during the remainder of the wet season, but groundwater discharge cannot significantly affect surface water solute concentrations because the creek flow rate is many orders of magnitude greater than the groundwater discharge rate.

Ranger Conceptual Model: Pit 1

Located on the Ranger 1 orebody east of the TSF, south of Pit 3, and west of the Corridor Creek tributary, Pit 1 was the first of Ranger's two pits. Open cut mining of Pit 1 commenced in May 1980, ceased in December 1994, and produced approximately 19.8 million tonnes of ore. Once the pit was mined out, tailings deposition into the pit commenced in 1996 and ceased in November 2008, yielding an average elevation of 12 m AHD for the tailings surface. Pit 1 served as a process water storage facility until 2012. Backfilling of Pit 1 with non-mineralised waste rock started in 2015 and was completed in 2020. Pit 1 is a likely source of COPCs because it has been used to store process water and tailings during the operations period and will hold tailings and waste rock after closure.

The key features and processes in the pre-mining period and during mining for the Pit 1 vicinity include the following:

- The pit vicinity is located on the western end of the Corridor Creek tributary, which receives managed released water, east of the TSF, and south of Pit 3.

- Prior to excavation, nearly the entire Pit 1 outline fell within the Djalkmarra Creek watershed, with the north-western margin draining toward Coonjimba Creek. The southwest part of the pit outline was a local topographic high. Groundwater would flow from south to north at the sitewide scale, but flow in the pit vicinity was from the topographic highs in the west to lower-elevation discharge areas in the Corridor Creek tributary.

- Like Pit 3, the Pit 1 area straddles the contacts between the LMS, UMS, and HWS hydrolithologic units, but its western margin also includes the Nanambu- LMS contact. Hydraulic conductivity in the pit shell rocks is typically very low (less than 10-4 m/d), with little to no inflow in the bedrock hydrolithologic units because of the large amounts of massive chlorite and chert. In 1984, after 4 yrs of mining, groundwater inflows abruptly increased to an average of about 8 L/s in the southeast margin of the pit between elevations of 0 and 12 m AHD.

- Early interpretations of the inflows in the southeast pit margin devised a new high permeability hydrolithologic unit called the MBL aquifer. Subsequent work by URS (2004) and Anderson *et al*. (2009) indicated that the inflows occurred along a permeable fracture set attributed to a pegmatite intrusion into the HWS rocks along a shallow horizon several tens of metres wide. They also indicated that the surrounding rocks had a lower hydraulic conductivity than that estimated by previous workers for the MBL aquifer. The INTERA (2014b) calibration included a hydrolithologic unit called the MBL zone, which was defined by hydraulic head responses during the calibration period and which had a lower hydraulic conductivity than that previously estimated for the so-called MBL aquifer. The MBL zone extent was further refined in the update to Ranger Conceptual Model in 2019.

- Injection and recovery packer testing of boreholes in the MBL zone near Pit 1 estimated very low hydraulic conductivity values (1E-05 m/d) at depths below 100 m, low values (1E-04 m/d) below 50-m depth, and higher values (1E-02 to 1E-03 m/d) between depths of 43 and 48 m . All the measured hydraulic conductivity values were at least three orders of magnitude lower than those used for the MBL aquifer in earlier models of Pit 1.

- In part, based on the conceptual and numerical modelling from Townley and Associates (2004), ERA constructed a seepage barrier along the south-eastern margin of Pit 1 in 2005 and 2006 to slow solute egress from process water and tailings stored in the pit. The Pit 1 seepage barrier was constructed at an angle that follows the slope of the Pit 1 wall from elevations of 0 to 14 m AHD across a 350-m length and with a design hydraulic conductivity of about 10-3 m/d.

- A single northwest-trending fault has been mapped as intersecting the pit shell at its northern margin, but inflows at that location were small to negligible (Salama and Foley 1997; Kin and Salama 1999; Kalf and Associates 2004; Townley and Associates 2004). Pegmatite intrusions have been mapped at the southeast margin and are associated with the highest observed pit inflows.

- Pit dewatering was aided by intermittent pumping at bore MBL and others from 1987 into late 2005 . Townley and Associates (2004) cite Kalf and Associates (2004) as providing evidence that bore MBL was pumped between 23 and 46 L/s for long periods of time through the end of 2003, but those data were not found in the cited report.

- Pumping at bore MBL was stopped in 2005 because it induced pit supernatant to migrate into the hydrolithologic units on the southeast margin of Pit 1, leading to rapid increases in solute concentrations at nearby bores. From 2006 through 2013, temporarily high pit water levels caused similar increases in solute concentrations at nearby bores on three occasions, but concentrations decreased within a few months.

- Pit dewatering rates after 1984 were estimated to average about 8 L/s.

- Dewatering in the pit created a hydraulic sink at Pit 1 during the mining period.

- When open-cut mining was completed in December 1994, the bottom elevation of the deepest part of the pit was about -150 m AHD.

The key features and processes for Pit 1 during and after decommissioning for consideration in the groundwater conceptual model include the following:

- After an underdrain was constructed, deposition of tailings into Pit 1 commenced in August 1996 and ceased in November 2008. Tailings reached a maximum elevation of 12 m AHD in Pit 1 and are expected to consolidate to an average tailings level of 7 m AHD at the end of decommissioning in 2026.
- Between May and October of 2012, 7,700 prefabricated vertical drains (wicks) were installed within the upper 40 m of the Pit 1 tailings mass to accelerate removal of tailings pore fluids and to promote development of a trafficable surface upon which to commence backfill operations.
- In recent years, waste rock was placed on Pit 1 as a pre-load to assist dewatering by the wicks and tailings consolidation. A layer of laterite was used to cover the waste rock pre-load beginning in 2015 and continuing into 2016.
- The tailings and pre-load will be covered by waste rock backfill to match the final landform design. The uppermost waste rock is intended to serve as growth media for revegetation.
- Until Pit 1 backfilling is completed, and the hydraulic heads in the shallow waste rock backfill increase above the heads along the downgradient pit margin, the pit will continue to act as a hydraulic sink preventing groundwater in the waste rock and tailings from flowing away from the pit.
- The majority of the pit tailings flux will be removed and treated.
- Once heads in Pit 1 increase to levels higher than heads along the downgradient pit margin, groundwater will begin to flow from the pit, carrying solutes from the backfill into weathered and unweathered hydrolithologic units between Pit 1 and the Corridor Creek tributary.
- The seepage barrier constructed along the southeast margin of Pit 1 has a top elevation of about 15 m AHD. The ground surface elevation in this area after decommissioning will be between about 20 to 22 m AHD. Since groundwater heads after closure are predicted to be about 20 m AHD, groundwater will easily flow through the 5-m thick area above the top of the seepage barrier, as well as around the ends of the barrier. Therefore, the seepage barrier and its long-term hydraulic properties will have negligible to no effect on solute release from Pit 1 after closure. The migration rate and loading from the tailings source is primarily controlled by the low hydraulic conductivity of the tailings and the surrounding rock up gradient of the tailings.

- Eventually, the post-closure groundwater flow system in the vicinity of Pit 1 will reach the topographically driven northwest-to-southeast flow expected for the final landform. Groundwater from Pit 1 will then discharge into the Corridor Creek tributary when it is flowing. When flow in the creek tributary ceases, groundwater is expected to continue to flow within the sediments of the creek bed. The rate of solute migration from the pit to the creek will decrease when creek water levels rise more quickly than nearby hydraulic heads. In the beginning of each wet season, this rapid rise in creek water levels can cause surface water to infiltrate into the subsurface, temporarily minimising solute migration into the creek. This can occur over a relatively large area when the creek flood waters exceed 14 m AHD. Groundwater and solutes will discharge to the creek tributary during the remainder of the wet season. Based on the observations that there is negligible base flow to the creek tributary during the dry season under current conditions, there will be negligible groundwater discharge to the creek tributary during the post-decommissioning period.

TSF conceptual model

Multiple studies into the conceptualisation of groundwater movement during the operation of the TSF as well as post closure have been undertaken over the years. Weaver *et al*. (2010) developed a comprehensive CM for the TSF and provided recommendations for additional work that would allow refinement and verification of their model. Golder Associates (2011) sought to implement that CM in a three- dimensional numerical model of solute migration from the TSF. Wakeman and Weaver (2015) provided an assessment of, and CM for, solute migration from the TSF to Gulungul Creek. Weaver (2015) provides assessment of solute migration from the TSF. INTERA (2016) further refined the conceptual model for the post closure TSF and undertook post closure solute transport modelling. The conceptual model has been further updated in 2019 by INTERA and post closure solute transport modelling with uncertainty analysis is currently underway and will be detailed in subsequent MCPs and the MTC Pit 3 closure application.

The key features and processes for the TSF vicinity prior to its construction include the following:

- The TSF footprint straddled a local topographic high that was part of the watersheds for Coonjimba, Gulungul, Djalkmarra, and Corridor creeks. In the original natural drainage, most of the surface water flow from the area covered by the TSF was to the north towards Coonjimba Creek, with the remainder flowing toward Gulungul Creek to the southwest and west, Djalkmarra Creek to the northeast, and Corridor Creek to the southeast.

- The TSF vicinity spans an area where the bedrock consists of granitic gneiss, biotite gneiss, and biotite schist of the Archean-age Nanambu Complex. Fresh (unweathered) Nanambu bedrock is overlain by approximately up to 20 m of highly weathered rock which is in turn overlain by up to 6 m of laterite, soils, and loose material. Minor pegmatites are present in the bedrock. Hydraulic conductivity in this area is typically very low (less than or equal to 10-3 m/d), but higher values are found in the shallow alluvium within the creek tributaries draining the local topographic high.

- Salama and Foley (1997) estimated pre-mining hydraulic heads of about 15 to about 25 m AHD in the vicinity of the TSF. Groundwater flow at the sitewide scale followed sitewide topography from south to north around the TSF vicinity, but within the TSF footprint, groundwater would flow from the local topographic high toward and along the nearest downgradient creek and tributary channels.

- Coffey and Hollingsworth (1979) identified a number of linear features in the TSF footprint that they considered as potential or inferred faults, which are depicted in Salama and Foley (1997). Based on their detailed mapping and logging of these linear features, Coffey and Hollingsworth (1979) determined that most of the potential faults were “healed”, which means that minerals had formed to occupy the entire void volume along the feature and left little or no pathways for fluid migration. They also conducted permeability measurements on 2- to 3-m- long intervals in bores drilled into most of the features and found that the hydraulic conductivity for all but a few of these intervals was typically low, on the order of 2.0E-3 m/d. The few exceptions were several shallow intervals with hydraulic conductivity values on the order of 10-1 m/d and two shallow intervals in the Coonjimba drainage with high values on the order of 9 m/d similar to that expected for alluvium. However, all of the deeper intervals in the Coonjimba drainage had hydraulic conductivity values that were orders of magnitude lower than the two shallow intervals, reaching about 10-3 m/d or lower. Hydraulic conductivity values for intact Nanambu bedrock were very low (<10-3 m/d) for nearly all intervals.

- A recent evaluation by Weaver *et al*. (2010) of the linear features identified by Coffey and Hollingsworth (1979) stated that there was little to no evidence that the inferred faults act as more permeable pathways than bedrock for solute transport, with the possible exception of the feature mapped as striking north from the TSF toward the Coonjimba drainage. Weaver *et al*. (2010) called this “the feature referred to as Fault 2A” as they had no evidence that it was a fault.

The key features and processes for the TSF during mine operations include the following:

- Surficial materials were scraped away down to the top of the weathered bedrock to provide a firm foundation for the footings of the TSF walls, which have a compacted clay core keyed into the weathered bedrock by an excavated cut-off (Weaver, *et al*. 2010 citing Volk, *et al*. 1980). Within the TSF, only the vegetation was removed.

- Construction of the TSF’s seven lifts from 1980 to 2012 raised local elevations by about 25 to 40 m over the original ground surface of about 18 to 34 m AHD Weaver *et al*. (2010), each time increasing the volume of tailings and process water held.

- Available water-level data for bores completed in the early 1980s and located on the perimeter of the TSF indicate that hydraulic heads continually rose at a relatively rapid rate from the time of construction through about 1984 to 1986. Several of the bores with the longest period of record show a sudden increase in hydraulic head in about

1999, but after this time, heads remained fairly stable with seasonal fluctuations. The addition of four lifts and an increase in height of 15.5 m between 1999 and 2012 had little impact on surrounding hydraulic heads suggesting that the effects of the TSF on hydraulic heads reached their maximum in about 1999.

- Recharge through the waste rock forming the TSF walls and hydraulic connection with the TSF are the likely causes for the local rise in hydraulic heads in and around the TSF up through 1999. The addition of four lifts thereafter apparently did not increase recharge and groundwater heads above their 1999 values.
- COPCs have migrated in groundwater away from the TSF. The COPC plumes have migrated farthest along Coonjimba Creek and Gulungul Creek tributaries 1 and 2 located south and west, respectively, of the TSF.

The key features and processes for the TSF during and after decommissioning include the following:

- Dredging and transfer of tailings out of the TSF will reduce the source mass and gradually lower the hydraulic head that is driving COPC migration away from the TSF area.
- Process water will be stored in the TSF following completion of dredging and tailings cleaning activities until water treatment has reduced the process water inventory sufficiently to transfer to a smaller storage facility.
- Reclamation of the TSF walls and re-distribution of the waste rock from the walls and stockpiles to match the final landform will change the recharge rates and likely cause a significant decrease in local hydraulic heads and gradient around the TSF resulting in much lower rates of groundwater flow.
- Groundwater will continue to flow from the TSF footprint toward the nearest tributary and creek channels. Rates of flow will be lower than those during the operations period because the construction and revegetation of the final landform will lead to an increase in ET and a decrease in recharge.
- Groundwater COPCs from the TSF footprint may potentially reach surface water in the nearest downgradient creeks and tributaries through base flow and transport of salts from groundwater exfiltration by overland flow. When surface water flows cease in the dry seasons, groundwater may continue to flow within the sediments of the creek channels.

The impacts to groundwater after site closure from the reclaimed TSF are expected to be less than those observed during the operational period because the majority of the COPC source mass (i.e., tailings and process water) will be removed and the driving force from the hydraulic gradient in the TSF area will be significantly reduced. Under closure conditions, most groundwater flow under the TSF footprint will be toward the north at a lower hydraulic gradient, resulting in slower transport rates, than exist under operational conditions. On the western side of the TSF footprint, groundwater flow will have lower hydraulic gradients, resulting in longer travel times and lower fluxes toward Gulungul Creek (Figure 5-58). The hydraulic gradient to the south will decrease under closure conditions, so that solutes that have already moved south of the TSF will be transported even more slowly (Figure 5-59).

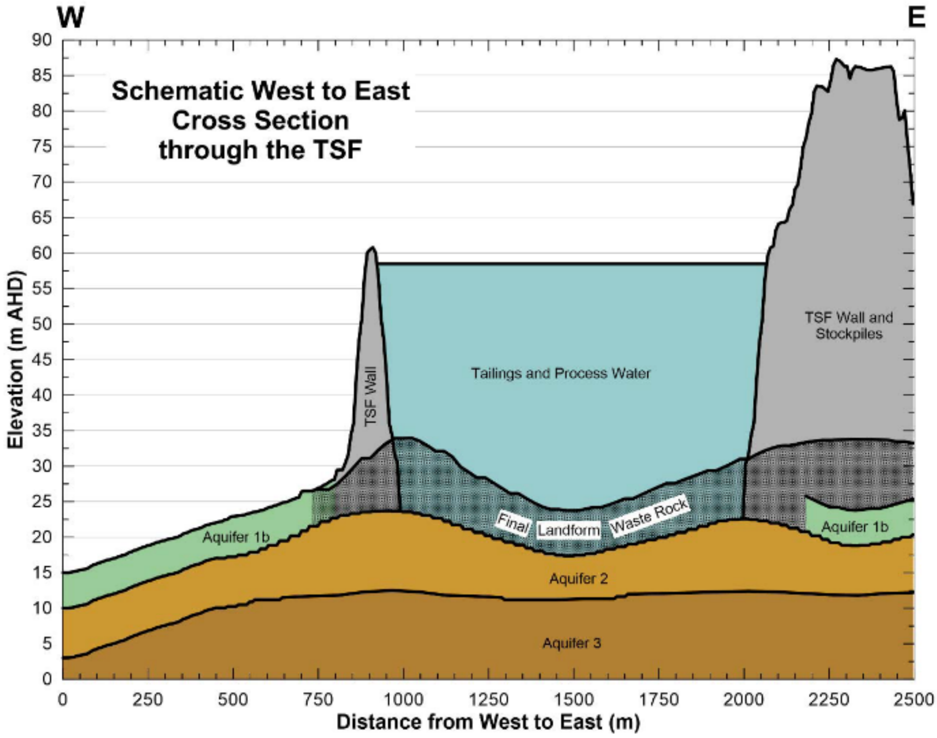


Figure 5-58: Schematic west to east cross-section through the TSF for the current configuration and the final landform waste rock (INTERA 2016)

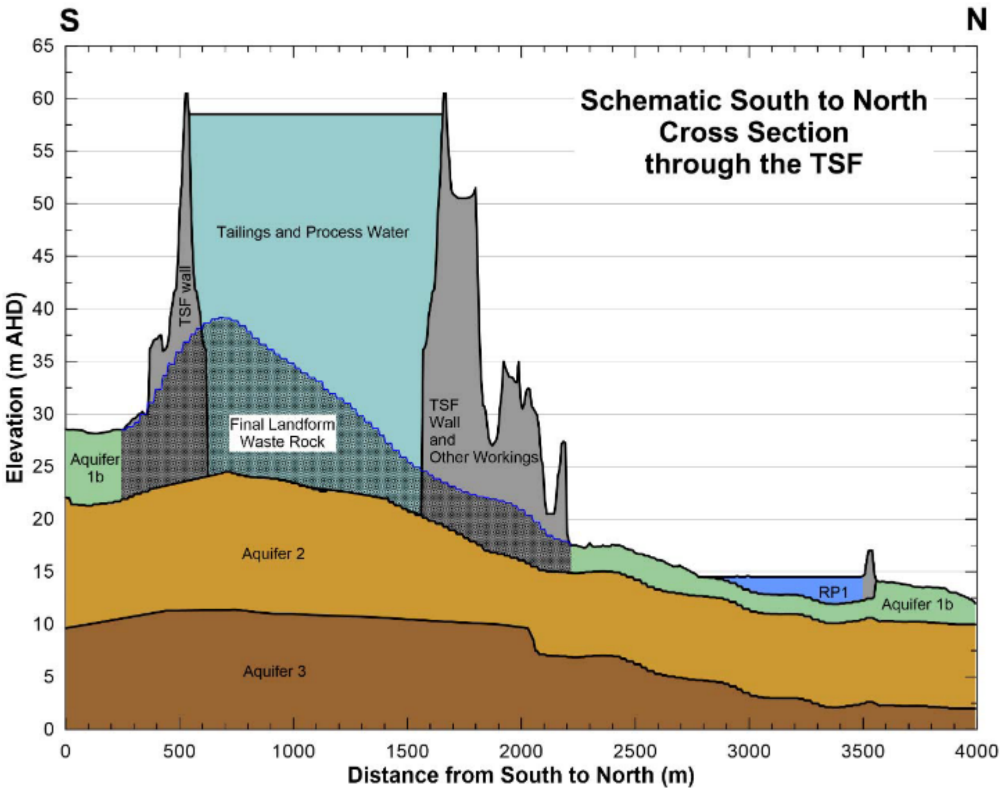


Figure 5-59: Schematic south to north cross-section through the TSF for the current configuration and the final (INTERA 2016)

Processing plant area conceptual model

The source of COPCs in the process plant area and some non-point (areal) sources associated with dust and dispersion from operational activities that have occurred at the site over many years are summarised in Table 5-26. Figure 5-60 shows the groundwater flow pathways from the processing plant area. Contours of long-term average hydraulic head (metres AHD) (white and yellow lines), groundwater divides (red lines), and general groundwater flow directions (large orange, blue, green, and purple arrows) in the vicinity of the processing plant area.

As planned in the closure strategy, shallow contaminated soil in the processing plant area is to be removed during decommissioning. Studies between 2006 and 2009 revealed that groundwater beneath the processing plant area had been affected by magnesium, manganese, sulfate, uranium, and organic contaminants, primarily total petroleum hydrocarbons, released by operational activities (Figure 5-61 to Figure 5-63). Additional investigations into the contamination of groundwater and soils under the process plant area commenced in late 2019 (Section 5.5.2.5).

Table 5-26 Contaminated sites located in or near the processing plant area (INTERA 2016)

Site #	Site name	Area (ha)	Source or nature of contaminant							
			Process water, pond water or tailings	Acid	Hydrocarbons	Chemicals	Metals	Organics and nutrients	Radiation, radioactive dust	Low risk industrial waste
3	Bulk fuel area - diesel storage and pump facility	0.76			Y					
4	Supply waste oil tanks	0.00			Y					
9	Maintenance workshop	1.31		Y	Y		Y			
10	Vehicle refuelling station	0.04			Y					
12	Mine maintenance workshop	0.17			Y	Y				
13	Mine wash down bay	0.15			Y				Y	
15	Acid plant*	1.34		Y						Y
16	Ammonia handling	0.25								Y
18	Emergency dump tank	0.60						Y		
19	Emergency response training facility/ gatehouse	0.09			Y	Y				
20	Fine crushing	2.44			Y				Y	
21	Grinding and pyrolusite	0.82	Y		Y	Y				
22	Hydrogen peroxide tanks	0.02				Y				
23	Laterite plant	2.62	Y			Y			Y	
24	Leaching CCDs clarification	2.14	Y						Y	
25	Lime mill	0.03	Y		Y	Y				
26	Neutralisation	0.27	Y		Y	Y				
27	Pond water holding tanks	0.38	Y		Y					

Site #	Site name	Area (ha)	Source or nature of contaminant							
			Process water, pond water or tailings	Acid	Hydrocarbons	Chemicals	Metals	Organics and nutrients	Radiation, radioactive dust	Low risk industrial waste
28	Precipitation, drying and packing	0.36							Y	
29	Primary crushing	1.12	Y		Y				Y	
30	Product warehouse	0.42							Y	
31	Sand blasting yard	0.35			Y	Y	Y			
32	Sand filters	0.18							Y	
33	Solvent extraction	1.17	Y		Y	Y				
34	Sulfur stockpile	0.77				Y				
35	Power station	1.15			Y					
36	Old sewage trenches	0.14						Y		
40	Demineralisation plant	0.04		Y		Y				
41	Radiometric sorter	1.07							Y	
43	Water treatment plants	0.92	Y			Y				
61	Old core yard	1.61							Y	
63	Plant services	0.13			Y					
66	Brine concentrator	0.93	Y		Y	Y				
67	New sewage trenches	0.28						Y		
69	R3D exploration facilities	0.20			Y	Y				
73	Leach tank failure	1.48		Y		Y			Y	
74	Shellsol underground tanks	0.06			Y					
75	Turbo burning yard	0.05			Y					

* Site 15 (former acid plant) is now the location of the brine concentrator (site 66).

ERA

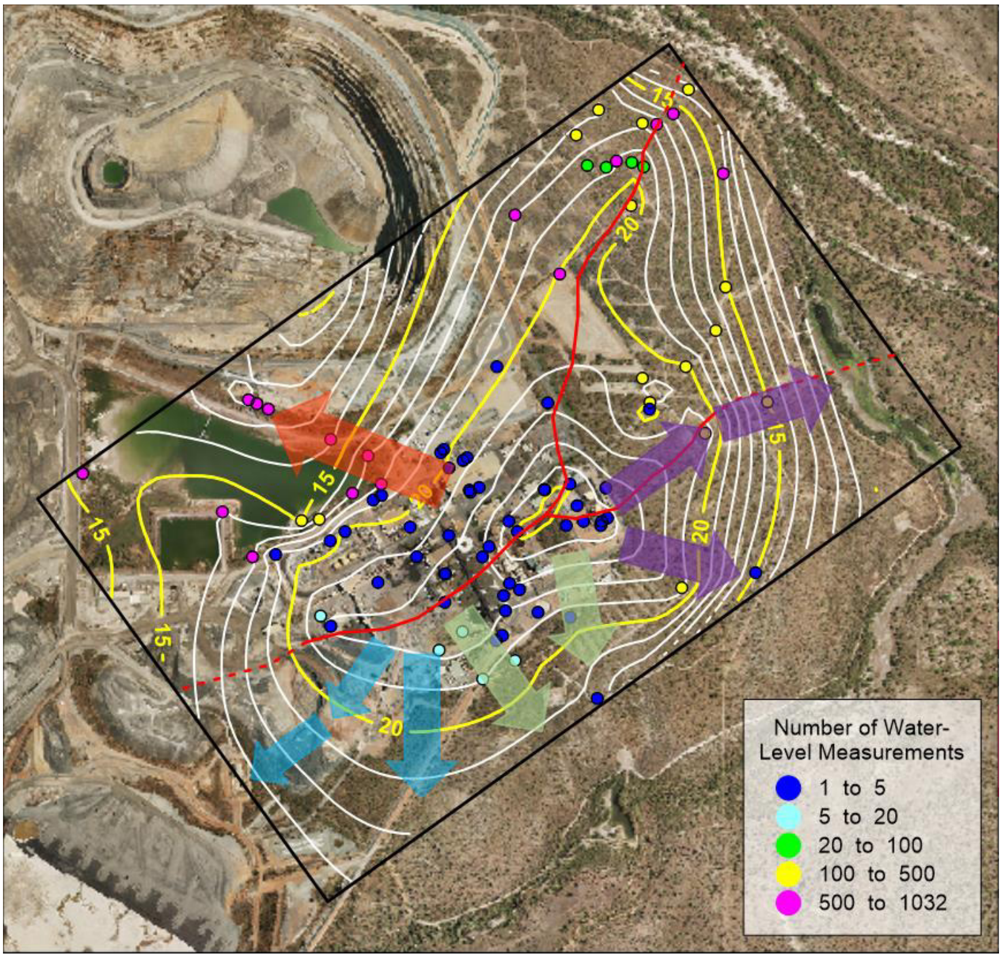


Figure 5-60: Groundwater flow pathways from the processing plant area towards Pit 1, Pit 3, Georgetown Billabong and Corridor Creek tributary (INTERA 2016)

Impacts to groundwater from operational activities appear to be minimal and located in the near vicinity of the processing plant area. During the preparation of this modelling it was noted that there was a lack of recent water quality data throughout much of the processing plant area leaving uncertainty about current groundwater conditions. Reclamation is expected to remove much of the COPC sources in the shallow soil, so groundwater concentrations are expected to decrease over time. Thus, the processing plant area was not expected to be an area of concern for groundwater after mine closure during the preparation of this modelling.

Based on the distance from the affected groundwater beneath the processing plant area to Corridor Creek and GTB and the low COPC concentrations seen in bores adjacent to Corridor Creek and GTB, contaminated runoff and/or groundwater discharge from the processing plant area are not expected to be of significant concern for surface water after closure.

Groundwater monitoring within the processing plant has increased in recent years to support future assessments. The assessment that the Process plant area is not expected to be an area of concern is being reviewed as part of the update to the post closure solute transport modelling and will be detailed in subsequent MCPs and the MTC Pit 3 closure application.

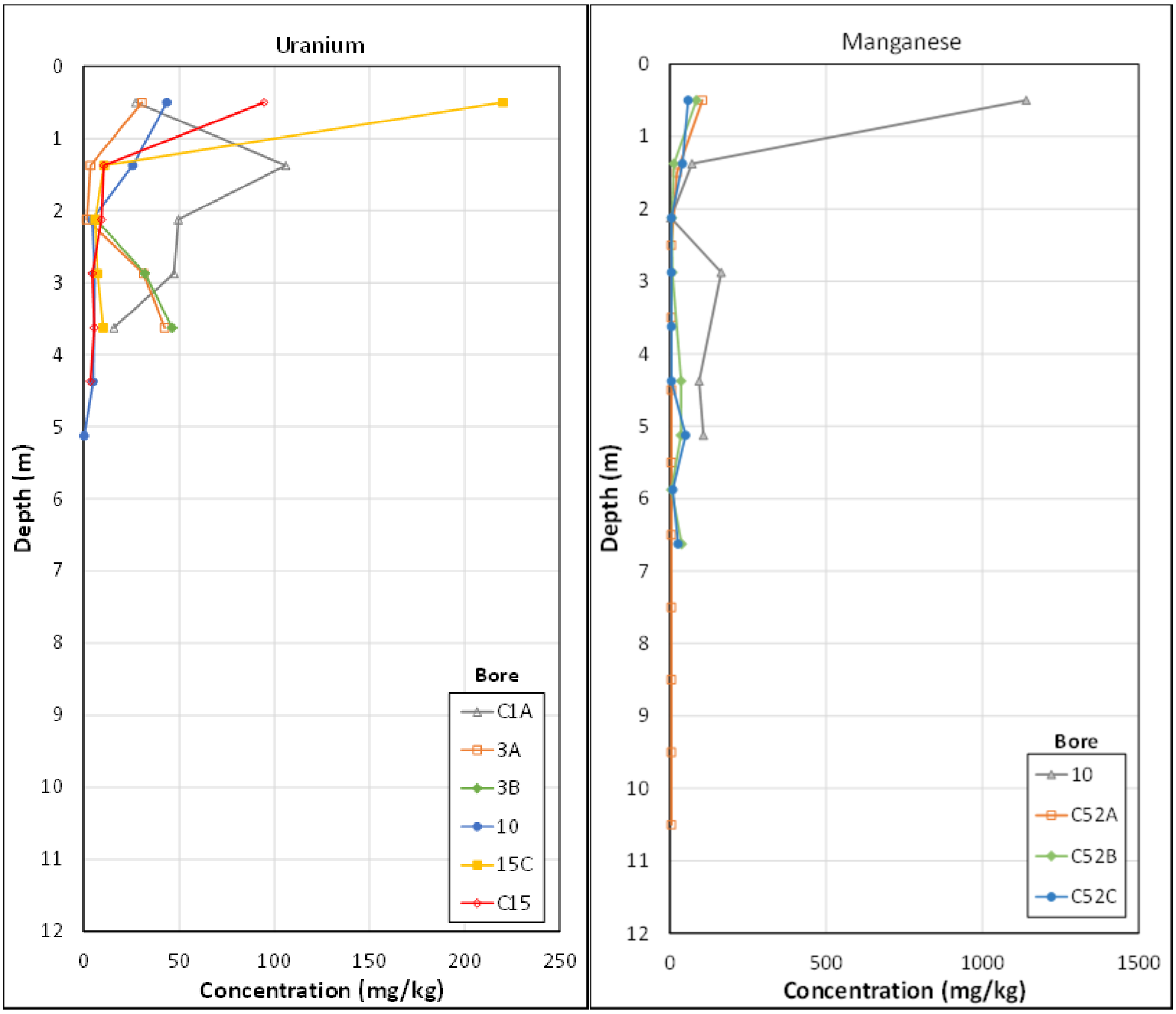


Figure 5-61: Uranium and manganese soil concentration versus depth; generally decreasing over depth (INTERA 2016)

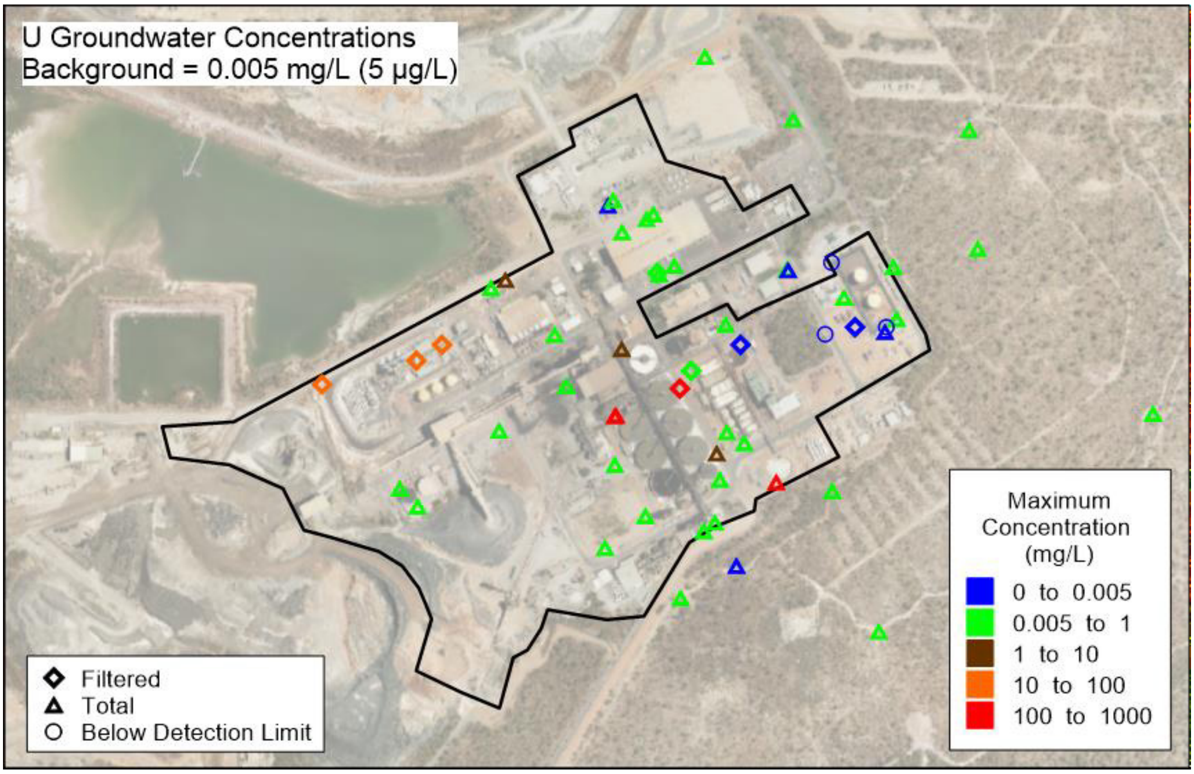


Figure 5-62: Maximum uranium in groundwater (data from 2006 – 2015) (INTERA 2016)

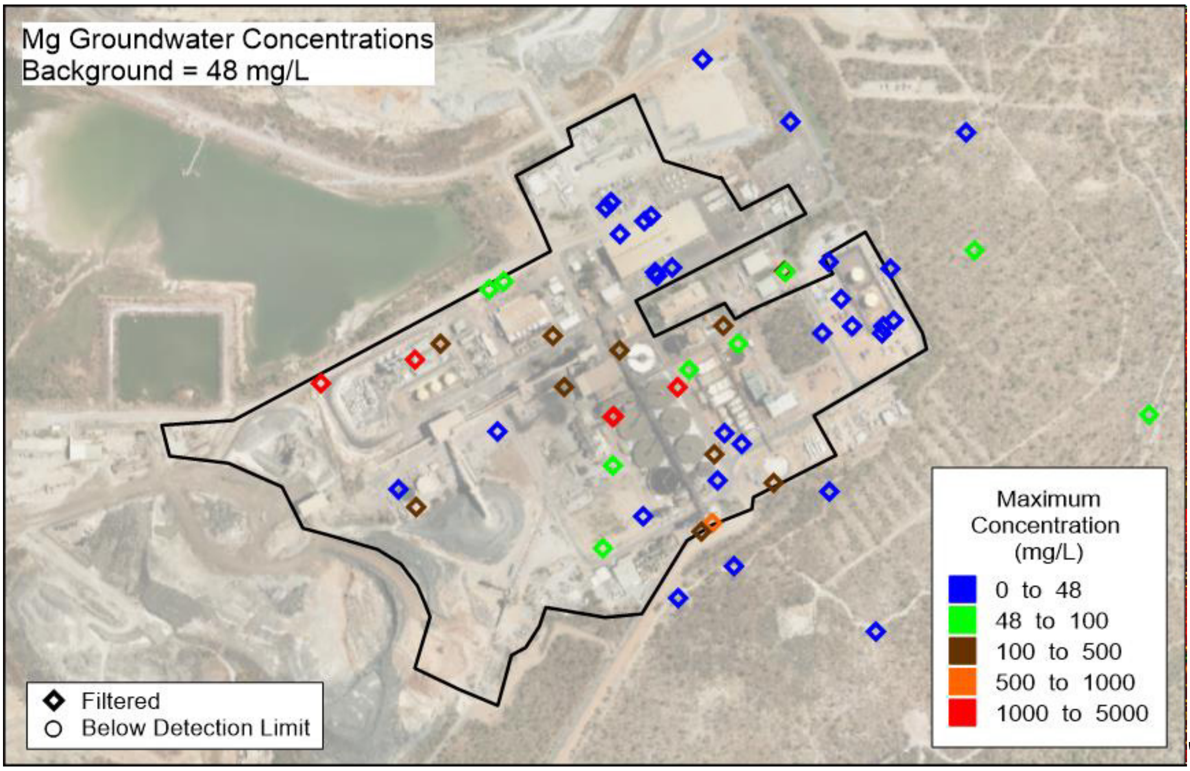


Figure 5-63: Maximum magnesium in groundwater (data from 2006 – 2015) (INTERA 2016)

LAAs conceptual model

The five areas of land application distributed across the Ranger Mine area are the Magela LAA (MLAA) and MLAA extension; the Djalkmarra LAA (east) and Djalkmarra LAA extension (west); the RP1 LAA and RP1 LAA extension; the Jabiru East Land Application Area (JELAA); and the Corridor Creek LAA (Figure 5-64).

As described in Section 5.5.2.4 uranium and radium-226 have been shown to be retained in the shallow soil; however, any future transport into surface water by erosion and runoff would be diluted to very low levels by the large creek flows. Irrigation with the dilute water produced by the treatment plants and natural recharge has been flushing out the conservative COPCs in recent years and will continue to do so prior to closure (Figure 5-64, Figure 5-65 and Figure 5-66). For all LAAs, the groundwater chemistry is expected to show limited to no impacts by the time of site closure.

The remediation of contaminated sites will be assessed and managed in accordance with the closure criteria outlined in Section 8.

The assessment that the LAA area not expected to be an area of concern is being reviewed as part of the update to the post closure solute transport modelling (section 5.5.2.10) and will be detailed in subsequent MCPs and the MTC Pit 3 closure application.

Ranger 3 Deeps conceptual model

Reclamation of the R3D decline and ventilation shaft will require backfilling with cemented aggregate fill and waste rock, which are potential COPC sources. Numerical modelling of COPC migration from closure of the entire proposed R3D mine concluded that solute loading to Magela Creek will be negligible. Therefore, leaching from the much smaller volume of backfill planned for the existing R3D workings (decline and ventilation shaft) will have no impact on the creek. Recovery of hydraulic heads to pre-excavation conditions in the deeper groundwater system will be expected to occur after closure as the hydrogeologic system re-equilibrates. No Long-term impact from depressurisation caused by excavation and dewatering of the exploration decline and shaft is expected.

Further refinement of the R3D conceptualisation was undertaken in 2018 by INTERA to assess the expected hydrological conditions for the R3D decline once the dewatering pumps were turned off and the decline and ventilation shaft were flooded. This is discussed in further detail in Section 5.4.3.9. The further assessment by INTERA in 2018 supports the INTERA 2016 conceptualisation and solute transport modelling.

Figure 5-64 Location of LAAs and associated monitoring bores

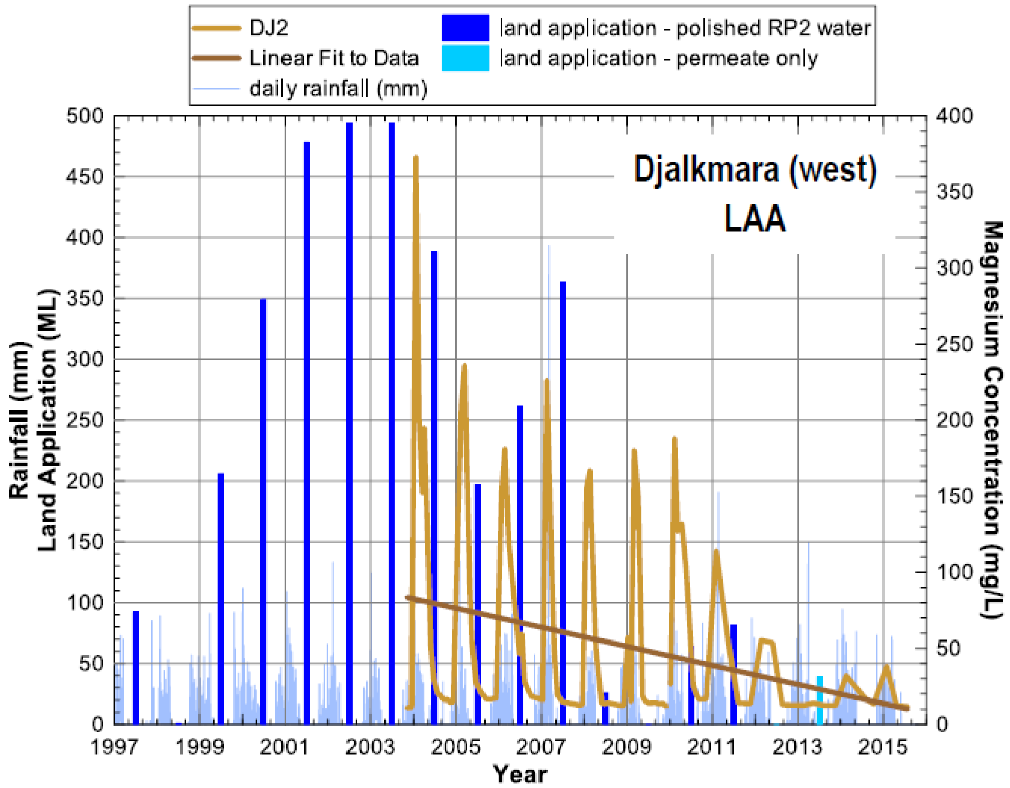


Figure 5-65 Magnesium observed in groundwater where irrigated with pond water (bore DJ2)

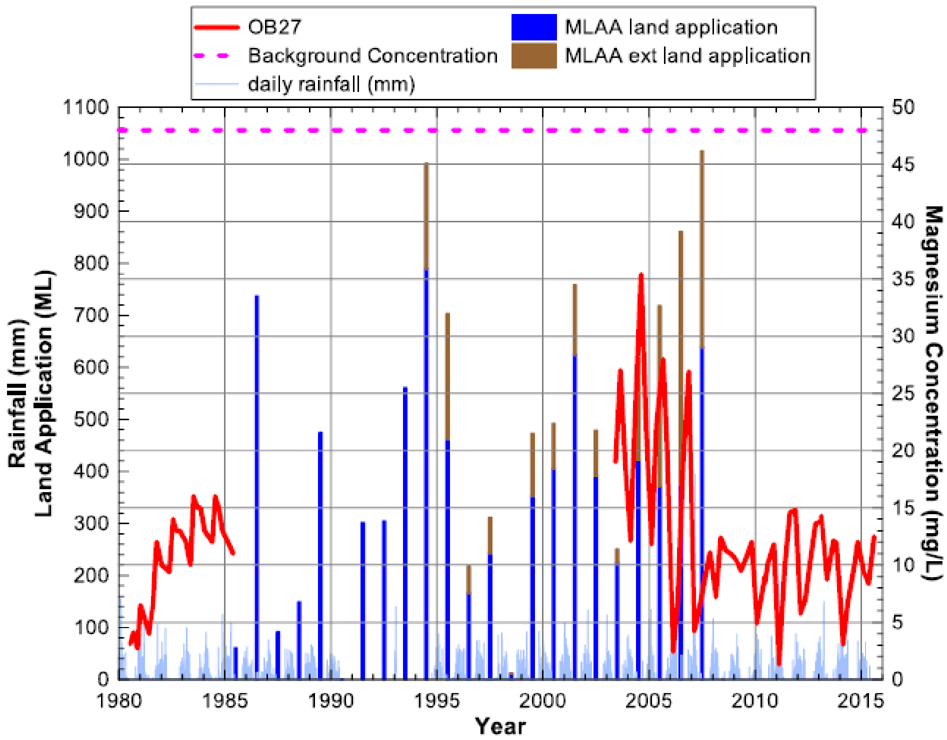


Figure 5-66: Surface water sulfate concentrations in bores OB27, MC27, and MC27 Deep (top) and bores MC12, MC12 Deep, 23562, and 83/1 Deep (bottom)

Landform waste rock conceptual model

Landform waste rock will leach COPCs, with concentrations for runoff much lower than those for groundwater that infiltrates to the water table through the waste rock. COPCs from the landform waste rock will migrate to Coonjimba Creek, Gulungul Creek and Magela Creeks and the Corridor Creek tributary by the runoff transport pathway and the groundwater discharge pathway. Estimated Mg loading from runoff is very small compared to that estimated for the groundwater pathway. Total estimated Mg loading from runoff and groundwater for landform waste rock, including that within the footprint of Pit 1 and Pit 3, is about 78 % of the historical average mine-derived Mg loading for the 1999 to 2012 period and is similar to the natural average Mg loading carried in Magela Creek surface water past the monitoring station upstream of the Ranger Mine for the 1999 to 2012 period.

Additional monitoring bores were drilled in the waste rock stockpiles in late 2018 and early 2019 (Section 5.4.3.11). Samples were waste rock were collected to inform the solute source term and have been analysed, results are currently undergoing review as part of the solute source term update to support the post closure solute transport modelling will be discussed in subsequent MCPs.

Conclusion

The Ranger Conceptual Model describes the elements of the Ranger Mine hydrogeologic and surface water environment that are important to understanding groundwater and surface water flow and solute migration within and out from the Ranger Mine at the appropriate time and space scales. Conceptual models were developed for the regional scale, sitewide scale, and the scale of individual areas of interest/concern where the COPC sources are located. The Ranger Conceptual Model provides a scientific framework based on the available evidence by which ERA can assess and implement decommissioning and closure activities consistent with regulatory environmental controls and rehabilitation requirements.

Updates to the solute transport modelling based on the updated Ranger Mine Conceptual Model are currently underway and will be discussed in subsequent MCPs and detailed in the MTC Pit 3 closure application (Section 5.5.2.9 and 5.5.2.10).

5.4.3.2 Pit 1 solute egress modelling – conclusions

ERA commissioned INTERA to develop a Pit 1 solute egress model to quantify the potential impacts to Corridor Creek for 10,000 years after closure. Potential impacts are defined as the mass loading to Corridor Creek over time of COPCs from the waste rock, tailings, and expressed process water (or PTF) in Pit 1.

Building on the models by CSIRO in 2012 and 2014, INTERA in 2014 and the previous set of conservative conceptual and numerical modelling tools that were designed to evaluate the closure of Pit 3, ERA has developed a comprehensive solute egress model for Pit 1 (INTERA 2016).

Predictions of the shallow Mg plume evolution from Pit 1 waste rock over time revealed that vadose zone leaching causes elevated groundwater concentrations in the western Pit 1 backfill through the first 270 yrs, but concentrations return to background thereafter (INTERA 2014b). Groundwater Mg concentrations from waste rock are much less in the downgradient weathered rock and sediments of the Corridor Creek tributary for the 10,000-yr simulation period, and fall below 60 mg/L after about 300 yrs. The groundwater Mg plume from Pit 1 waste rock reaches the sediments of the Corridor Creek tributary within 25 yrs after the simulation starts, and then continues to move downgradient through those sediments until it equilibrates with the dilute recharge, surface water infiltration, and groundwater discharge. It is important to understand that the groundwater Mg concentrations from Pit 1 waste rock after 300 yrs would not be distinguishable from background groundwater Mg concentrations caused by leaching of the bedrock and weathered rock along and beneath the Corridor Creek tributary.

Compared to the waste rock source, Mg leaching from the Pit 1 tailings source creates a deeper Mg plume in the groundwater between Pit 1 and the Corridor Creek tributary. A dilute portion of the tailings Mg plume (less than 60 mg/L) reaches ground surface at the downgradient margin of Pit 1 and exits as groundwater exfiltration within the first 25 yrs, but the plume does not reach the Corridor Creek tributary until sometime in the next 25 yrs. Groundwater flow drives the subsurface plume downward into the MBL zone and then toward the Corridor Creek tributary.

The pit tailings flux source after 95% removal creates a shallow Mg groundwater plume that migrates out of Pit 1 with much higher concentrations than the Mg plumes from the waste rock backfill and tailings sources. The shallow pit tailing flux Mg groundwater plume reaches ground surface at the downgradient margin of Pit 1 by the second year, reaches the Corridor Creek tributary by 25 yrs, and falls below 60 mg/L at the tributary after 60 yrs.

In summary, modelling of solute transport revealed that COPCs in the Pit 1 waste rock backfill, tailings, and pit tailings flux will likely migrate to the Corridor Creek tributary during the 10,000-yr assessment period. In all cases evaluated, loading from pit tailings flux is expected to only persist for several decades. The peak Mg loading from the combined waste rock, tailings, and pit tailings flux is estimated to be 17,700 kg/yr and to occur at 10 yrs after closure, corresponding to the peak period of higher source strength concentration from the pit tailings flux. The reactive COPCs, comprising U, Mn, ^{226}Ra, TAN, NO_3-N, total-P, and ^{210}Po, will also migrate from Pit 1 to the Corridor Creek tributary, with negligibly small loadings for ^{226}Ra and ^{210}Po.

5.4.3.3 Pit 3 solute transport modelling

INTERA (2014a) developed a numerical modelling of solute transport in groundwater to assess the potential impact of solutes leaching from different backfill scenarios for Pit 3 closure. The modelling specifically focused on quantifying the timing and rates of solutes migrating from the brine and tailings deposited in Pit 3 to Magela Creek (INTERA 2014a). This modelling was further updated by INTERA in 2016 and is undergoing further review and update to support the MTC Pit 3 closure application, details of the updated modelling will be provided in subsequent MCP's and the MTC Pit 3 closure application (Section 5.5.2.10).

Pit 3 will continue to be a hydraulic sink during the decommissioning period, but eventually Ranger's post-closure groundwater flow system in the vicinity of Pit 3 will reach the topographically driven south-to-north flow expected for the final landform. Groundwater and COPCs from Pit 3 will then migrate toward Magela Creek, which is the nearest discharge area.

Together with the brine injected into the underfill, the tailings and waste rock used to backfill will act as sources of COPCs, leaching Mg, U, Mn, ^{226}Ra, TAN, NO3-N, total-P, and ^{210}Po after closure.

Vadose zone waste rock will initially leach Mg, U, Mn, and ^{226}Ra at higher concentrations during about the first 280 yrs after closure, but concentrations will decrease thereafter when the small amounts of pyrite present in the waste rock have been oxidized.

After closure, some groundwater and COPCs will discharge into Magela Creek when it is flowing. As the base flow discharge rate is many orders of magnitude smaller than the surface water flow rate, the mass flux from groundwater is expected to be diluted in the high flow, low concentration creek surface water. Groundwater and COPCs in the Magela Creek sediments are expected to continue to migrate within the sediments of the creek bed throughout the year, eventually discharging to surface water downstream at or before the confluence of Coonjimba Billabong with Magela Creek.

Groundwater and COPCs could be brought to the ground surface on the downgradient margin of Pit 3 by groundwater exfiltration. COPCs may form salts during the dry season that would later be transported to Magela Creek by overland flow during the wet season.

Modelling of solute transport using a number of conservative assumptions estimated the mass of Pit 3 Mg and other COPCs that will be transported into Magela Creek. Loading of Mg to Magela Creek from brine will be negligible, whereas the Mg loading from waste rock will always be much larger than that from tailings. Peak annual Mg loading to Magela Creek surface water from waste rock, tailings, and brine was estimated be about 30,000 kg/yr, which is a small fraction of the average surface water. Long-term Mg loading from the combined sources from Pit 3 is estimated to be even smaller, averaging 13,900 kg/yr. The reactive COPCs, comprising U, Mn, ^{226}Ra, TAN, NO_3-N, total-P, and ^{210}Po, will also migrate from Pit 3 to Magela Creek, with negligibly small loadings for ^{226}Ra and ^{210}Po.

Each of a wide range of analyses investigating uncertainties in the driving force and hydraulic properties and alternative CMs demonstrated that the total Mg loading from Pit 3 is unlikely to be much greater than the estimated peak and long-term loadings.

In conclusion, Pit 3 has been a hydraulic sink during the mine operation period and, therefore, not a source of COPC contamination to groundwater or surface water. Closure conditions for Pit 3 include COPC sources from brine, tailings, and waste rock emplaced in the pit. Numerical modelling indicates these sources will migrate to Magela Creek during the 10,000-yr assessment period.

Reactive transport modelling

Reactive transport modelling was undertaken by INTERA in 2014 to support the solute egress modelling. Results of the reactive transport modelling demonstrated that attenuation of uranium and manganese transport in the relatively conductive ancestral Magela sands would only be effective over times less than about 100 years and attenuation in the weathered rock would be effective over times less than 7,500 years. Results showed that radium-226 does not attenuate in any appreciable manner in either the ancestral Magela sands or the weathered rock.

Solute loadings for U, Mn, Ra-226, TAN, NO_3-N, total-P, and Po-210, from waste rock, tailings, and brine sources were estimated by conservatively assuming no attenuation and scaling the Mg loadings by the ratio of the long-term reactive solute concentrations. The scaling calculations showed that the solute loadings to Magela Creek from the Pit 3 brine reactive solutes will be negligible. Average annual long-term loadings to Magela Creek for uranium is approximately 55 kilograms per year for the combined waste rock and tailings sources. Average annual Mn loadings to Magela Creek from the combined sources is 750 kilograms per year. Mass loadings of radium-226 to Magela Creek from the combined sources are estimated to be roughly 3 milligrams per year (1.1 x 10^5 milli-becquerels per year). Solute loadings for TAN for the combined sources are 400 kilograms per year. Average annual NO_3-N loadings to Magela Creek from the combined sources is 150 kilograms per year. Solute loadings for total phosphorus for the combined sources are 19 kilograms per year. Loading from polonium was negligible for all simulations with source data.

Secondary uranium and magnesium minerals associated with the waste rock landform

In the solute transport model the source term for COPCs is generated from weathering of waste rock placed in the shells of Pit 3 and Pit 1, and over the post-closure landscape, before solutes egress with groundwater into the receiving environment. The magnesium and uranium source terms were based on empirical data, constrained in the long-term by possible weathering pathways that invoked the formation of secondary carbonates such as hydromagnesite [$Mg_5(CO_3)4(OH)_2{\cdot}4H_2O$] and/or clays such as saponite [$Ca_{0.1}Na_{0.1}Mg_{2.25}Fe^{2+}_{0.75}Si_3AlO_{10}(OH)_2{\cdot}4(H_2O)$] in the variably and permanently groundwater-saturated zones of the waste rock overburden. The transport of Mg and uranium along flow paths through adjacent soil considered possible attenuation through sorption, ion exchange and secondary mineralisation as discussed above in Reactive transport modelling.

In 2016 ERA investigated a Ranger Mine stockpile to identify secondary minerals formed after prolonged burial and exposure to weathering. The aim was to examine whether the secondary minerals assumed by the solute transport model, which immobilise Mg and uranium, are generated during weathering.

Available literature provided a strong knowledge base about source term and secondary mineral generation. It is established that in the variably water saturated zone of the stockpile chlorite [$Mg_5Al_2Si_3O_{10}(OH)_8$] breaks down rapidly in contact with natural rainfall and acids generated by pyrite [FeS_2] oxidation. The source term concentrations for uranium and phosphorus generated by the leaching of chlorite rock in experimental columns (Overall *et al.*

2001) were consistent with the concentrations required to precipitate saleeite [$Mg(UO_2)_2(PO_4)_2 \cdot 10(H_2O)$] as a secondary mineral. Another column experiment representing weathering of tailings containing chlorite in the permanently water-saturated zone (Puhalovich & Pugh 2007), observed that sulfate reducing bacteria mediated the mineralisation of magnesite [$MgCO_3$]. In that experiment the source terms for Mg, observed experimentally as well as in the field, were also consistent with the concentrations required to precipitate magnesite, a mineral related to hydromagnesite. This literature guided interpretation of stockpile weathering.

In the 2016 investigation, ERA collected weathered rocks and exfiltrated groundwater from recently exposed faces of the former core of a stockpile. The rock samples were analysed for secondary minerals, and the groundwater was tested for constituent elements associated with these minerals. A computer model was used to reconcile secondary minerals observed in the stockpile with element concentrations in the groundwater.

The outcome of the investigation was support for the 320 milligrams per litre maximum peak loading for Mg assumed by the INTERA (2014a) solute transport model. The investigation also confirmed several of the main secondary minerals assumed by the INTERA (2014a) model: kaolinite [Al2Si2O5(OH)4], goethite [FeOOH], illite [K0.6 Mg0.25 Al2.3Si3.5O10(OH)2]. palygorskite, a magnesium clay mineral [(Mg,Al)2Si4O10(OH)·4(H2O)] was observed, whilst hydro-magnesite or magnesite were not observed. It is considered that the variably water-saturated groundwater environment of the stockpile represents the future weathering environment of the upper waste rock zone of the final landform, but not the permanently groundwater-saturated lower waste rock zone that will occur in the shells of Pit 3 and Pit 1. This permanently saturated zone should support sulfate reducing bacteria, which is known to facilitate the mineralisation of magnesite (Puhalovich & Pugh 2007). Secondary hydro-magnesite could also form in this water saturated environment.

Some additional secondary uranium minerals were identified in the stockpile (saleeite, torbernite Cu(UO2)2(PO4)2·8-12(H2O)/metatorbenite Cu(UO2)2(PO4)2·8(H2O) and uranophane Ca(UO2)2SiO3(OH)2·5(H2O)). Uraninite (UO2) is likely to form in the permanently groundwater saturated zone. Because these minerals potentially could form additional geochemical sinks for uranium in the final landform that were not included in the solute transport model, this investigation confirms that the solute transport model is conservative for uranium.

ERA is currently reviewing the geochemical source term with respect to predicting the seepage of contaminants from the waste rock final landform and buried tailings. Updates to the waste rock landform source term will be detailed in subsequent MCPs and the MTC Pit 3 closure application. (Section 0)

5.4.3.4 Peer review of solute modelling

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

The initial peer review in 2015 was to address feedback raised during the proposed R3D underground mine EIS consultation. The second peer review in 2016, was appended to the Pit 1 notification intended to assess the potential environmental impact of the Pit 1 closure design.

The scope of the initial peer review covered the development of the groundwater flow and solute transport models, calibration of the groundwater flow model, and the application of those models to predict solute loading to Magela Creek expected to occur in a 10,000 year period following closure of the R3D underground workings (Smith 2015). The review specifically considered the groundwater modelling in the context of the Australia Groundwater Modelling Guidelines. Dr Smith concluded in respect to alignment with the Australian groundwater Modelling Guidelines and overall modelling approach used by INTERA:

> *"In my opinion, subject to various observations provided I the body of this report, each of the ten questions listed in Table 9.1 [compliance checklist' can be answered in the affirmative … I consider the hydrogeologic models developed for the evaluation of groundwater impacts associated with the Ranger 3 Deeps Project to be well-suited for their intended purpose."*

The scope of the Pit 1 peer review covered the development of the conceptual models for groundwater flow and solute transport, construction of the simulation model, calibration of the groundwater flow model, and the application of the model to predict COPC loading to Corridor Creek over a 10,000 year period following closure of Pit 1. As in the case of the initial peer review Dr Smith considered the INTERA groundwater modelling in the context of the Australia Groundwater Modelling Guidelines. Dr Smith (2016) concluded in respect to alignment with the Australian groundwater Modelling Guidelines and overall modelling approach used by INTERA:

> *"The Australian groundwater modelling guidelines support a pragmatic approach to modelling and encourage consideration of simple modelling options where they are appropriate. In my opinion, considered in relation to the intended purpose of the model, the three-dimensional hydrogeologic model constructed to aid in the assessment of the closure plan for Pit 1 is based on a reasonable balance between the degree of complexity embedded in the model and the utility of the model. ERA took advantage of a number of approximations and assumptions to achieve acceptable efficiencies in model development, model calibration and model application. One of the principal uses of*

hydrogeological models is their use as a tool to gain site-specific, quantitative insight to the key factors that control the patterns and rates of groundwater flow and, in the case here, factors determining loading of COPC to Corridor Creek. In my view, the model and complementary discussion in the modelling report are used effectively to this end."

The independent review and analysis of the hydrogeologic models developed for the evaluation of groundwater impacts associated with R3D and Pit 1 were considered to be well-suited for their intended purpose.

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

5.4.3.5 Further work

ERA has requested that INTERA updated the existing Ranger Conceptual Model and post-closure solute transport modelling. The update to the Ranger Conceptual model was completed in April 2019 and is detailed in Section 5.4.3.1. Updates to the post-closure solute transport modelling are scheduled to be completed in 2020 following a number of supporting studies. Updates to predictions of post-closure solute transport modelling will be provided to in subsequent MCPs..

5.4.3.6 Assessment of post-closure Mg loading to Magela Creek from Pit 3 tailings

The objective of this modelling study (report 22 March 2019), conducted to support the Pit 3 Tailings Deposition Application, was to estimate peak magnesium (Mg) loading to Magela Creek for each of two Pit 3 tailings deposition options over a 10,000-year time period and to assess the sensitivity of predicted loading to changes in key parameters.

INTERA developed and applied a three-dimensional groundwater flow and transport model for post-closure conditions to estimate the peak loading of Mg to Magela Creek from Pit 3 tailings for the M3D2 and M2D2 deposition options. The model was constructed using the recent Ranger Conceptual Model (RCM) groundwater flow calibration and post-closure flow models. Tailings deposition characteristics were used in the modelling to account for updated tailings source concentrations, volumes and hydraulic properties specific to the M3D2 and M2D2 deposition options. The assessment included a sensitivity analysis that varied hydraulic conductivity (K) of the tailings, K of the excavation damaged zone, and the tailings Mg source concentration.

Peak Mg loading to Magela Creek using the base case model parameters for the M3D2 option is about 4,500 kg/year and that for the M2D2 option is about 8,800 kg/year. These predicted loadings represent about 3 and 7 %, respectively, of the mean historical natural loading of 135,000 kg/year in Magela Creek at station MCUS located upstream of the mine and about 3 to 5 % of the mean historical mine-derived loading of 178,000 kg/year. The estimated number of groundwater pore volumes passed through the tailings in 10,000 years are very small (about 0.8 for the M3D2 option and about 1.6 for the M2D2 option).

The resultant modelling predicted that Mg loadings to Magela Creek from Pit 3 tailings for the M3D2 and M2D2 deposition options and the sensitivity analysis represent a small fraction of the mean natural Mg loading in Magela Creek upstream of the Ranger Mine and of the mean historical mine-derived Mg loading.

5.4.3.7 Evaluation of extent and hydraulic properties of the MBL zone near Ranger Pit 1

The study (report dated 4 January 2018) objective was to undertake an investigation of the MBL zone between the Ranger Mine Pit 1 and Corridor Creek tributary. The objectives of the investigation were to refine the three-dimensional extent, estimate hydraulic conductivity and storage properties, examine how interpreted post-closure solute transport pathways may change as a result of changes to the interpretation, and estimate reduction in groundwater ingress to Pit 1 resulting from abstraction from MB-L bore pumping. The report details the data, methods, models and previous investigations used to re-evaluate the extent and properties of the MBL zone.

Compared to the MBL zone represented in the INTERA (2014a) model, the revised MBL zone extends further to the northeast and southeast, is reduced by about half in thickness, and has an increased hydraulic conductivity. The revised extent and properties for the MBL zone are not expected to change the predicted pathways for solute migration from Pit 1 tailings to the Corridor Creek Tributary. Further review of the impacts to groundwater flux between Pit 1 and Corridor creek as a result of the updated MBL zone conceptualisation is to be undertaken as part of the post-closure groundwater solute transport modelling.

The analysis indicated that the estimated percentage of process water pumped from Pit 1 that was sourced by groundwater ingress from the MBL zone reduced from 40 % in the 2015-2016 water season to 15 % in the 2016-2017 water season. The period during which bore MB-L was pumped corresponded to about half of the 2016-2017 water season and resulted in an estimated 58 % reduction (from 6.2 to 2.6 L/s) in the average rate of MBL zone groundwater ingress into the pit. The water balance analysis confirms that pumping bore MB-L reduces groundwater inflow into Pit 1 from the MBL zone.

The findings and assessments from this study were used to support to the Ranger Conceptual Model update completed in March 2019.

5.4.3.8 Assessment of effect of tailings deposition on flow from Pit 3

The SSB raised concern regarding the environmental effects of the current method of tailings deposition into Pit 3, prompting ERA to request INTERA to assess the effect of tailings deposition and consolidation on the lateral flow of tailings pore water from the pit. Rapid deposition of tailings results in excess pore pressure in the tailings pore fluid. Consolidation of tailings, and coincident reduction in tailings hydraulic conductivity (K), occurs as these excess pore pressures dissipate. INTERA developed two two-dimensional cross-section groundwater flow models to simulate conditions at the end of tailings deposition to assess the flow of this expressed fluid. The cross-section locations were selected to coincide with groundwater flow paths between the pit and Magela Creek.

Both cross-section models showed that tailings pore fluid primarily flows directly into the overlying process water. The remainder flows into the excavation-damaged zone (EDZ) located around the pit or into the underdrain located in the pit between the tailings and underlying underfill. From the underdrain and the EDZ, essentially 100 % of the tailings pore fluid flows along the EDZ and into the process water.

The modelling results demonstrated that:

- there was negligible outflow of tailings pore fluid from Pit 3 or the EDZ into the surrounding formations: almost 100 % of tailings pore waters entering the underdrain and EDZ flows to the process water overlying tailings
- the tailings deposition method currently used by ERA does not pose an environmental threat from lateral flow of tailings pore fluid during the period of tailings deposition.

5.4.3.9 Evaluation of hydrological conditions after halt of pumping in the Ranger 3 Deeps decline

The study (report date 22 March 2018) objective was to assess the expected hydrological conditions for the R3D decline once the dewatering pumps are turned off and the decline and ventilation shaft flood. The following aspects were addressed:

- time taken for water level to rise in the decline to -20 m AHD after pumping has stopped
- pumping rate required to maintain the water level in the decline at -20 m AHD
- time required for the groundwater system to reach equilibrium after pumping stops
- impacts of not grouting the four standpipes located in cuddies along the decline
- approach and value of monitoring the water-level rise in the decline and shaft
- groundwater assessment and conceptualisation after mine closure.

Three-dimensional groundwater modelling was implemented to match inflows to the decline during and since excavation and to predict the water-level rise in the decline after dewatering ceases. Modelling results indicate that the time for the water level in the decline and ventilation shaft to reach -20 m AHD after pumping stops is about 490 days (about 1.3 years). Observed inflows from the base of the weathered zone into the decline range from 0.5 to 1.5 L/s in the dry and wet seasons, respectively, and flows into the ventilation shaft range from 0.5 to 1 L/s in the dry and wet seasons, respectively. Based on these observed data, pumping rates required to maintain the decline water level at -20 m AHD were estimated to range from 1 L/s during the dry season to 2.5 L/s in the wet season. The time required for the decline and shaft to flood above -20 m AHD to near equilibrium water-level conditions at 18 m AHD is estimated to be short (several months) after all pumping ceases and may occur concurrently with the backfilling of waste rock in the decline.

Shallow groundwater heads at the water table are expected to recover to natural conditions within several years after the upper parts of the decline and shaft are backfilled. Groundwater gradients will be downward in the vicinity of the decline portal and the ventilation shaft and, therefore, upward movement of groundwater from four remaining standpipes, if left ungrouted, will not occur. Downward flow along the decline into deeper bedrock units is expected to be negligible and, therefore, installation of bulkheads to further limit this flow is considered unnecessary.

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. Therefore, the R3D decline, and ventilation shaft are not considered a potential area of concern after mine closure.

5.4.3.10 Predictive modelling of Ranger post-closure solute loading with uncertainty analysis

ERA has requested INTERA carry out groundwater modelling to predict transport of COPCs from minesite sources and COPC mass loading to surface waters over the next 10,000 years as a step to demonstrating achievement of environmental outcomes. Inputs to the groundwater flow and solute transport models (i.e., model parameters) will have some uncertainty, as will the model predictions of COPC mass loading to surface water.

A summary excerpt from the scope of work developed by INTERA is provided below. At the time of preparation of this report, works were still underway on the project and results were not available for publishing. Details on the project execution and results will be detailed in subsequent MCPs and the MTC Pit 3 closure application.

This scope to conduct a constrained uncertainty analysis on groundwater COPC loading to surface water receptors was developed using our experience and the scientific literature for uncertainty analysis and groundwater modelling (Freeze *et al*. 1990; Moore and Doherty 2005; Doherty *et al*. 2007; Tonkin and Doherty 2009; Doherty *et al*. 2010; Barnett *et al*. 2012; Anderson *et al*. 2015; Doherty 2015; Watermark Numerical Computing 2019; White 2018). The scope is consistent with and informed by the recent guidance from Middlemis *et al*. (2019) and Middlemis and Peeters (2018) for conducting uncertainty analyses of groundwater models.

The overall objective is to develop probabilistic predictions of solute loading from Ranger Mine sources to Magela, Corridor, Coonjimba, and Gulungul creeks in the 10,000 years following mine closure. Solute loads to the creeks are to be calculated for 20 COPC: magnesium (Mg), 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.

INTERA have proposed to incorporate model parameter uncertainty together with calibration data constraints into an uncertainty analysis of COPC loading using a 3-step approach. The steps comprise preparing inputs to the constrained uncertainty analysis, carrying out the uncertainty analysis to predict future COPC loads, and compiling the load predictions for use in assessing potential impacts by ERA.

INTERA's proposed approach adopts the Monte Carlo method to generate equally probable realisations of model inputs and combines it with a framework based on Bayes rule (Bayesian framework) to constrain model inputs using calibration data. In the Monte Carlo method, model inputs are defined as random variables with probabaility distribution functions (PDFs) that are randomly sampled to create a set of equally probable realisations, which, when used in a predictive model, yield a set of model results with which to estimate a PDF of predictions. The Bayesian framework provides the theoretical and operational means to take initial estimates of model parameter PDFs and use other information, such as the observations of groundwater heads used to calibrate the Ranger sitewide groundwater flow model described in INTERA (2019a), to update the PDFs so that their ranges of values yield model results consistent with the other information or observations.

INTERA will predict loads from all or nearly all COPC sources using the null space Monte Carlo (NSMC) method (Tonkin and Doherty 2009; Doherty *et al*. 2010; Navarro Nevada Environmental Services 2010; Doherty 2015). The NSMC uncertainty analysis will be conducted using the three-dimensional numerical groundwater calibration flow model (INTERA 2019a) updated in the previous step together with the three-dimensional numerical groundwater flow and transport predictive models for the sources. INTERA has experience with the NSMC method, having used it to assess uncertainty in plume migration from underground nuclear testing (Navarro Nevada Environmental Services 2010) and more recently in 2018 to estimate post-closure risks from closure of a uranium mine in central New Mexico (INTERA 2018).

The NSMC method provides an efficient means to generate prediction PDFs from posterior parameter PDFs created using the prior parameter PDFs, calibration data set, and the calibration flow model. Random sampling of the prior PDF for each model parameter will produce a large number of sets of prior parameter values, called prior parameter realisations, which will be updated using the PEST null space tool and the PEST calibration tools to create sets of posterior parameter values (Watermark Numerical Computing 2019). These resulting posterior parameter realisations are then run in the predictive model to create COPC loads over time (e.g., horsetail plots like those shown in Figure 2a). This means that both the three-dimensional numerical calibration and predictive models must be run a large number of times. INTERA recently upgraded its Austin computational cluster from 48 to 144 nodes, which should assist in managing the relatively long current model run times and large number of simulations.

Carrying out the NSMC uncertainty analysis process comprises the following tasks, referred to below as NSMC tasks 1 through 7.

1. develop prior PDFs for all input parameters in the calibration and predictive models.
2. review prior PDFs with ERA and stakeholders.
3. construct and test predictive groundwater flow and transport models.
4. generate random sets of parameter values from prior PDFs (i.e., generate the prior parameter realisations).

5. use PEST null space and calibration tools to update prior parameter realisations using the calibration data and calibration model to produce posterior parameter realisations.

6. run the predictive models using the posterior parameter realisations.

7. compile and combine, if necessary, results of predicted COPC loads.

Development of prior PDFs in NSMC task 1 is required for each model parameter. This is a vital step for all model parameters used in the calibration and predictive models.. The roughly 50 input parameters for the calibration flow model include:

- horizontal and vertical hydraulic conductivity for each HLU
- specific yield and specific storage for each HLU
- parameters for boundary conditions representative of the active mining period such as groundwater recharge rates, evapotranspiration (ET) extinction depth and maximum rate, stages for creeks and retention ponds, conductance values for pit drains and creek general head boundaries (GHBs)

Additional input parameters for the predictive models include:

- horizontal and vertical hydraulic conductivity for pit backfill and landform waste rock HLUs
- effective porosity for all HLUs
- boundary condition parameters for the post-closure period including groundwater recharge, ET, and creek and billabong GHBs
- parameters characterising source concentration and leaching rates

Given the numbers of HLUs and boundary conditions and the number of parameters needed for each, INTERA expects that prior PDFs will be needed for roughly 100 to 200 input parameters. The prior PDFs will be described using theoretical distributions derived from the available site-specific data, past model results, and INTERA's expert judgement. Potential theoretical distributions include uniform and normal distributions and their logarithmic transforms. For example, the horizontal and vertical hydraulic conductivity input parameters may be represented as log normal PDFs because their values for a single HLU often span more than an order of magnitude. The means of the prior PDFs are equal to the calibration values for parameters in the calibration solution space and to the estimated means for parameters in the calibration null space. INTERA recommends that ERA and INTERA jointly develop the prior parameter PDFs in NSMC task 1 and then discuss them with stakeholders in NSMC task 2 before proceeding with the uncertainty analysis. These discussions between ERA, INTERA and the SSB commenced in December 2019 and will continue throughout the modelling project.

The predictive models for COPC sources will be constructed and tested in NSMC task 3. At present, INTERA plans to create a single predictive model for all but two sources, called the main predictive model. Model testing will include investigating numerical convergence, representation of each COPC source, suitability of model gridding, and reasonability of model results. A separate variable-density model will be created and tested to predict COPC loading from Pit 3 brine placed in the Pit 3 underfill.

Groundwater flow boundary conditions in the predictive model domain are assumed to be steady. Transport boundary conditions may be steady for some sources and time varying for others. The starting time for the predictive simulations corresponds to the time when groundwater flow is in equilibrium with climatic and surface water conditions; which has been estimated to occur during the first few decades after mine closure. This assumption is important to achieve the objective of developing probabilistic predictions of solute loading from Ranger Mine sources to Magela, Corridor, Coonjimba, and Gulungul Creeks in the 10,000 years following mine closure.

NSMC task 4 will create random samples of model parameter values (realisations) from the prior parameter PDFs created and finalised in NSMC tasks 1 and 2. We propose to use an appropriate random sampling algorithm such as that found in PEST (Watermark Numerical Computing 2019) or similar routines to generate a large number of prior parameter realisations.

NSMC task 5 is the core of the NSMC process and can be a computationally demanding task. The goal is to produce posterior parameter realisations that do calibrate the groundwater flow model. Each prior parameter realization will first be reprojected into the null space using the PEST PNULPAR tool to create the posterior parameter realisations. INTERA plans to run each reprojected realisation in PEST calibration mode with the singular value decomposition PEST tool, which should reduce the run time required (Doherty 2015).

In NSMC task 6, the posterior parameter realisations created in NSMC task 5 will be run in the post-closure predictive models created in NSMC task 3 to produce predictions of COPC loads over time. Results from each predictive model will be similar to one of the curves on the horsetail plot depicted in.

For the last NSMC task, INTERA will examine the horsetail plots for all predictive models over time and combine them into total COPC loads at times of interest. INTERA will also compile the results into the formats needed by ERA to assess potential impacts.

The predicted total COPC loads from groundwater over time cannot be directly compared to an indicator of environmental impact. The predicted COPC loads will be used to assess potential impacts for threshold COPC concentrations in creek surface water through integration with the Ranger Surface Water Model currently undergoing update. The total COPC loads at a chosen probability level for selected times from the groundwater uncertainty analysis would be used as inputs to a surface water model of the creeks.

5.4.3.11 Drilling and installation of monitoring bores in the waste rock stockpiles

During December 2018 and January 2019 ERA undertook a hydrogeological drilling program to drill and construct 9 monitoring bores in various locations through the existing waste rock stockpiles at the Ranger Mine. The objective of the monitoring bores was to support the understanding of source concentrations of COPCs from the waste rock stockpiles to inform groundwater modelling being undertaken by INTERA. (Section 5.5.2.6)

Drilling of the bores was undertaken by J and S Drilling services, with hydrogeological site support provided by INTERA (SP_OB_PL01 through SP_OB_PL03) and Coffey (SP_OB_PL04 through SP_OB_PL09). Following completion of drilling the bores were unable to be developed, a plan to develop the bores is currently being scoped for execution in the 2nd half of 2019.

Groundwater level and quality monitoring of these bores has commenced by the site water management team. Data obtained from monitoring will be used to inform the sitewide groundwater solute transport modelling being undertaken by INTERA for completion in 2020 (Section 5.5.2.10)

5.4.4 Surface water modelling

Over the decades following the creation of the post-mine final landform the site vegetation will mature, and in time the site is expected to largely merge in with the surrounding environment. However the buried tailings and waste rock resulting from the mining process will (with the effect of rainfall, runoff and groundwater movement over the coming millennia) lead to the gradual release of a range of COPCs into the environment. An assessment of the COPC loads likely to be released from the site over the next 10,000 years has been undertaken in a previous study.

The purpose of the surface water modelling is to assist with planning and supporting the approvals required to rehabilitate the minesite by providing estimates of the concentrations of nominated COPCs in receiving surface waters over a period of 10,000 years following the rehabilitation of the mine. The area of interest is the Magela Creek catchment, from the rehabilitated minesite down to Mudginberri Billabong.

A surface water model developed by Williams *et al.* (2013) was previously used to evaluate COPC reporting downstream of the Magela Creek and Gulungul Creek confluence after mine closure. This evaluation applied the surface water model in a PCSWMM model platform, which increased the original model functionality by using an industry standard, GIS compatible, model platform. The original model, developed for an earlier version of the final landform design, was updated to represent the current landform design (V5) and the whole of site conceptual model (INTERA 2016). In 2017 Water Solutions commenced a new, independently developed surface water model to predict the concentrations of COPCs in surface waters of the Magela Creek catchment over the next 10,000 years. The model development was completed in 2020. Further updates are planned to the Water Solutions developed surface water model (Section 5.5.2.11) to include updated solute loadings from groundwater solute transport modelling currently being undertaken by INTERA (Section 5.5.2.10). Results will be detailed in future MCP.

Solute transport modelling (INTERA 2016) has indicated that rainfall entering the waste rock cover will influence solute egress, with 10 percent recharge of the groundwater-shed being from rainfall (INTERA 2016). Furthermore, higher source strength concentrations of COPCs in the waste rock landform predicted to occur between years 50 to 270, and ceasing after year 270, is also expected to influence solute egress. Over the long term (270 to 10,000 years), solute generation will involve groundwater reacting with waste rock, and mixing with slow egress of buried tailings source load some 5,500 years after mine closure. These source terms were predicted by INTERA (2016), and were used in the surface water model. The source terms and solute transport modelling is currently undergoing significant update which when completed will supersede the values and predictions reported in INTERA (2016). Details on this update are provided in Section 0.

The following sections present the surface water modelling development for solute egress modelling from the rehabilitated minesite. The configuration, calibration and simulation of the Ranger Surface Water Model (RWSM) has been undertaken in four major stages.

1. RSWM was configured and calibrated to simulate flow in the study area
2. the RSWM was then configured and calibrated to simulate water quality in the study area
3. the daily site loading time series were developed, based on estimated groundwater discharges to the surface water system, to represent the expected discharge of COPCs from the rehabilitated site over the next 10,000 years.
4. Five scenarios were simulated using the model; a No Mine scenario for reference, and scenarios at the Year 1, Year 20, Year 270 and Year 10,000 time horizons after mine closure. A set of probabilistic statistics have been developed describing flow and COPC concentrations for the 18 modelled COPCs at five key output locations upstream and downstream of the mine on Gulungul and Magela Creeks (GS28, End RPA, GS12, GCLB and GS18) and also including Coonjimba, Georgetown, Gulungul and Mudginberri Billabongs (Figure 1).

ERA is in the process of undertaking further updates to the RSWM. This updated information will be included in the next iteration of the MCP. More information is provided below and current supporting study information in provided in Section 5.5.2.11

5.4.4.1 Flow configuration and calibration

Key characteristic of the flow configuration and calibration of the RSWM are summarised below:

- The study area was subdivided into 15 subcatchments based on the creek network, gauging stations and major points of interest, with the key points of interest and subcatchments in the central part of the model shown on Figure 5-67 Key RSWM study area locations, Water Solutions (2020)
- Daily streamflow estimates were derived from data recorded at five key gauging stations, GS28, GS01, GS09, GS12 and GS18 (Figure 5-67), and used as the key

recorded time series against which the model flows were calibrated. The available periods of record varied from 8 to 47 years, with all recorded data being in the period 1971 to current.

- 129 years of daily rainfall estimates were obtained from the SILO database for each of the 15 sub-catchments, and 129 years of daily evaporation estimates were derived based on recorded American Class A pan evaporation data at the Jabiru Airport weather station.
- Rainfall and evaporation estimates were converted to runoff using the AWBM rainfall runoff model, with low flow losses added to ensure that dry seasons were adequately simulated.
- Reach transmission losses were included to simulate losses from flow as it travels along the creek channels included in the model.
- Channel routing, using the Watershed bounded network model (WBNM) routing methodology, was included to simulate the attenuation of flow as it travels along the modelled creeks.
- Three backwater billabongs (Georgetown, Coonjimba, and Gulungul Billabongs) were included in the model, with the focus on matching their behaviour over the dry season. The backwater billabongs were positioned to accept inflow from their own sub-catchment and backflow from Magela Creek, with a low flow bypass included for low level Magela Creek flows. Storage curves were derived for each billabong based on available survey data, and seepage rates were estimated based on calibration to available level records over the dry season.
- Three first flush channel storages were included in the model upstream of Mudginberri Billabong, to provide a reasonable match to the average timing of first flows into the billabong.
- One named on-line billabong was included in the model, Mudginberri Billabong, at the downstream end of the study area. A storage elevation-volume-area curve was derived for Mudginberri Billabong based on available survey data, and a spillway rating curve was developed based on the rating curve used for GS18. A conceptual groundwater/side storage was included in parallel with Mudginberri Billabong that absorbs a portion of large inflows in the first part of the wet season and provides a better match to the recorded levels over the wet season.

The flow calibration was evaluated using a range of statistics and plots, including annual statistics, average monthly flow plots, daily flow exceedance plots, billabong levels and daily flow plots. Three key plots are shown below to illustrate the calibration achieved: Figure 5-68 shows the mean monthly flows at GS28, on Magela Creek upstream of the mine, demonstrating that the model is matching the typical wet - dry seasonal pattern of flows. Figure 5-69 shows the daily flow exceedance plot at GS09, on Magela Creek next to the mine, demonstrating that the model is providing a good match to recorded flow rates across the flow regime. Figure 5-70 shows the modelled and recorded levels in Mudginberri Billabong (GS18), demonstrating a good match to recorded water levels at the downstream end of the model.

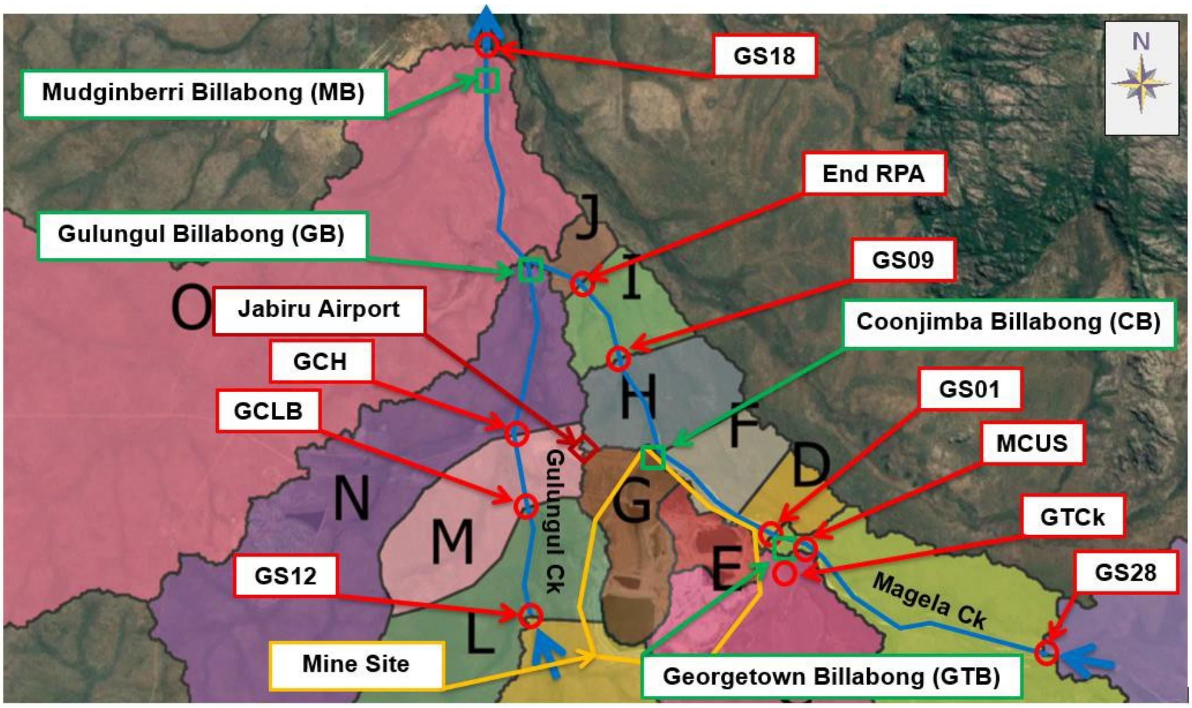


Figure 5-67 Key RSWM study area locations, Water Solutions (2020)

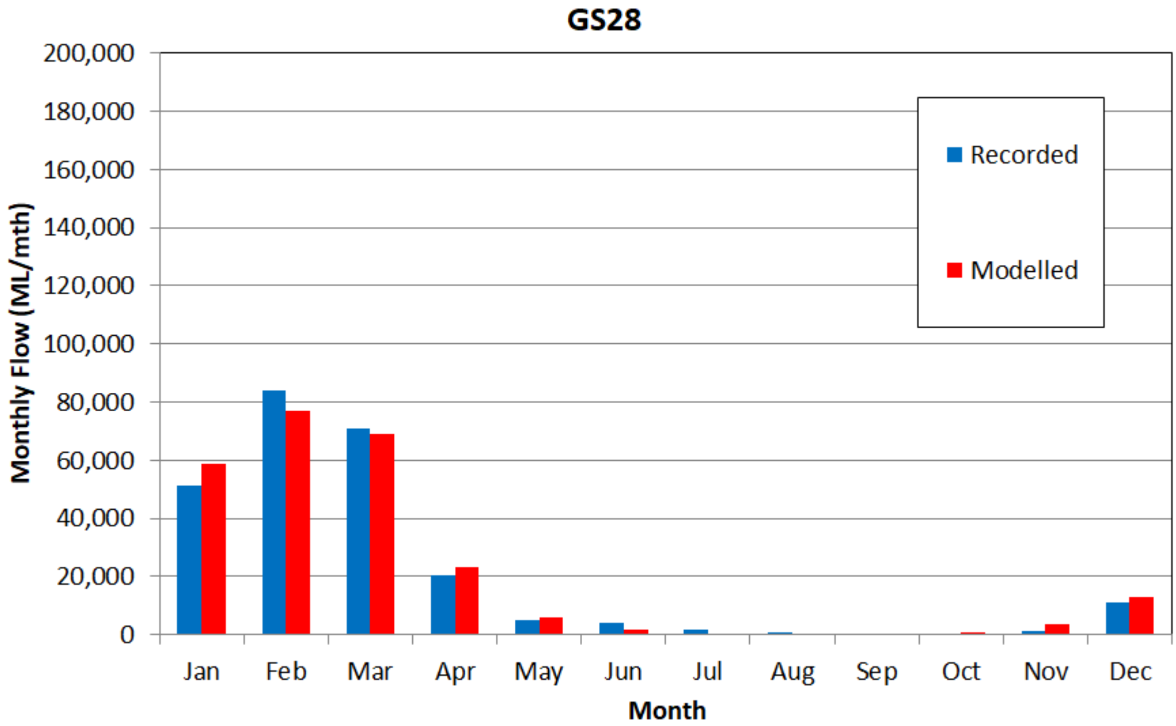


Figure 5-68 RSWM mean monthly flow - GS28, Water Solutions (2020)

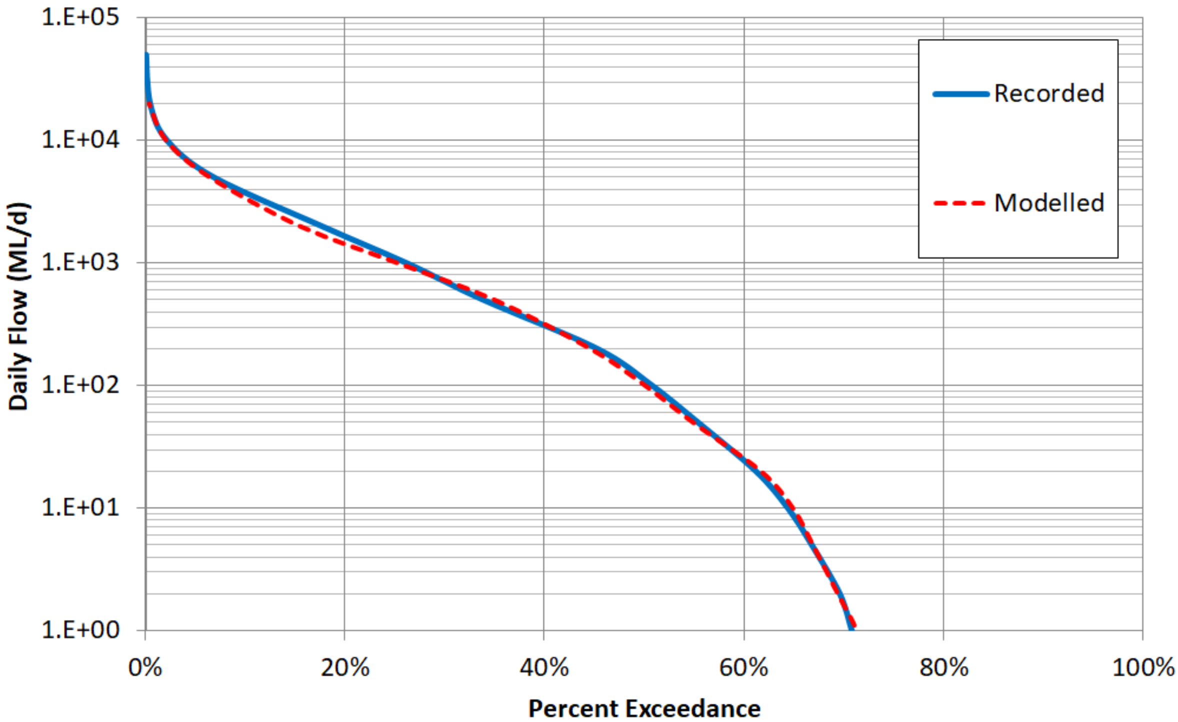


Figure 5-69 RSWM daily flow exceedance - GS09, Water Solutions (2020)

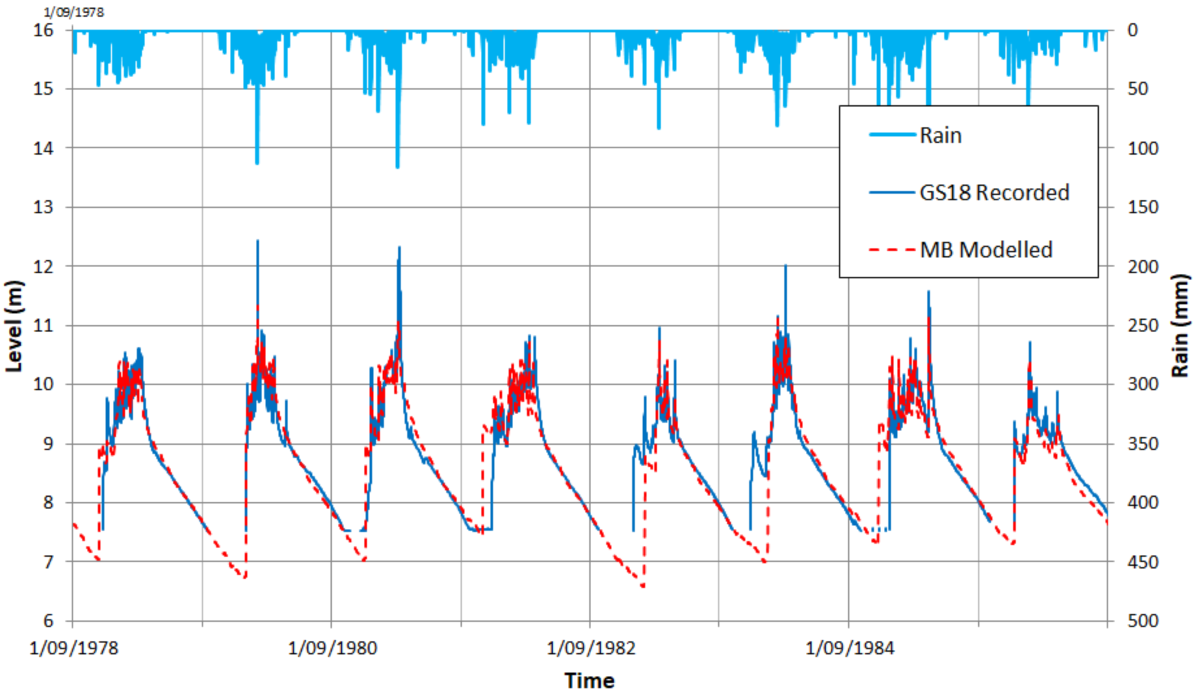


Figure 5-70 RSWM Mudginberri Billabong storage levels, Water Solutions (2020)

5.4.4.2 Water quality configuration and calibration

Key characteristics of the water quality configuration and calibration of the RSWM are summarised below:

18 COPC were modelled, as listed in The last element required in the configuration and calibration of the model was to estimate the 129 year daily time series of TSS loads for the site. TSS loads are expected to peak in Y1 and then settle down to background levels by Y20 with the growth of vegetation and the consolidation of material at the site.

- Table 5-27
- COPCs were assumed to behave conservatively in flow, i.e. conservation of mass applies.
- The derivation of initial estimates of natural catchment loading was based on a review of previous research
- Recorded water quality data were available for 10 locations in the study area, obtained from a range of sources including ERA, the Supervising Scientist and the NT Government. The available periods of record varied from a single recorded point for

some COPCs at some sites, up to many years of data, with all recorded data being in the period 1971 to 2018.

- The model was configured with the initial estimates of natural catchment loads and the results reviewed against the available data. Based on this review a suite of six natural runoff water quality relationships were developed:
  - Flat Concentration,
  - First Flow,
  - First Event,
  - Exhaustion,
  - Flat Load
  - a flow vs concentration rating curve approach.

The developed suite of relationships was applied, singly or in concert, to each COPC iteratively until an adequate calibration was achieved. The resultant relationships and key parameters are summarised in The last element required in the configuration and calibration of the model was to estimate the 129 year daily time series of TSS loads for the site. TSS loads are expected to peak in Y1 and then settle down to background levels by Y20 with the growth of vegetation and the consolidation of material at the site.

- Table 5-27 and Table 5-28.

The recorded data available for the water quality calibration tended to be widely scattered, of varying accuracy, and with extensive data at detection limits, which meant that it was difficult to develop summary statistics or plots without introducing bias. Thus the water quality calibration was conducted based on review of time series plots of modelled and recorded data.

5.4.4.3 Derivation of site loading time series

With the flow and natural water quality processes in the model well established through the flow and water quality calibration summarised above, one further task was required before the model simulations could be run and assessed - To estimate the additional COPC loads likely to come from the rehabilitated minesite over the specified10,000 year period.

Four key time horizons within the 10,000 period were selected, Y1, Y20, Y270, and Y10,000, each representing a period of time when peak delivery of COPCs is expected to be generated by at least one of the rehabilitated mine sources.

Average annual estimates of COPC loads at the four nominated time horizons were derived from previous studies by INTERA for all COPCs except TSS. A summary of the derived total site load for each COPC is provided in the table below (Table 5-29)

These average annual estimates were disaggregated to daily values over the 129 year simulation period using a method based on typical groundwater contributions to the surface water system, based on advice from INTERA. Figure 5-71 below provides a sample of one of the daily site loading traces developed using the determined methodology (for Mg at the Corridor Ck site loading location), and Figure 5-72 provides an appreciation of the annual variation in COPC loading resulting from the developed methodology.

The last element required in the configuration and calibration of the model was to estimate the 129 year daily time series of TSS loads for the site. TSS loads are expected to peak in Y1 and then settle down to background levels by Y20 with the growth of vegetation and the consolidation of material at the site.

Table 5-27 RSWM Natural runoff water quality relationships parameters, Water Solutions (2020)

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 date 15 January
Uranium	U	• Exhaustion - 4E-5 mg/L, end date 31 August
Ammoniacal Nitrogen	NH3-N (or TAN)	• 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	Ra226	• Flat Concentration – 60E-12 mg/L • First Event – 120E-12 mg/L
Polonium	Po210	• Flat Concentration - 0.031E-12 mg/L • First Event - 0.037E-12 mg/L
Total Suspended Solids	TSS	• Exhaustion – 1.5 mg/L, end date 31 August • Flow v Concentration, see Table 2

Table 5-28 RSWM TSS flow vs concentration relationship, Water Solutions (2020)

Flow (ML/d/ha)	TSS Concentration (mg/L)
0	0
1.6E1	0
1.6E2	1
1.6E3	5
1.6E4	35
1.6E5	50
1.6E6	50

Table 5-29 Source loads at time horizons - total site loads, Water Solutions (2020)

COPC Description		Average Annual Load (kg/a)			
Name	Symbol	Y1	Y20	Y270	Y10000
Magnesium	Mg	2.74E+04	1.38E+05	1.51E+05	7.12E+04
Calcium	Ca	4.60E+03	2.26E+04	2.72E+04	1.25E+04
Nitrate	NO3-N	1.51E+02	6.82E+02	9.43E+02	4.16E+02
Manganese	Mn	1.08E+03	1.04E+04	4.21E+03	2.99E+03
Uranium	U	1.01E+02	4.58E+02	6.30E+02	2.78E+02
Ammoniacal Nitrogen	NH3-N (or TAN)	5.36E+02	4.14E+03	1.62E+03	1.19E+03
Orthophosphate	PO4-P	1.91E+01	8.72E+01	1.18E+02	5.24E+01
Copper	Cu	1.51E-01	1.07E+00	3.91E-01	3.02E-01
Lead	Pb	8.96E-03	3.16E+00	5.14E-01	6.12E-01
Cadmium	Cd	1.23E-02	8.72E-02	3.19E-02	2.47E-02
Iron	Fe	2.30E+01	4.67E+03	7.73E+02	9.10E+02
Zinc	Zn	7.84E-01	1.34E+01	3.27E+00	3.07E+00
Chromium	Cr	3.70E-02	2.60E-01	9.54E-02	7.37E-02
Vanadium	V	5.04E-03	3.54E-02	1.30E-02	1.00E-02
Nickel	Ni	6.16E-02	6.90E+00	1.18E+00	1.36E+00
Radium	Ra226	4.77E-06	2.30E-05	2.93E-05	1.32E-05
Polonium	Po210	1.18E-10	8.33E-10	3.04E-10	2.35E-10

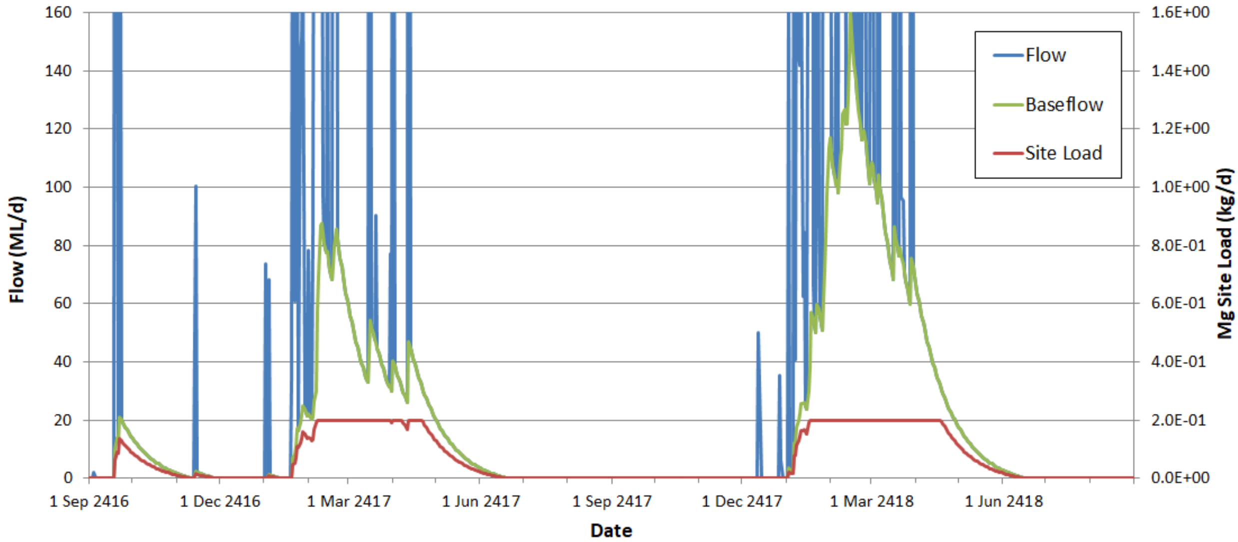


Figure 5-71 Example site loading trace (Corridor Creek - Magnesium), Water Solutions (2020)

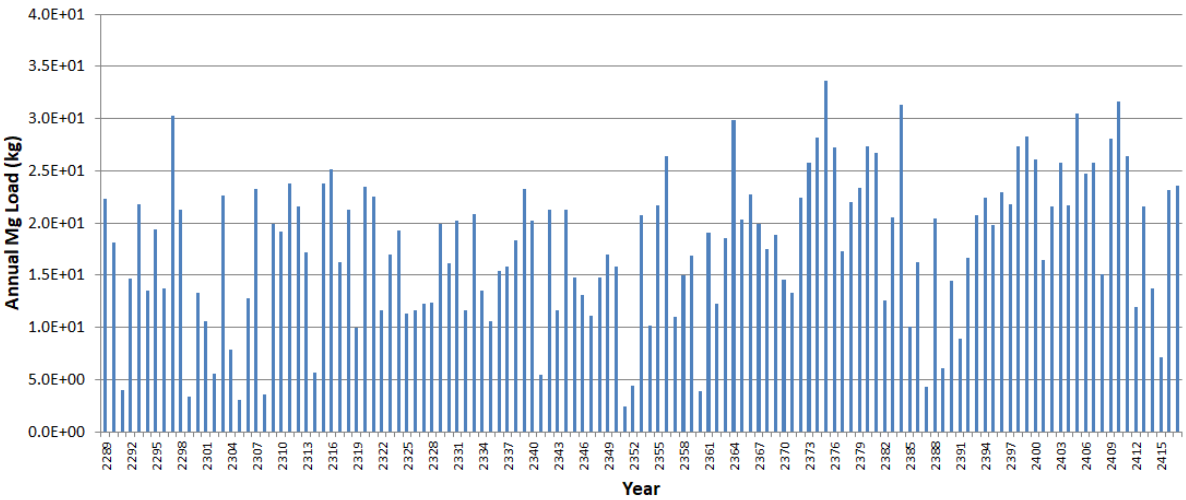


Figure 5-72 Example Annual COPC loading pattern (Corridor Creek - Magnesium), Water Solutions (2020)

Based on suspended sediment data collected from the trial landform at the mine, a Y1 average annual rehabilitated catchment TSS concentration of 120 mg/L was adopted. The derived natural catchment TSS concentration rates were scaled up to match this average annual concentration. Figure 5-73 below provides a sample of the derived TSS site loading concentrations, showing that the estimated rehabilitated site TSS discharge is significantly higher than estimated natural catchment discharge.

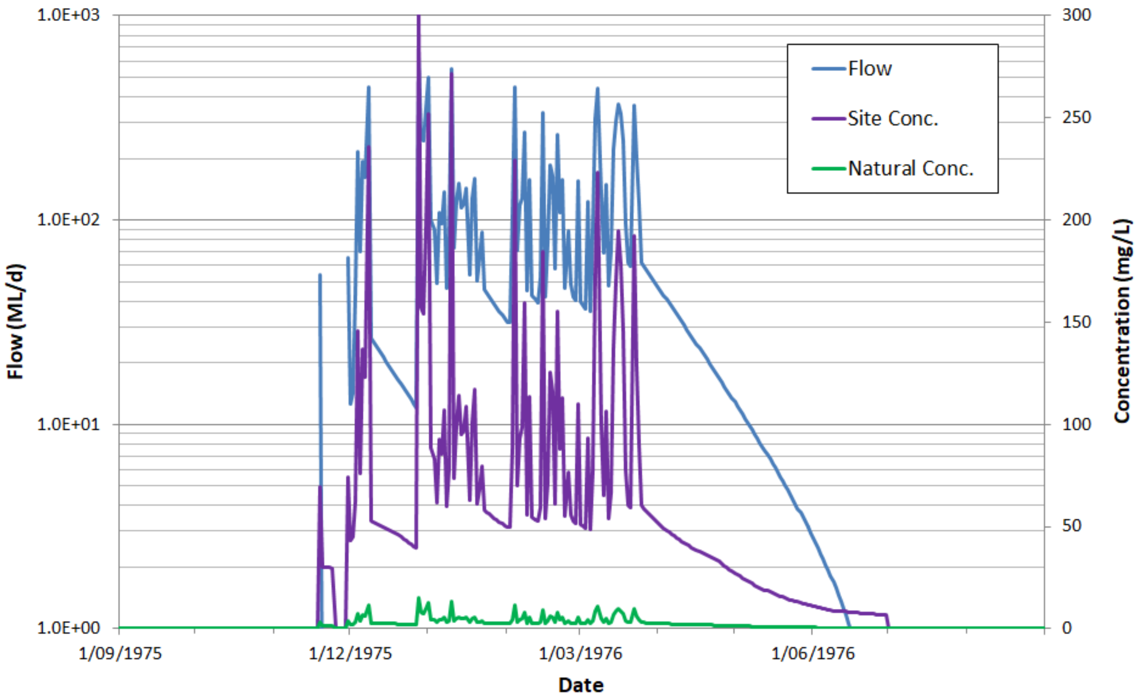


Figure 5-73 Sample site TSS loads, Water Solutions, (2020)

Figure 5-74 below provides an appreciation of the variation in annual TSS loading over the 129 year simulation period that results from the application of the developed methodology. The annual TSS loads vary substantially, with the largest TSS discharge associated with the 2006-7 water year, the year that contains the largest flood on record.

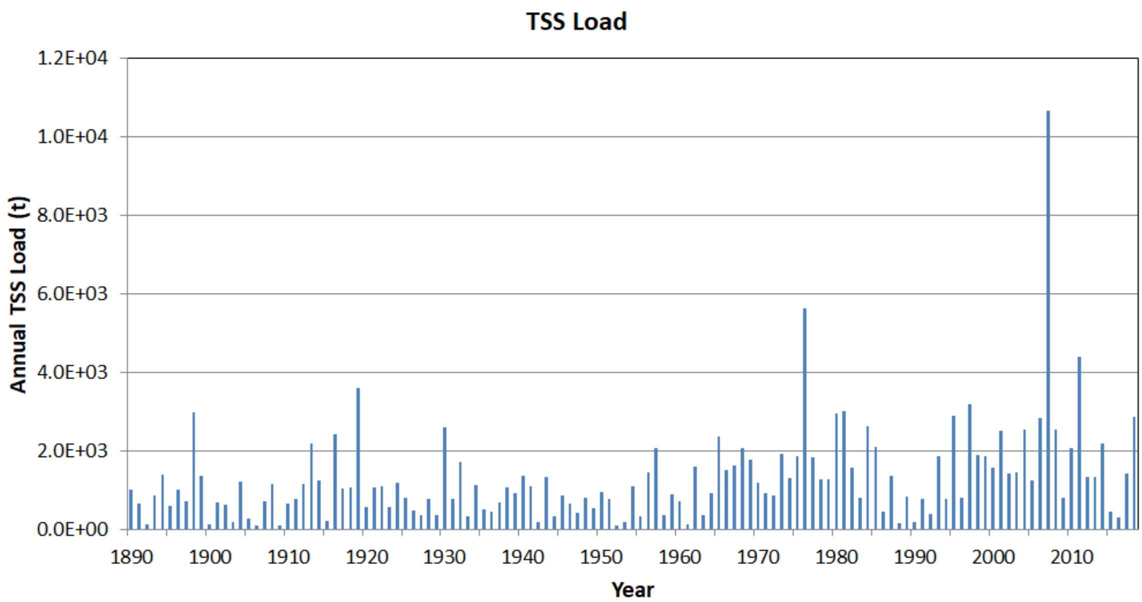


Figure 5-74 Annual TSS loading Pattern, Water Solutions (2020)

5.4.4.4 Simulations

Five scenarios were simulated using the configured and calibrated model. The first modelled scenario is the case used for model calibration, referred to as the 'No Mine' case as it represents just the loads from natural catchment sources, that is, no loads are included from the minesite. (This scenario has been included in the results to assist in understanding the results for the other four scenarios.) The other four scenarios are the selected four time horizons Y1, Y20, Y270 and Y10000.

A standard set of results at five key reporting locations (GS28, GS12, End RPA, GCLB and GS18 (Figure 5-67) has been developed for each scenario in order to provide a concise understanding of the results produced by the model. Other reporting locations include billabongs as per Figure 5-67 This includes statistics on the model flow rates, COPC mass loads and COPC concentrations.

The mean annual flow at each key location in all scenarios is shown in the table below. All five scenarios have the same flows, with the only difference between the five scenarios being the site COPC loads that are applied.

Table 5-30 shows that the mean annual flow increases from GS28 to End RPA and from GS12 to GCLB, reflecting the inflows from the catchments between these locations. However the mean annual flow at GS18 is less than the combined mean annual flow at End RPA and GCLB. This reduction is due to the considerable volume of breakouts and losses in the lower reach of Magela Creek above Mudginberri Billabong. In all, some 39% of the tributary inflows to the model are lost to surface flows in the main channel of Magela Creek, either via seepage, evaporation, breakouts or storage effects in the model.

Table 5-30 Mean annual surface water flow, Water Solutions (2020)

Location	Mean Annual Flow **(ML/a)**
GS28	1.97E+05
End RPA	2.42E+05
GS12	2.09E+04
GCLB	2.79E+04
GS18	2.26E+05

Figure 5-75 shows the mean monthly flows over the 129 simulated years at the five key locations. This figure shows the expected wet – dry season pattern. Monthly flows tend to increase from GS28 to End RPA and from GS12 to GCLB, but flows at GS18 are generally less than the sum of the flows at End RPA and GCLB. A monthly shift can also be observed - flow at GS18 is considerably less that upstream in the early wet season, but is comparatively higher late in the wet season, reflecting the filling up of the various billabongs, bed sands, floodplain stores, etc., allowing more of the upstream flow to make it past Mudginberri Billabong later in the wet season.

Figure 5-76 shows the daily flow exceedance over the 129 simulated years at the five key locations. This figure shows that GS12 and GCLB are fairly similar, being relatively close together, and that End RPA and GS18 are similar, with End RPA being physically located much closer to GS18 than to GS28.

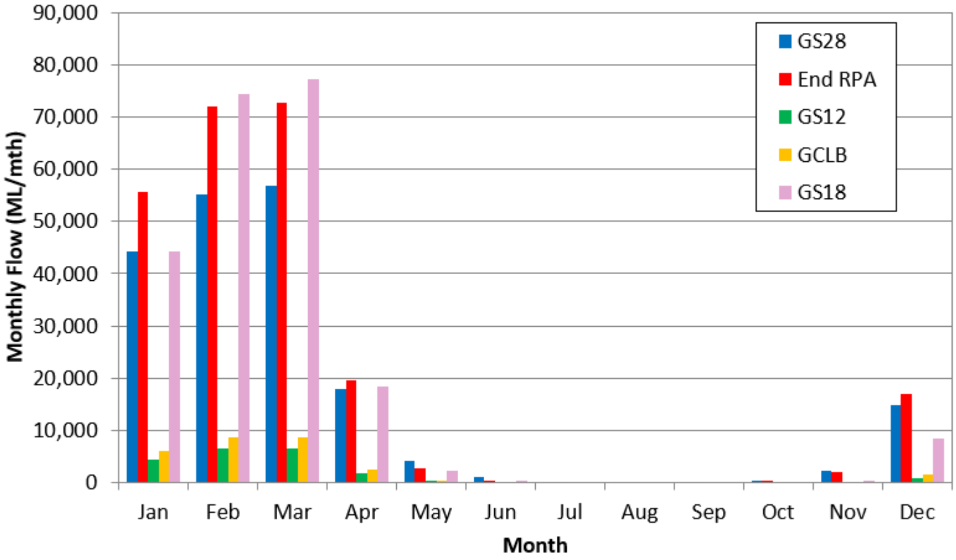


Figure 5-75 Mean monthly flows, Water Solutions (2020)

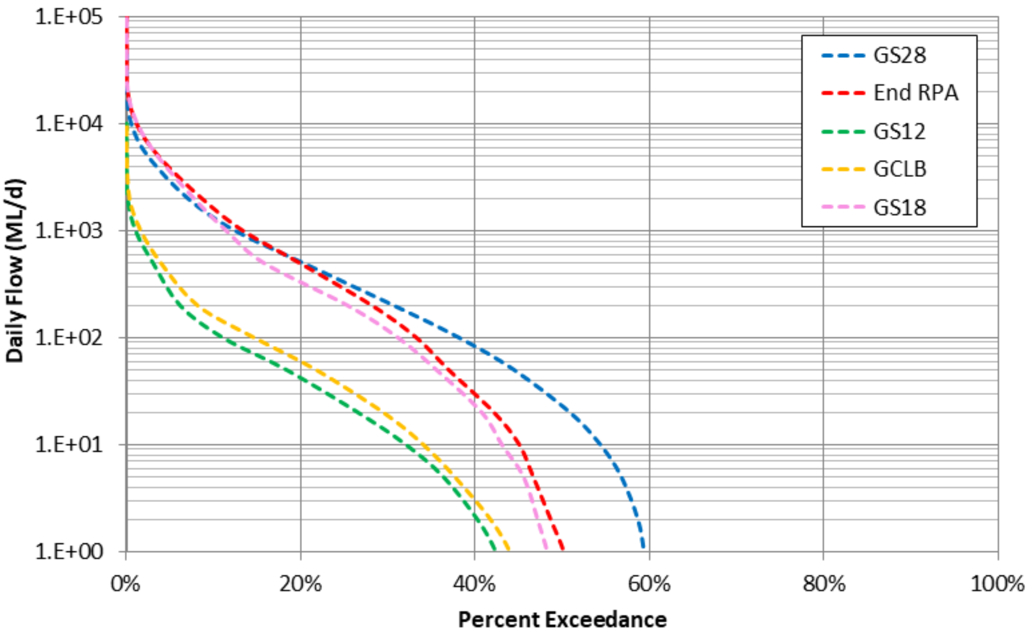


Figure 5-76 Daily flow exceedance, Water Solutions (2020)

Table 5-31 shows that site loads for some COPCs are of a similar order to natural loads (e.g. Mg), while others are much larger than natural loads (e.g. U) or much smaller than natural loads (e.g. Cu).

A number of potential improvements or extensions to the model have been identified during the project, and the model provides results that allows future work to more closely focus on areas of likely concern. The results produced by the RWSM are considered preliminary by ERA and not being used for evaluation against closure criteria. The RSWM model is currently undergoing further updates to address key stakeholder feedback, address improvements identified through development of the model, and included updated post closure solute transport loadings predictions (Section 5.5.2.11). Results from the RSWM update will be provided in the MTC Pit 3 closure application.

Following completion of the update to the RSWM in late 2020, multiple projects, including assessments of sediment accumulation, human diet and health, ecosystem vulnerability, release water pathways and cumulative aquatic risks can be conducted to assess if water quality closure criteria/objectives will be met. This will include additional studies such as assessing the traditional diet, risks associated with the predicted water quality, and predictions of accumulation of uranium into sediments. This will also inform decisions on what is as low as reasonably achievable (ALARA) on the RPA. Updates to the RSWM will be provided in future versions of the MCP.

Table 5-31 Mean annual COPC loads in model inputs, Water Solutions (2020)

COPC Description		Natural Load (kg/a)	Site Load (kg/a)			
Name	Symbol		Y1	Y20	Y270	Y10000
Magnesium	Mg	1.29E+05	2.74E+04	1.38E+05	1.51E+05	7.12E+04
Calcium	Ca	9.29E+04	4.60E+03	2.26E+04	2.72E+04	1.25E+04
Nitrate	NO3-N	2.36E+03	1.51E+02	6.82E+02	9.43E+02	4.16E+02
Manganese	Mn	2.28E+03	1.08E+03	1.04E+04	4.21E+03	2.99E+03
Uranium	U	1.05E+01	1.01E+02	4.58E+02	6.30E+02	2.78E+02
Ammoniacal Nitrogen	NH3-N (or TAN)	1.85E+03	5.36E+02	4.14E+03	1.62E+03	1.19E+03
Orthophosphate	PO4-P	9.99E+02	1.91E+01	8.72E+01	1.18E+02	5.24E+01
Copper	Cu	7.36E+01	1.51E-01	1.07E+00	3.91E-01	3.02E-01
Lead	Pb	9.20E+00	8.96E-03	3.16E+00	5.14E-01	6.12E-01
Cadmium	Cd	9.20E+00	1.23E-02	8.72E-02	3.19E-02	2.47E-02
Iron	Fe	3.79E+04	2.30E+01	4.67E+03	7.73E+02	9.10E+02
Zinc	Zn	1.47E+02	7.84E-01	1.34E+01	3.27E+00	3.07E+00
Chromium	Cr	1.10E+02	3.70E-02	2.60E-01	9.54E-02	7.37E-02
Vanadium	V	1.29E+02	5.04E-03	3.54E-02	1.30E-02	1.00E-02
Nickel	Ni	3.68E+02	6.16E-02	6.90E+00	1.18E+00	1.36E+00
Radium	Ra226	2.42E-05	4.77E-06	2.30E-05	2.93E-05	1.32E-05
Polonium	Po210	1.19E-08	1.18E-10	8.33E-10	3.04E-10	2.35E-10
Total Suspended Sediment	TSS	1.86E+06	1.19E+06	0.00E+00	0.00E+00	0.00E+00

5.4.5 Aquatic ecosystem assessment & framework development

ERA contracted BMT Ltd. to define a process to interpret modelling results against regulatory requirements. The broad aim of the project is 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.

The project is in its third phase. The first two phases involved review of existing information and stakeholder meetings to identify preliminary indicators for all primary environmental objectives and draft environmental and community values (ECVs) for different water types on and off the RPA (BMT WBM 2017, BMT 2018). More information on the supporting study in Section 5.5.2.16)

The third phase of the project developed a Vulnerability Assessment Framework (VAF) to aid the interpretation of modelling results, with a focus on the potential effects of magnesium on ECVs of the mine area.

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 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.

The VAF involved the following steps:

- identification of ECVs, including ‘key species’ that are important from biodiversity and cultural perspectives, as well as important habitats and other groups
- selection of a set of ecosystem components and processes based on the approach outlined in the 'National Framework and Guidance for Describing the Ecological Character of Australia’s Ramsar Wetlands’ (DEWHA 2008)
- development of conceptual models of key processes and linkages with ECVs
- preparation of conceptual diagrams to illustrate and summarise key ecological processes operating in the study area. The process diagrams provide a basis for examining potential timing of mining releases (i.e. exposure) and key biological processes in this project phase.
- assessment of the direct (i.e. toxicity) and indirect (i.e. food resources and habitats) sensitivity of ECVs to magnesium; (iv) assessment of the adaptive capacity of ECVs.
- consideration of sensitivity at the individual organism level, and how this translates to vulnerability at higher organisation levels (the local species population, assemblage, community/habitat and/or ecosystem level) as well as the capacity of biota to recover

Vulnerability is based on the consideration of following elements (De Lange *et al.* 2010, Weißhuhn *et al.* 2018):

- level of exposure to stressors – which will be predicted by the surface water modelling project
- sensitivities to stressors such as magnesium, 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 recover following a perturbation, such as exposure to a contaminant. This is also known as resilience or adaptive capacity

The level of exposure will be predicted by the surface water modelling. Scoring matrices and descriptions were developed to categorise sensitivity and resilience. These were based on multiple information sources including ecotoxicology assessments and field studies, local and national literature, and expert elicitation from an independent expert panel.

The scoring of sensitivity and adaptive capacity for the selected ecosystem components was undertaken independently by the expert panel and project team. Scoring results were received in June 2019 and a draft report distributed to the expert panel in late 2019. Finalisation of the report is pending rescoring to include several new lines of evidence on magnesium effects produced by the SSB (draft summary received July 2020). Re-scoring of ecosystem sensitivity to magnesium is planned for Q3 2020 to provide information to inform the Pit 3 application.

5.5 Supporting studies

ERA, in collaboration with stakeholders, has prepared a list of Key Knowledge Needs (KKNs) to address gaps within closure planning. Both ERA and the SSB will implement the KKN projects, either independently or cooperatively depending on the project

The list of KKNs as updated in May 2020 is provided as Appendix 5.4

This section provides summaries of the closure supporting studies and is arranged into the overarching study areas below to align with the KKN themes where practical.

- Landform
- Water and Sediment
- Health Impacts of Radiation and Contaminants,
- Ecosystem establishment.

5.5.1 Landform

This section provides summaries of the completed studies relating to landform development.

KKN title	Project title
LAN2: Understanding the landscape-scale processes and extreme events affecting landform stability	Assessment of impact on stability of the rehabilitated landform from identified landscape-scale processes
LAN3: Predicting erosion of the rehabilitated landform	Rock Size Distribution on Pit 1 final landform
	Monitoring of Pit 1 Landform Shape, Stability and Consolidation
	Pit 1 Monitoring of Sediment Discharge

5.5.1.1 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.

Once the two mined-out pits have been backfilled with tailings and waste rock, the landform and surface cover will be built to the final approved 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 from 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 TSF walls and western edges of the southern and western stockpiles sit atop high ridgelines in the pre-mining landscape. These ridges form prominent features of the final landform and, combined with a reinstated ridgeline over Pit 1, restore catchment areas to close equivalents of their pre-mining form. Topography of the final landform is similar to the pre-mining landform; maximum elevation after consolidation increases from 38 metres pre-mining to a final landform maximum of 44 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). The final landform design described in McGovern (2006) continues to be revised to ensure that it takes into consideration changing stockpile material grades, volumes and locations.

The preliminary slope analysis performed on final landform version 5 (FLv5) 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 5 percent (Figure 5-77). A slope analysis was also completed as part of the erosion and sediment control design work. This showed slopes vary from about 1 in 30 (3 %) to 1 in 200 (0.5 %), with the larger catchments tending to have lower slopes, although this is not always the case. This has not changed significantly in the latest version of the final landform, FLv6.2 and it continues to meet the original design intent (Section 9.4.5).

Each version of the landform has been subjected to landform evolution modelling by the SSB to assess the performance of the landform against closure criteria. The landform evolution modelling undertaken by the SSB (Lowry & Saynor 2015) applied a modified version of the CAESAR-Lisflood landform evaluation model (Coulthard *et al.* 2002, Coulthard *et al.* 2013) to assess the geomorphic stability of the final RPA landform over timeframes ranging from decades to millennia.

The CAESAR-Lisflood is an enhanced version of the CAESAR landform evaluation model that had previously been used to assess the geomorphic stability of the Ranger Mine TLF. 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 5-78.

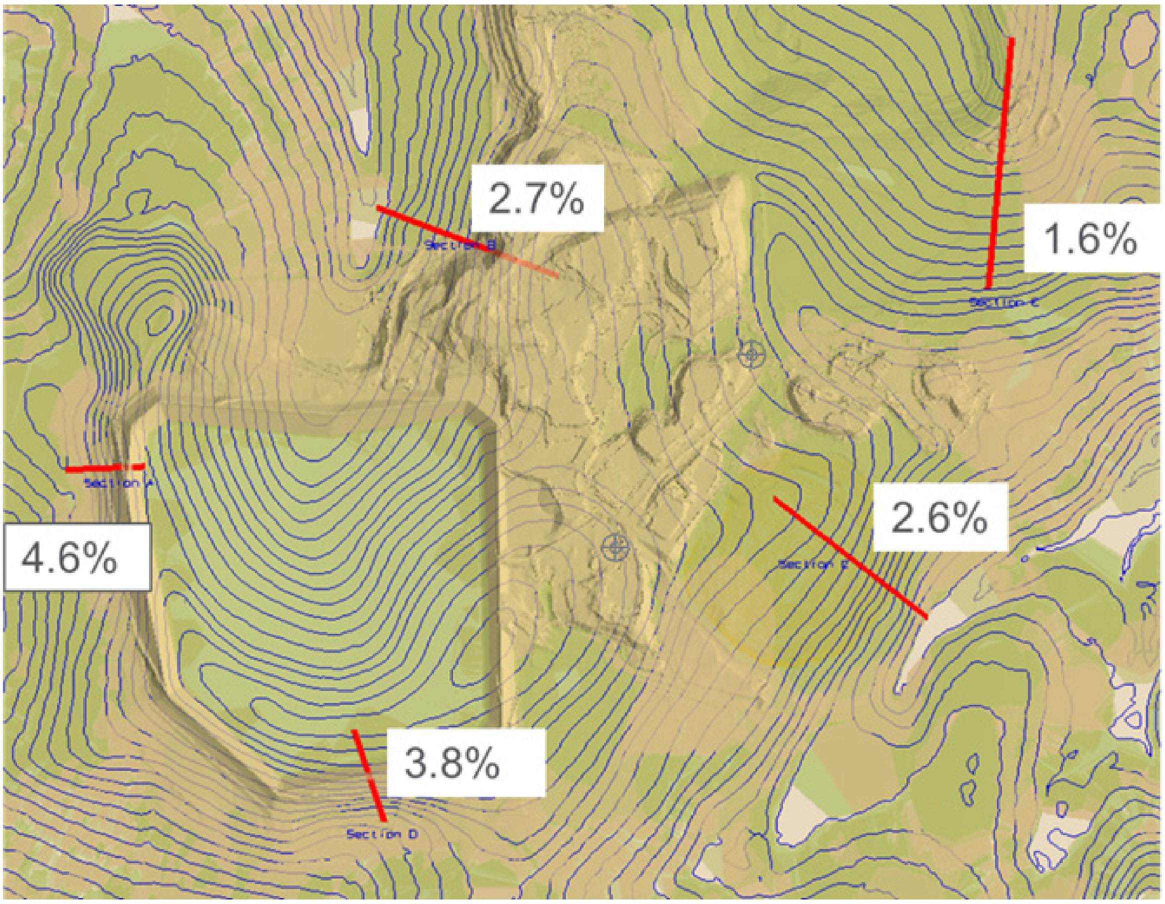


Figure 5-77: Preliminary slope analysis looking at the steepest slopes

The model has, to date, been conservative in nature, having only minimal vegetation on the surface for the entire 10,000-year period, and currently excludes any orthodox storm water and erosion control structures to reduce bedload yields. However, more recently the SSB has incorporated a grass cover layer.

The modelling conducted in 2013 on the fourth version of the landform (Lowry *et al*., 2013) identified a number of potential erosion issues across Pit 1 and Pit 3 tailings. The landform was subsequently redesigned to version five (FLv5) based on the results of this model and assessed by the SSB (Supervising Scientist 2016b). The SSB subsequently recommended in January 2016 (Supervising Scientist 2016b) that the landform design be modified to reduce the chance of deep gully formation, particularly in the Djalkmarra Creek and Corridor Creek catchments. The Supervising Scientist (2016b) put forth the following options for consideration:

- modification of the slopes within the affected catchments
- application of an armoured surface to sections of the catchment to make the surface more resistant to fluvial erosion and runoff
- armouring the toe of the landform in the area currently occupied by the road around the south-east edge of Pit 3

The study (Lowry & Saynor 2015, Supervising Scientist 2016b), predicted both the locations of gully formation and the broad scale erosion and deposition across the landform with long-term denudation rates being calculated. 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.

Modelled denudation rates after 10,000 years provided by the SSB are:

- Coonjimba: 0.05 mm per year
- Corridor Creek: 0.03 mm per year
- Djalkmarra Creek: 0.02 mm per year
- natural background: 0.01 – 0.04 mm per year

Predicted erosion for simulated periods of up to 10,000 years in the Corridor Creek and Djalkmarra catchments has been shown in Figure 5-79 and Figure 5-80, respectively. These modelled results indicated an exponential decline in erosion/gully formation, but also the potential formation of gullies up to 9 m deep in areas of the landform that are close to buried tailings. These will be the locations for the design of drainage channels and other erosion mitigations to minimise the potential impact on landform stability and revegetation success.

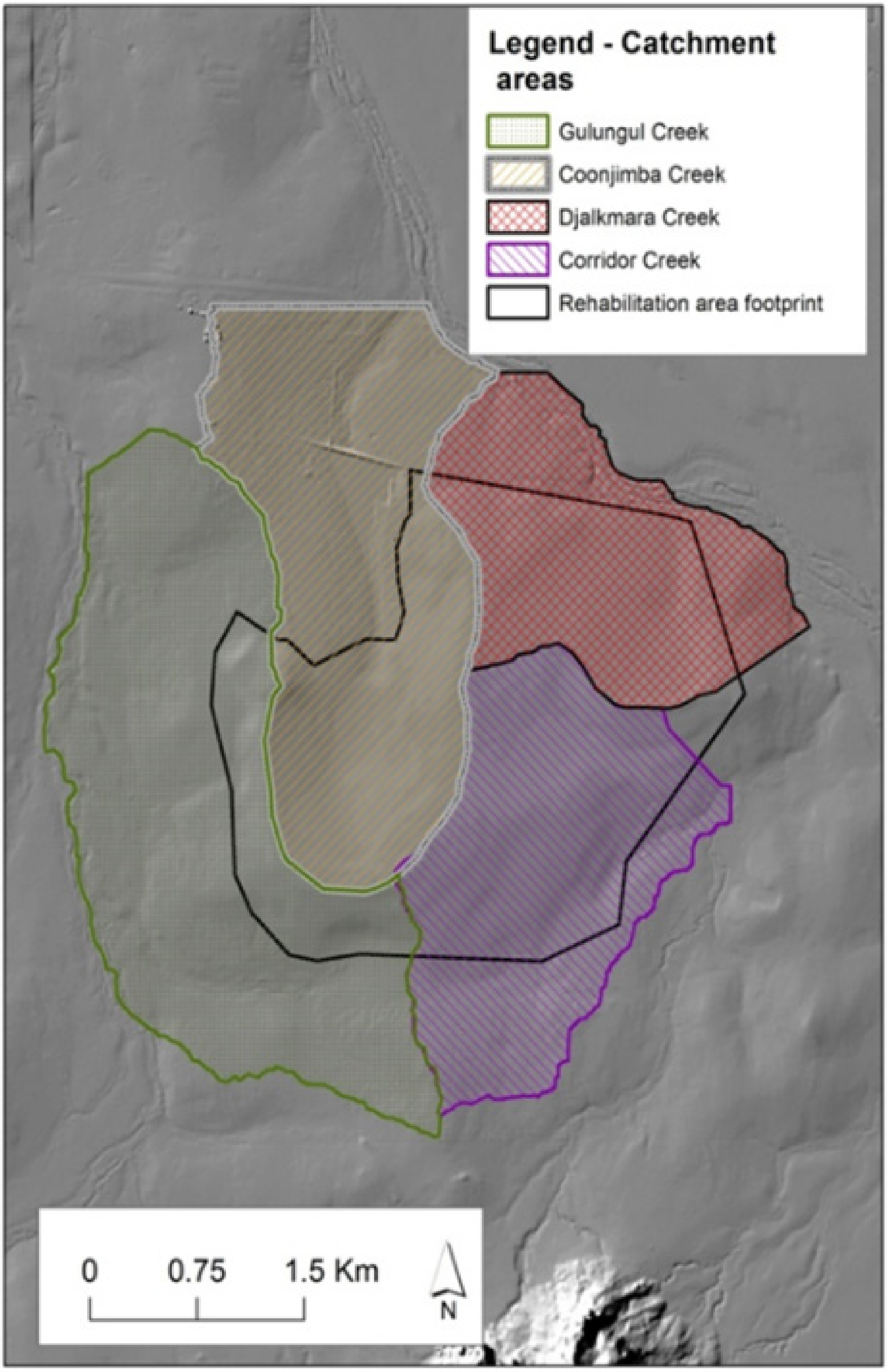


Figure 5-78: Catchment areas – Ranger Mine conceptual landform (Lowry & Saynor 2015)

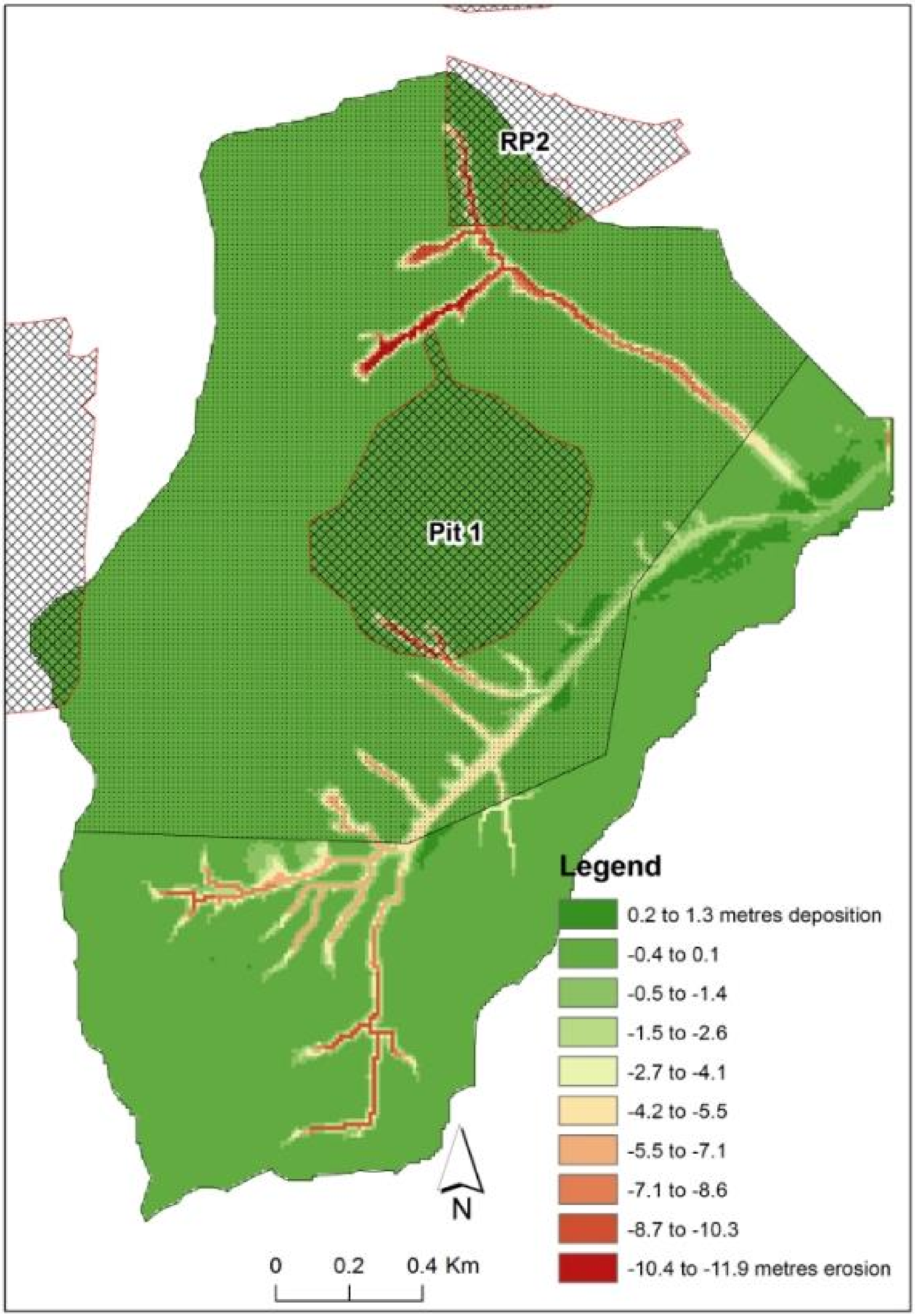


Figure 5-79: Corridor Creek catchment – extent of erosion/deposition zones after simulated period of 10,000 years (Supervising Scientist 2016d)

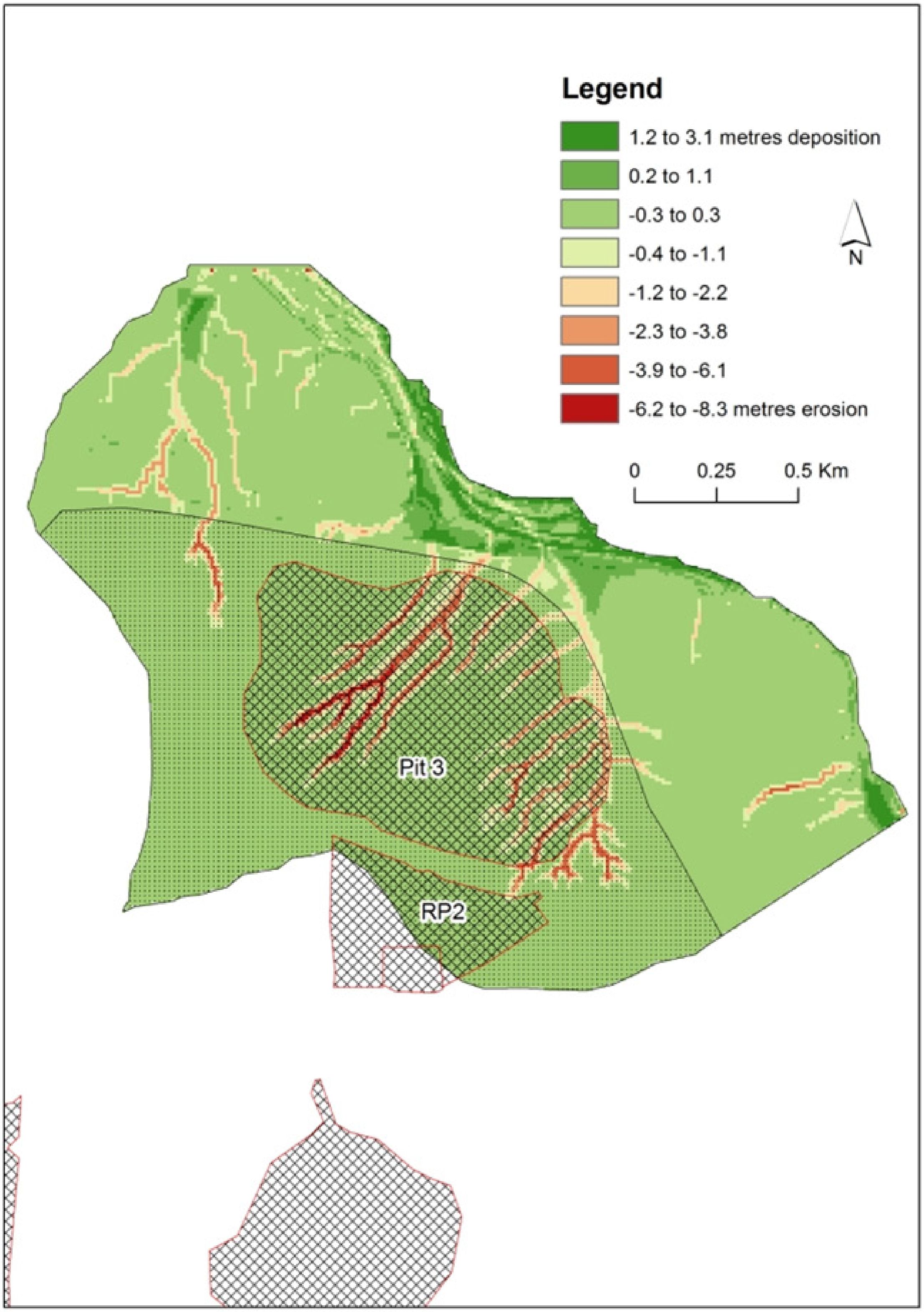


Figure 5-80: Djalkmarra catchment – extent of erosion/deposition zones after simulated period of 10,000 years (Supervising Scientist 2016c)

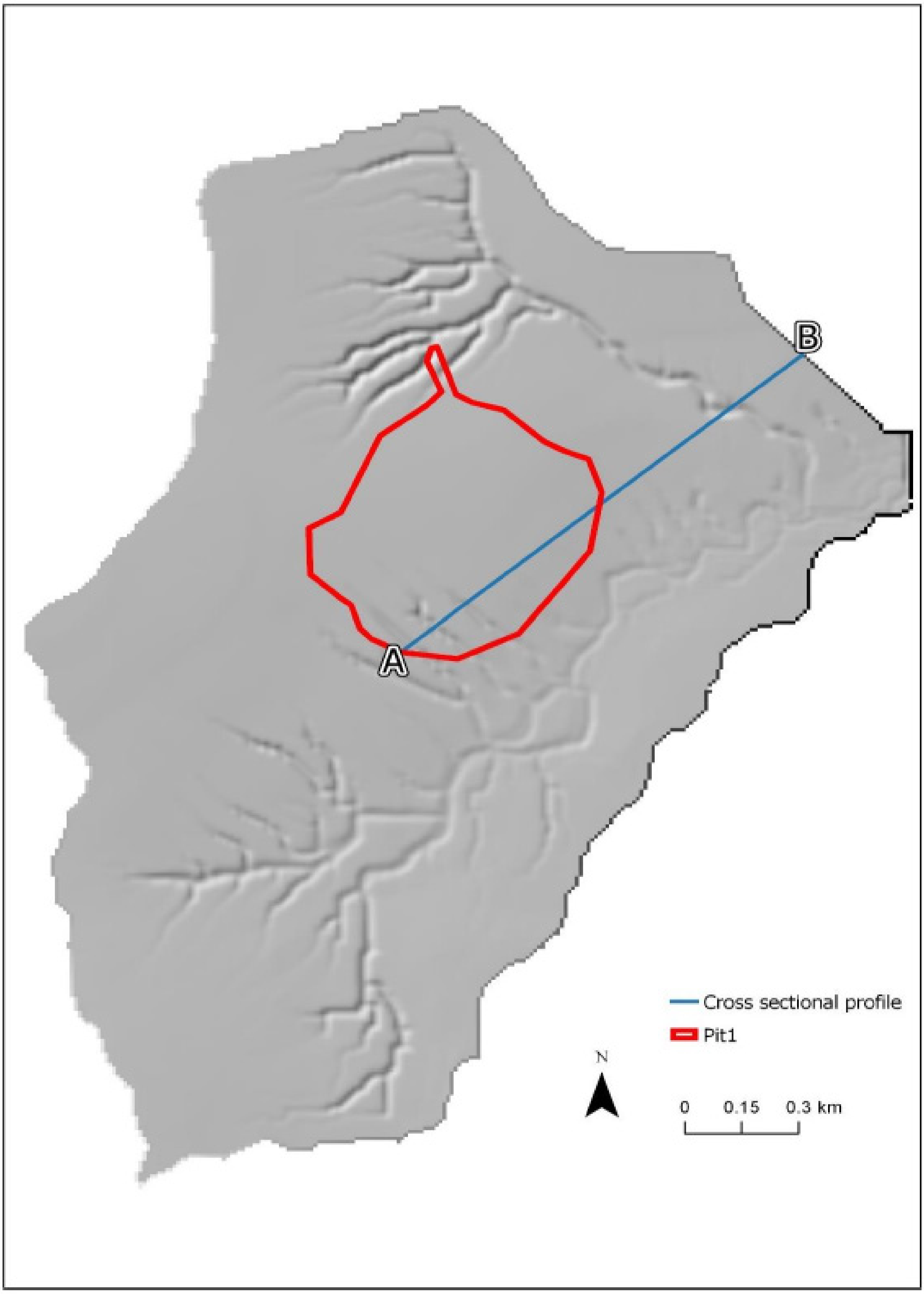


Figure 5-81 Surface of Corridor Creek catchment after a simulated period of 10,000 years under an extreme dry-rainfall, grass cover only scenario (Supervising Scientist 2019)

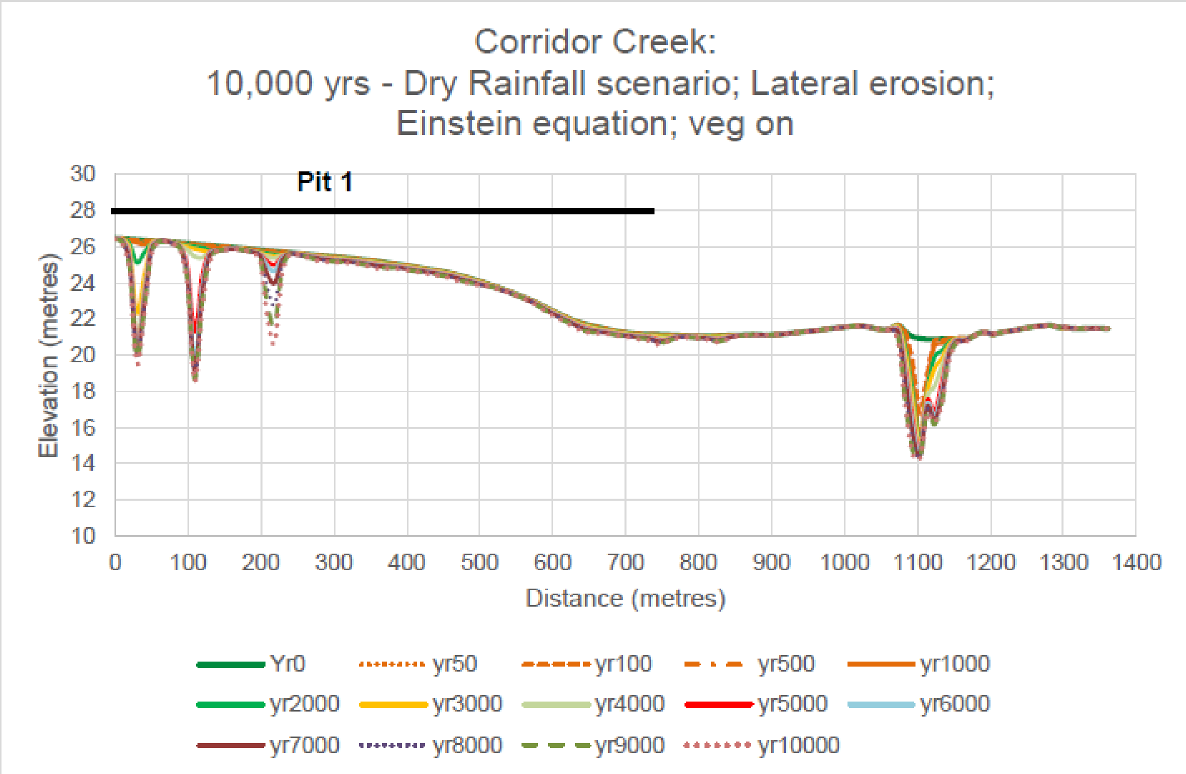


Figure 5-82 Profile across Pit 1 (extent of Pit 1 shown by black line) after a simulated period of 10,000years under an extreme dry-rainfall, grass cover only scenario (Supervising Scientist 2019)

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
- Based on the modelling and advice from the SSB, changes to the final landform design surface were made to address concerns in key areas and incorporated into the final landform version FLv6.2. This included the diversion of all major drainages away from the pits and areas identified in the modelling predictions. The DEM Version FLV6.2 was provided to the SSB in 2018 for assessment on the performance of selected catchments of the landform, using the CAESAR-Lisflood landform evolution model (LEM). The SSB conducted a number of simulations on the current FLV6.2 landform in order to assess, at an early stage, erosion characteristics over the Pit 1 catchment, and whether the landform is adequate for assessment of the final landform against closure criteria. The SSB provided their feedback in a memorandum dated 21 February 2019, with additional advice provided in Technical Advice #010 on 13 September 2019. The most recent advice provided by the SSB is summarised below.
- Initial simulations run up to 1,000 years across the Corridor Creek catchment indicated that gullies deep enough to expose tailings are unlikely to form across the surface of Pit 1 within a simulated period of 1,000 years. Subsequent simulations have since been run to model a range of scenarios in the Corridor Creek catchment for a simulated period of 10,000 years.
- Simulations of an extreme dry-rainfall scenario, over a 10,000-year period, predict several gullies with approximate depths of up to 8 metres may form across the southern edge of the Pit 1 surface with gullies at the deepest point at a depth of about 19mAHD. This simulation predicts that there remains up to 13m of waste rock between the bottom of the predicted gullies and the predicted tailing surface provided by settlement monitoring (Figure 5-81 and Figure 5-82). This scenario included the presence of grass cover, which serves to reduce the effect of erosion, but does not include the establishment of a full vegetation community.
- By applying an armoured surface to this same Pit 1 surface at the initiation of gully formation at year 1,000, it was found that further gully growth or formation was prevented within the subsequent 1,000 year simulated period (Figure 5-83).
- Annual denudation rates for the extreme dry-rainfall scenario of the Corridor Creek catchment were predicted fall into the range of background rates within 10,000 years, of 0.04mm/yr +/- 0.03 (Figure 5-84).

The SSB stated that additional rainfall scenarios are now being modelled, for periods up to 10,000 years, including extreme wet-rainfall scenarios. Further assessments are also required of the FLV6.2 landform outside of the Corridor Creek catchment, thereby identifying locations on the final landform may require additional mitigation such as surface armouring, to eliminate any significant gullying. Results of these simulations will be presented in subsequent versions of this MCP, once completed.

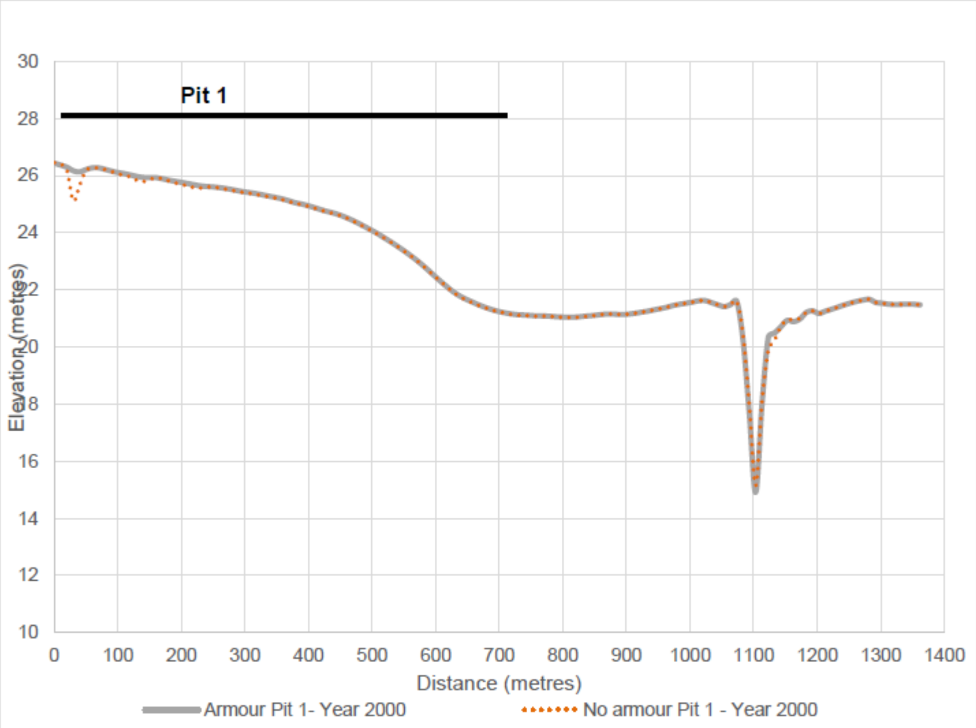


Figure 5-83 Effect of armour versus unarmoured surface on gully formation in the Corridor Creek catchment (Supervising Scientist 2019)

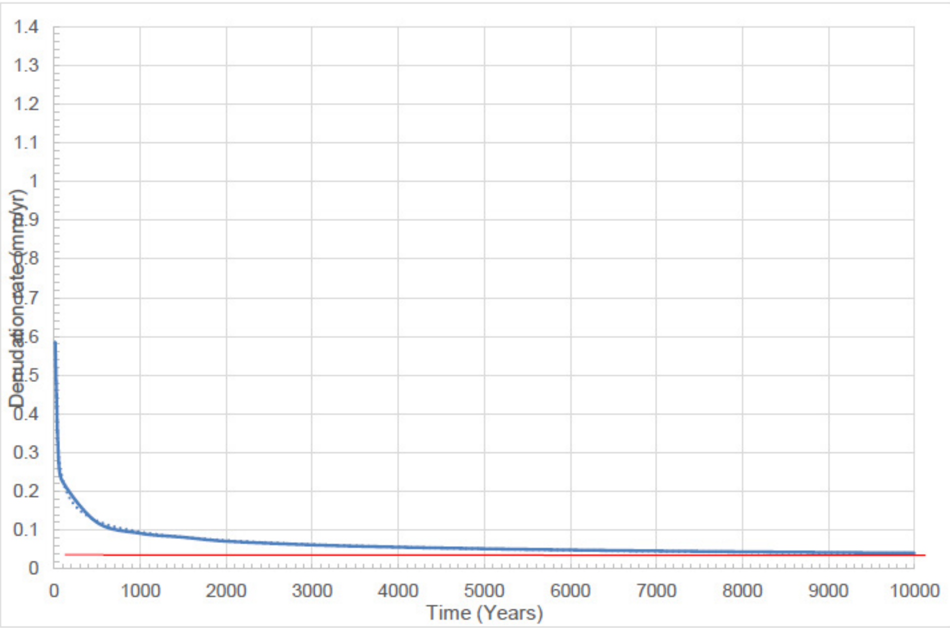


Figure 5-84 Modelled denudation rate over a simulated period of 10,000 years under an extreme dry-rainfall, grass cover only simulation. The red line represents the background denudation rate (Supervising Scientist 2019)

The results of the simulations to date provide a guide for future enhancements both to the landform design and to the landform evaluation model software. Existing results combined with the proposed work will provide increased confidence that the CAESAR-Lisflood model will be able to correctly predict the potential paths for evolution of a rehabilitated landform once it has been constructed.

The SSB has advised ERA that landform erosion modelling results are indicative only and should not be used to provide precise locations or depths of potential gully erosion, as such this information has only been used to guide the development of the final landform.

In mid-2019 ERA engaged a Rio Tinto hydrologist to build capacity in the assessment of closure landforms using the CAESER-Lisflood landform evolution modelling software. ERA is currently evaluating closure landforms and completing sensitivity testing of key model parameters including climate sequences, rainfall losses, particle size distribution and vegetation cover. This project has allowed for faster evaluation of landforms, and a better understanding of the modelling process and the implications for erosion outcomes dependent upon both landform design and parameter choice.

As mentioned above, the landform design is an iterative process. Design of drainage channels and other erosion mitigations is ongoing to minimise the potential impact on landform stability and revegetation success. ERA's ongoing engagement with a Rio Tinto hydrologist will assist ERA in understanding whether incremental changes in landform design are achievable and/or beneficial, and to better provide input into the final evaluation of landform stability at closure (denudation and formation of gullies).

5.5.1.2 Final landform material properties

The bulk material movement will be completed by moving all material with potential for environmental impact to the bottom of the mined-out pits where extensive solute modelling studies show it will be contained without any significant negative impacts on the natural environment. The final landform material is proposed to be low uranium content 1s waste overburden rock which is found in select stockpiles on the Ranger Mine. The remainder of the landform and pit backfill material will be made up of a mixture of 2s and 1s waste rock. Refer to Section 2.2.1 for details of the rock grading and content.

Table 5-32 shows the indicative particle size distribution for the 1s waste rock material taken from the Ranger Mine TLF (Saynor & Houghton 2011). ERA have also completed particle size distribution analysis for larger mineralised material in the Ranger Mine stockpiles, for various grades of material ranging from 2s to 7s, using fragmentation software. Figure 5-85 provides the results of this analysis.

Table 5-32: Particle size distribution for waste rock landform (by sieve analysis)

Sample name	% Sample > 2 mm	% Sample < 2 mm	% Sample < 63 µm	Total sample mass (g)
Minimum	50.4	21.3	20.9	3,922
Maximum	78.7	49.6	4.3	9,422
Average	63.1	36.9	9.6	6,198

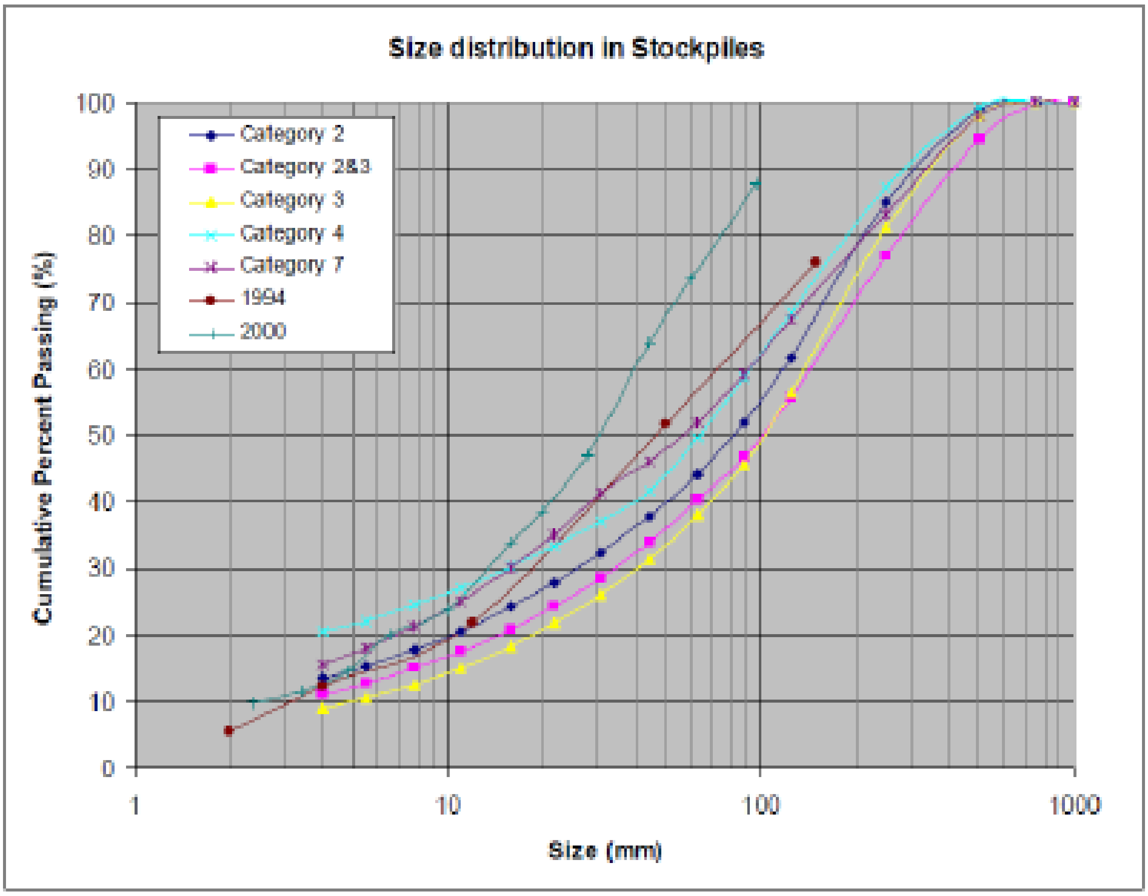


Figure 5-85: Particle size distribution for waste rock in stockpiles (by fragmentation software)

Hollingsworth *et al.* (2003a p 4-5) describes the significant number of studies that have been completed on the waste rock in stockpiles on-site, particularly in relation to soil formation. An excerpt from this report (excluding references) is provided as follows:

> *"Much of the rock material exposed on the surface of the stockpiles weathers rapidly to form rudimentary soil materials. A stony armour surface develops within five years, together with an underlying vesicular silty crust, analogous to desert pavement soils. This effectively seals the surface and is responsible for low infiltration rates. Below the*

compacted surface layer, the stockpiles can have very low bulk densities and consequently appreciable deformation and settlement was anticipated in the long term.

The chemistry and mineralogy of waste rock material has been analysed and rapid weathering and physical degradation of waste rock on the surfaces of the stockpiles has been observed. This weathering is compared with the end products of weathering in the soils and saprolite of the natural landscape.

A number of distinct 'mine soil' types have been recognised on the waste rock stockpiles. These include:

- *unweathered and weathered rock without profile development*
- *stony/gravelly desert-like pavement and an intergranular surface vesicular crust; with or without an A0 horizon*
- *stony/gravelly desert-like pavement and an intergranular surface vesicular crust overlying a vesicular loamy or silty crust horizon; with or without an A0 horizon*
- *stony/gravelly desert-like pavement and an intergranular surface vesicular crust overlying an altered, reddened B horizon with a weak tendency to become gravel-free and contain introduced fines and salts; with or without an A0 horizon*
- *bisequal soil; with or without an A0 horizon (surface litter layer)*
- *pseudo-acid sulfate soil with vesicular loamy crust; occurs in shallow depressions where seasonally perched water tables occur.; with or without an A0 horizon, and*
- *pseudo-acid sulfate soils without a vesicular crust, associated with alluvial fans on the banks of retention ponds.*

Incipient soil features develop within two years of construction of the waste rock stockpiles. Colour mottling (due to increased hydromorphy), variations in soil texture (as a result of water erosion of fine material), structure development, decrease in pH (due to pyrite oxidation) and sulfate weathering were recognised. Acid mine drainage risk has been generally low. Rock analyses of orebody 1 material indicated that total S levels in the samples of waste rock and ore were, with few exceptions, less than 0.04 percent, corresponding to very low potential acid sulfate risk. However, individual rock samples from the '7P' ore stockpile contained 3.51 percent S and exhibited conspicuous acid leaching and weathering features. This would account for the pseudo-acid sulfate soils that have been described.

Higher risks of acid generation in drainage water were identified with orebody 3 material. The more reactive behaviour of orebody 3 material has had implications for stockpile management. There are clear implications from the behaviour of this material in the future for the management and selection of materials that are suitable for finishing the final landform.

Mine soils were more fertile than the natural undisturbed soils of the area, and stockpiled natural soils, in terms of plant seedling growth. However, both P and N were deficient for optimal plant growth. In addition, glasshouse bioassays of mine soils indicated that symbiotic micro-organisms (rhizobia and mycorrhizal fungi) were absent or poorly represented in mine soils, other than those with a vegetation assemblage. It was found that there was no preferential (active) uptake or accumulation of U by plants. Also, all mine soil samples contained high exchangeable Mg levels and high concentrations of exchangeable K and S were measured in pseudo-acid sulfate soils."

Table 5-33 and Table 5-34 show the edaphic properties measured for the rehabilitated waste rock landform and the analogue natural landform (Hollingsworth 2010).

Table 5-33: 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 5-34: 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	

5.5.2 Water and sediment

This section provides summaries of the completed studies relating to Water and sediments as well as selected completed and ongoing KKN related studies. Some studies inform multiple KKNs and have only been included once to avoid repetition.

KKN title	Project title	Status	Section
WS1: Characterising contaminant sources on the RPA	Background COPCs in Groundwater	Completed	5.5.2.1
	Aquatic Sediments	In Progress	5.5.2.2
	Acid Sulfate Sediments Conceptual Model	Completed	5.5.2.3
	Interpreting Soil Assessments for Land Application Areas	In Progress	5.5.2.4
	Non-aquatic contaminated sites sampling	Completed	5.5.2.5
	Stockpile Drilling	Completed	5.5.2.6
	Solute Source Update	In Progress	0

KKN title	Project title	Status	Section
WS2: Predicting transport of contaminants in groundwater	Literature Review on Contaminant Mobility	Completed	5.5.2.8
	Update Groundwater Solute Transport modelling and Conceptual Model	Completed	5.5.2.9
	Post closure Solute Transport modelling with uncertainty analysis	In Progress	5.5.2.10
WS3: Predicting transport of contaminants in surface water	Surface water modelling	In Progress	5.5.2.11
	Surface water groundwater interaction	In Progress	5.5.2.12
WS5: Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health	Acid Sulfate Sediments management options	In Progress	5.5.2.13
	Surface Water Pathway Risk Assessments (Release pathways onsite).	Planned	5.5.2.14
WS6: Determining the impact of nutrients in surface water on aquatic biodiversity and ecosystem health	Eutrophication Risk Study	In Progress	5.5.2.15
WS7: Determining the impact of contaminants in surface and ground-water on aquatic biodiversity and ecosystem health	Aquatic Ecosystem Assessment & Framework Development	In Progress	5.5.2.16

5.5.2.1 Background COPCs in groundwater

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- WS2. Predicting transport of contaminants in groundwater
- WS7. Determining the impact of contaminants in surface and ground-water on aquatic biodiversity and ecosystem health
- RAD2. Radionuclides in aquatic ecosystems
- RAD9. Impacts of contaminants on human health

Background COPCs require characterisation in order to identify the natural range in concentrations in different HLUs across the site. This will inform the post-closure solute transport modelling projects, solute source Area / Concentration conceptual model and surface water modelling projects

Groundwater and surface water modelling are key requirements to support the Pit 3 capping and backfill application to MTC. (Project is discussed in Section 5.2.7)

Previous studies on background COPCs in groundwater at the Ranger Mine were completed by Esslemont (2015, 2017). The key objectives of this study were to better define a list of site-specific background dataset and to derive background concentration limit/threshold for each of the COPC.

Scope and approach

- review of historical studies to provide justification for focussing on the previously selected COPC
- database collation and initial screening: Download of comprehensive dataset from ERA and initial review and screening to remove data not useable in the assessment.
- identification and extraction of background dataset
- review of data quality objectives
- ensure representative data are queried and obtained for appropriate locations and times
- identification of important data characteristics and patterns that need to be considered in the full evaluation
- screening of data for acceptable quality considering analytical methods, method detection limits, presence of laboratory qualifies and metadata
- visualisation of data
- development of descriptive data statistics
- evaluation of data gaps
- assessment of data types, metadata, completeness through time and space for the corresponding hydrolithologic units
- evaluation of sample size and frequency to ascertain the likelihood that the existing data are sufficient to characterise background concentrations with the desired level of acceptability
- development of background dataset
- justification of inclusion or exclusion of data points from the site specific background data set using a compilation of several lines of evidence. This includes temporal analysis, population partitioning, geochemical analysis and chemical fingerprinting

- integration of all the lines of evidence to develop the background dataset with consideration for the conceptual hydrogeological model
- derivation of background COPC concentration limits and background threshold values
- active monitoring of the project through regular engagement with the consultant Environmental Resources Management (ERM).

Results and conclusion

The project was completed in June 2020 with delivery of the report *Ranger Uranium Mine Background Evaluation* dated 5 June 2020. In support of the report ERM developed nine interactive html dashboards allowing for full interrogation of the dataset and statistical analysis undertaken to develop the background threshold values. ERM presented via teleconference to stakeholders at the Ranger Closure Consultative Forum on 19th June 2020 where the report and supporting appendices were provided to stakeholders for review and feedback.

The completed project effectively refined the COPC list and identified the background dataset, established site-specific background datasets where minimum data criteria were met, and established background threshold values (BTVs) for COPCs in groundwater at the Ranger Mine. Further information on this project is described in section 5.2.7

Feedback was received from the SSB via email in July 2020. The SSB advised that, where sufficient data was available, they are in agreement with the COPC background threshold values that have been derived. Where there was insufficient data to develop a COPC background threshold value a suitable approach is required, either a low confidence value or future assessment following collection of additional data. Follow up engagement with the SSB has commenced and an approach is being developed to address this data gap.

Feedback from the DPIR was received on 26 August 2020 and was in agreement with comments made by the SSB.

5.5.2.2 Aquatic sediments

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health
- RAD9. Impacts of contaminants on human health

Aquatic sediment sampling is required to understand any potential ecological impacts related to mine contaminated sediments. This will inform ALARA-BPT assessments which in turn inform the decommissioning requirements for onsite waterbodies.

An Independent Surface Water Working Group (ISWWG), established by ERA and the GAC to review surface water management and monitoring at Ranger Mine, made 15 recommendations (Hart & Taylor 2013). One recommendation related to sediment monitoring:

> *"A sediment monitoring program be re-introduced. In doing so due consideration needs to be given to the technical challenges in designing a program to reliably evaluate possible adverse environmental impacts during the operational phase of the mine, while providing benchmark data to detect possible impacts after closure."*

Parry (2016), recommended a sampling and analyses program based on leading practice and a review of historical data from earlier investigations of billabong sediments. The recommendations, agreed to by a stakeholder working group, were trialled in 2015 and implemented and refined in 2016 (Esslemont 2016). The sediment sampling conducted in 2016 was reported by Esslemont and Iles (2017).

These reports contain a well described pre-closure baseline dataset and demonstrate that there has been no sediment contamination in off-site billabongs as a result of mining. Given the improved water quality leaving the minesite in recent years the risk of sediment contamination off the RPA occurring now is negligible.

Metal contamination of onsite billabongs has not increased in recent years and the formation of acid sulfate soils (ASS) is now the recognised priority hazard to sediments in water bodies on the RPA. Therfore, the focus has now shifted away from routine monitoring of on and off site sediments to a targeted program to understand the ASS issues.

Sediment monitoring was undertaken to investigate acid occurrences in Coonjimba Billabong (Esslemont & Iles, 2015 and Esslemont, 2016). A review of this work contained recommendations for sediment sampling to improve the understanding of the ASS status and risks (Baldwin, 2017). This lead to the development of an ASS conceptual model for the minesite which will underpin the design of the ASS sampling program for 2020.

The objectives for this project are to:

- collect and analyse data from a sediment sampling program
- provide an inventory and assessment of sediment contamination (including ASS status) in waterbodies on the minesite (relative to reference sites) to inform closure risks and decommissioning plans.
- document the decommissioning plans in the Final Landform application
- inform future aquatic ecosystem monitoring that may be undertaken between 2020 and 2024

Scope & approach

Sediments from billabongs on the RPA will be sampled and analysed for COPCs identified in Parry 2016 and additional analytes identified for assessing the ASS risk.

The sampling locations are being finalised based on a review of the ASS conceptual model and recommendations from the SSB and their consultant. The sampling locations will be reviewed with stakeholders. Parameters have been previously agreed to by stakeholders. The need for sampling in future years will be based on the outcomes of the 2020 campaign and future risk assessments.

The sampling and analysis plan was reviewed by stakeholders during development (2018 – 2020).

Delays to sampling due to the permitting process for off-site locations, and delays in finalising the ASS conceptual model resulted in improvements to the sampling plan. The updated sampling, analysis and quality plan will be discussed with stakeholders prior to sampling. Stakeholders will review and evaluate draft reports prior to finalisation.

5.5.2.3 Acid sulfate sediments conceptual model

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health

Historical sampling and assessment results have identified both potential acid sulfate sediment (PASS) and actual acid sulfate sediment (AASS) in Coonjimba Billabong (Esslemont & Iles 2015, Esslemont 2016). ASS in Retention Pond 1 has also been identified in the past (Esslemont 2016). In addition, CSIRO mapping (2011) identified a high probability of ASS presence in some areas on the minesite, including Georgetown Billabong, TSF, RP1, Coonjimba Billabong, former Djalkmarra Billabong and Magela Creek.

Subsequently, in order to assess the potential for, and risk from, ASS formation at the RPA, ERA engaged ERM to undertake an assessment based on the historical and current operational activities.

A preliminary site wide conceptual model has been developed, based on a collation and review of historical topography, groundwater and surface water data, and existing soil and sediment sampling result (ERM 2020a). The objective of the model is to further understand:

- source dynamics of ASS formation at the site
- mechanisms of PASS exposure and oxidation to form AASS
- potential pathways for acidification products (dissolved metals, acid and sulfate) from ASS sources areas
- surface water and groundwater receptors that may receive such acidification products

- potentially complete source-pathway-receptor (SPR) linkages

The following sections present the general methodology of the ASS assessment and key findings from the ERM assessment.

Scope and approach

The assessment involved a desktop review of site-specific reports on ASS, ground and surface water quality datasets, water level, historic rainfall, water management practices and consolidated GIS analysis to identify areas that met the conditions required to potentially form ASS.

The key differentiated terminologies adopted in this assessment, as shown in Figure 5-86, include:

- potential acid sulfate sediments: sediments that contain sulphides in a reduced condition and have the potential to generate acid if oxidised
- actual acid sulfate sediments: sediments that have oxidised to release acid, sulfate, and/or metal load
- areas where PASS or AASS have been confirmed based on sediment sampling or other assessment
- areas where the potential for ASS to have formed are identified in this assessment based on elevated concentration, water-logged conditions and other attributes

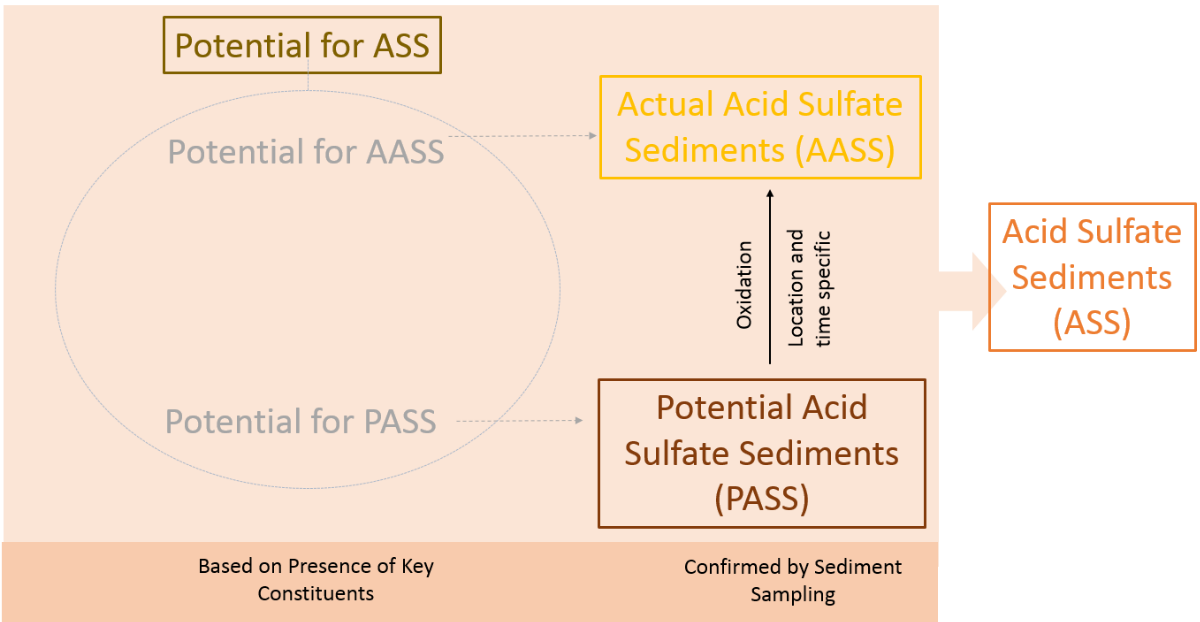


Figure 5-86 ASS terminologies (ERM 2020)

The conceptual model was developed using the structure shown in Figure 5-87, with section references as in ERM 2020. 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. Two former conditions can be interpreted from the consolidated historical data. However, due to the lack of data available for organic matter, a non-limiting environment is assumed in this assessment.

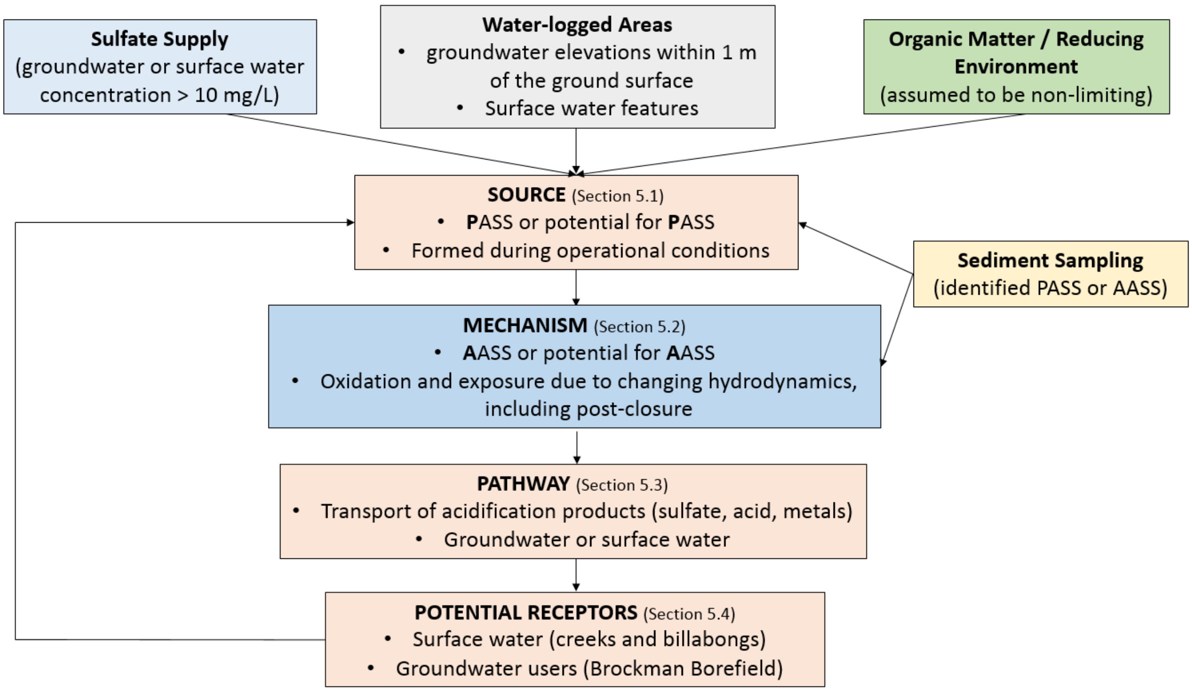


Figure 5-87 Development of preliminary site wide ASS conceptual model (ERM, 2020)

Considering the high seasonal variation in water quality and quantity, the preliminary site wide assessment was based on certain temporal periods for data interpretation to consider local seasonal behaviour of surface water and groundwater, and hydrodynamic changes resulted from water management activities. Six different time periods were assessed:

- wet-wet and following dry season
- dry-wet and following dry season
- wet season and following dry season corresponding to the onset of ASS conditions

The maximum sulfate concentrations in surface and groundwater and maximum groundwater elevations were selected from datasets for locations across the site for these periods as a conservative approach. The screened surface and groundwater datasets were consolidated and entered into GIS to identify areas with overlap of attributes required for ASS formation. The areas meeting these conditions are identified as “sources”, i.e. areas with potential for ASS formation.

Areas of sulfate supply and potential receptors for ASS products were also identified for each of the PASS source areas to develop a source-pathway-receptor linkage model.

Results and conclusion

The following results were produced for each time period being assessed:

- a set of sulfate concentration and groundwater elevation maps for each of 2 groundwater zones
- a map for each time period showing the intersection of sulfate concentrations ≥10 mg SO_4/L at or within 1 meter of the surface

Figure 5-88 summarises the results of these outputs, plus surface water where maximum concentrations of sulfate were ≥10 mg/L, in a preliminary ASS conceptual model. Note that areas shown as "not considered" are those areas where no or limited groundwater data were available for the periods of assessment. These areas will be considered in the next stage for the ASS assessment.

There are several areas conservatively considered to represent PASS or potential for PASS sources areas. These include the Coonjimba Creek/Coonjimba Billabong alignment, Magela Creek, Corridor Creek, and Gulungul Creek, where sulfate concentrations higher than 10 mg/L in groundwater occurred together with water logged conditions, or sulfate concentrations in surface water drainage lines and surface water bodies were higher than 10 mg/L.

The yellow shaded areas are considered a source (potential ASS area) in at least one of the 6 time periods assessed. Note that only a few small areas were identified as sources in all 6 time periods.

In many of the identified source areas AASS or PASS may not be present. A mechanism is required to shift from potential source area to PASS and further onto AASS. For example, potential source areas may be limited in organic matter, and thus no PASS or AASS can be formed. On the contrary, natural or mine-related changes to the hydrodynamic at the site may expose PASS that has the potential for oxidation and release of acidification into the surrounding environment and form AASS. For example, Coonjimba Billabong and areas along the Coonjimba Creek are identified as a PASS source area, where past acidification events were observed with both AASS and PASS have been identified along the alignment.

Figure 5-89 summarises the source-pathway-receptor linkages for the ASS conceptual model, with the source areas, the pathways for transportation and the potential receptors identified.

Several operational areas were identified as sulfate supply areas in regards to sulfate concentration in surface water and groundwater. These areas include the TSF and surrounding run-off collection sumps, process plant area, Sed2B, Corridor Creek Wetland filter, RP1 wetland filter, Western Stockpile and LAAs. Some of these sulfate supplies will not be present after closure. Others are included in the post-closure contaminant source conceptual model and the potential for them to be ASS sources will be assessed in the next steps.

The main surface water receptors that have the potential to be exposed to and impacted by oxidation of PASS and AASS include Coonjimba Creek, Coonjimba Billabong, Corridor Creek and Gulungul Creek (Figure 5-89).

The uncertainties in this stage of the assessment arise from accuracy of the DEM topographic surface, and the limitation of data availability in some areas for the periods analysed. In addition, there is uncertainty with temporal variation, as only maximum sulfate concentrations during the early wet season is adopted in this assessment; whereas a sustained increase above 10 mg/L sulfate is required to form ASS.

To confirm the presence of AASS and potential risk to the receptor areas now and following closure, a sampling program and risk assessment will be conducted in the near future, refer to Section 5.5.2.2

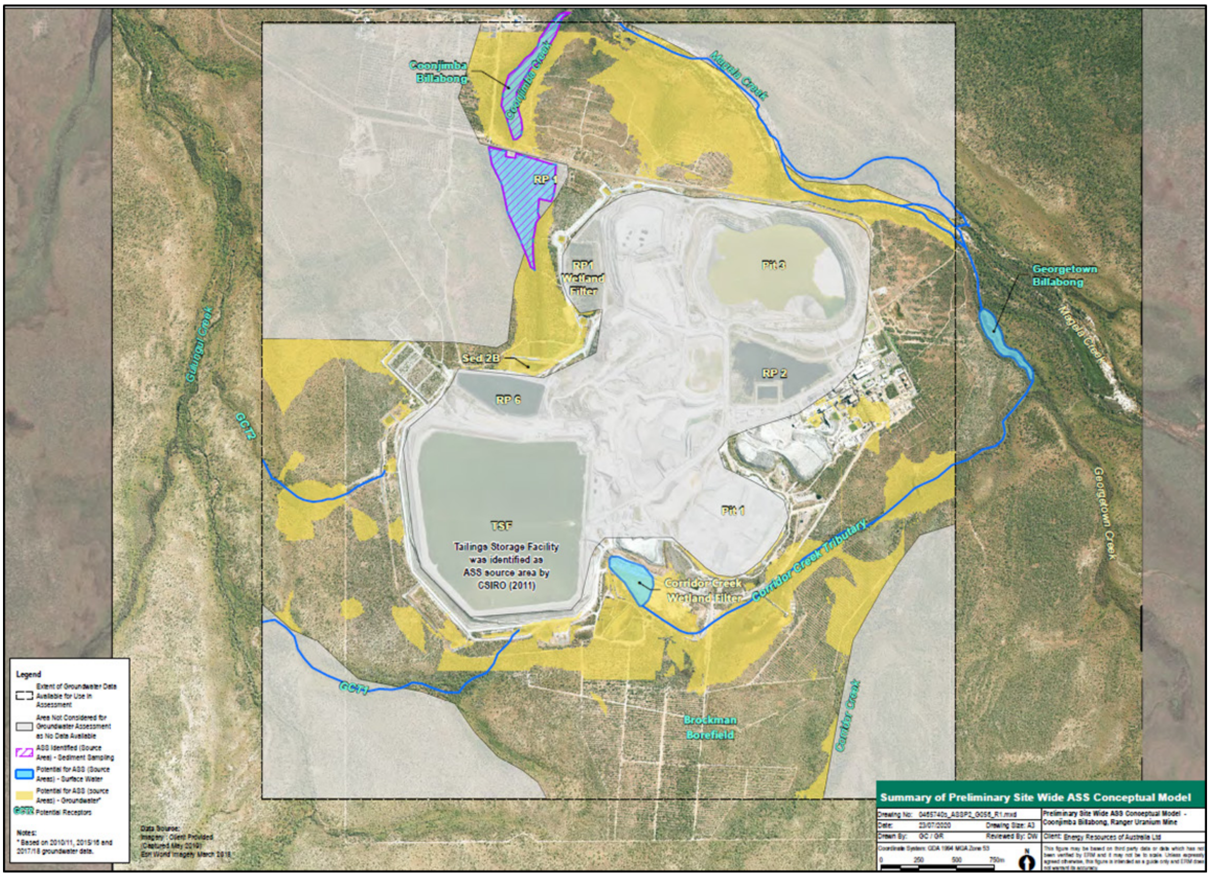


Figure 5-88 Summary of preliminary site wide ASS conceptual model

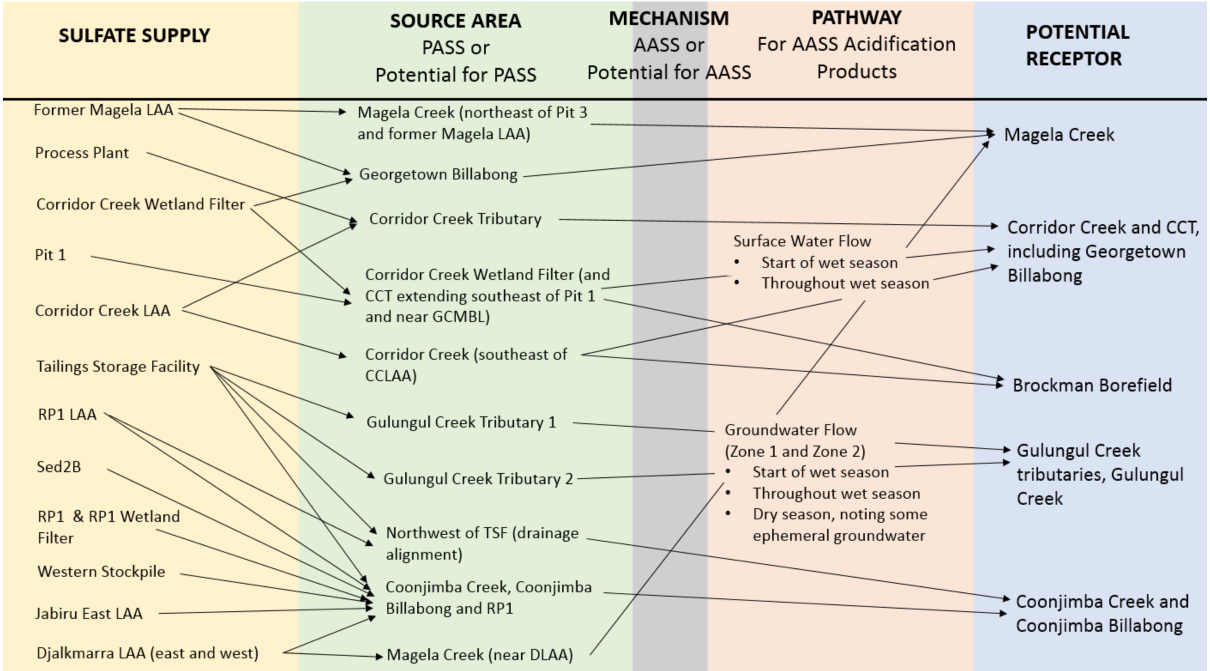


Figure 5-89 Summary of SPR linkages (ERM, 2020)

Following the development of the preliminary ASS conceptual model, ERA will investigate the risk associated with each conceptualised PASS source location. Targeted sediment sampling during 2020 dry season, along with the development of a location specific risk-ranking, are proposed to evaluate potential ASS formation in the sources areas identified. The risk-ranking for each identified PASS sources area will be based on location specific concentrations in surface water and groundwater, likelihood of hydrodynamic changes associated with closure, and the sensitivity of the potential receptor to acidification products. The risk assessment can then be used as a tool for monitoring regime development. An ASS model for closure conditions will be developed to inform closure risks and management strategies.

5.5.2.4 Interpreting soil assessments for land application areas

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- RAD9. Impacts of contaminants on human health

Previous assessments identified soils and sediments on the RPA that have become contaminated through treatment of pond water in wetlands and bunds, irrigation of pond water in the LAAs, the accumulation of low-level contaminants in waters passing through billabongs, and seeps and spills in the plant areas. An objective for closure is for soils to be remediated to a level where their environmental impact is ALARA.

LAAs have been used on the RPA since 1985 as a method of water disposal, primarily during the dry season. Types of water historically applied to the LAAs consist of:

- untreated pond water from RP2
- polished RP2 water – water that has passed through a constructed wetland filter
- managed release water
- permeate water – Water Treatment Plant permeate and Brine Concentrator distillate.

The LAAs have been designed to retain uranium in near-surface soils. Irrigated water disposed of at the LAAs has improved through time. There are eight LAAs at the RPA (Figure 5-90), spread across five areas. These consist of Magela LAA (MLAA) and MLAA extension, Djalkmarra LAA (east) (DLAA) and DLAA extension (west), RP1LAA and RP1LAA extension, Jabiru East LAA (JELAA), and Corridor Creek LAA (CCLAA). These cover a total area of 338 ha consisting of native and/or disturbed woodland or sparse woodland.

The behaviour of contaminants in the soils at Ranger and the contamination status of the LAAs has been studied extensively, with assessment available since 1979. Given the nature of the LAAs, soil investigations have largely focused on the upper 0.1m below ground level (BGL) of soils, however deeper samples (up to 6m BGL) have also been collected.

Recently, two sampling campaigns were undertaken in 2018 and 2019 to characterise the contemporary condition of soils within the LAAs (SLR 2018b, 2019). In 2020, a comprehensive literature review of the LAAs was undertaken (ERM, 2020 draft). All known data was also collated into an excel database, enabling data interrogation far easier than has been possible historically. This data is currently being analysed and a summary of findings will be provided in the next MCP.

A review of the information from the literature review and excel database is now underway to determine contamination of the LAAs. This will inform a BPT assessment, thereby informing the approach for remediation for each LAA, if required, based on ALARA. Detailed remediation plans, where needed, will be provided in future updates of the MCP.

The objective of this project is to understand what contaminants are present on the rehabilitated landform, whilst informing what COPCs to human health may exist. This will inform what level of remediation is needed for each LAA.

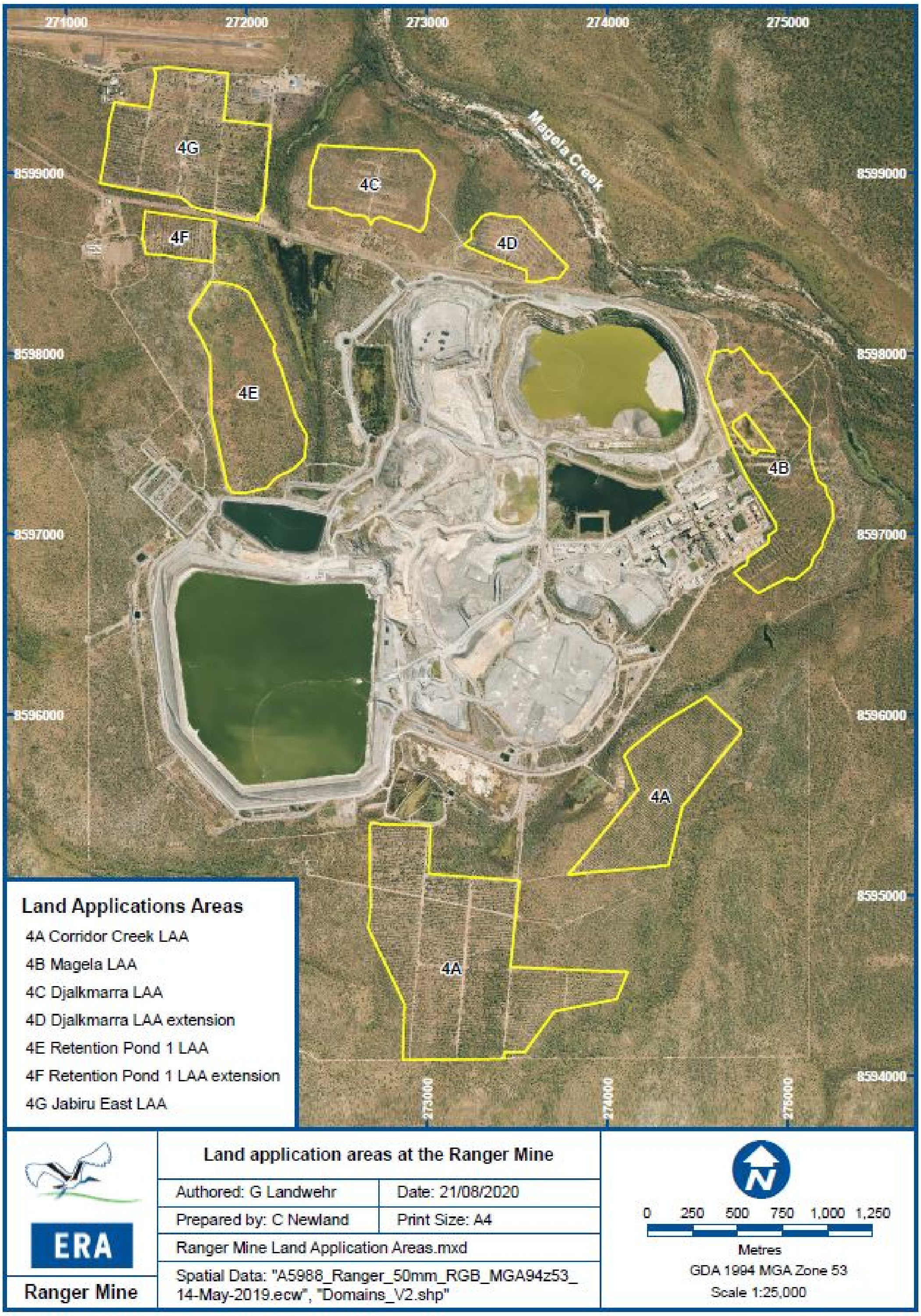


Figure 5-90 Land Application Areas at the Ranger Mine

Scope and Approach

The scope of this project is to:

- cohesively link all historical LAA soil investigations by undertaking a literature analysis;
- create a database of all LAA soil data available to enable analysis of results;
- understand the contamination and mobility of COPCs at each LAA;
- undertake a BPT assessment for each LAA to determine, if required, the level of remediation to be undertaken to ensure ALARA. BPT assessments will take the source-pathway-receptor exposure model into account when determining the final management option.

No additional sampling is planned at this stage to further inform this project. The current dataset is considered to be sufficient for informed decisions regarding the level of remediation (if any) required for each LAA. Historical LAA and 'background' soil data (up to 6m BGL) will be used to develop LAA conceptual site models and spatially map sediment concentrations.

The outcomes of the report will be reviewed and reported internally through the Water and Closure Operational Forum. Data will also be presented to stakeholders at the RCCF and/or MTC; whichever is sooner. Updates will be included in future updates of the MCP and KKN closeout evidence will be reported to stakeholder groups and ARRTC.

5.5.2.5 Non-aquatic contaminated sites sampling

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- RAD2. Radionuclides in aquatic ecosystems
- RAD9. Impacts of contaminants on human health

A comparative assessment of COPCs and their respective source(s) (e.g. waste rock, tailings/pore water, groundwater, soils) is needed, including consideration of any remnant 'hotspots' that may be present post-rehabilitation of the Ranger Mine. This information contributes to whole-of-site contaminant transport modelling to predict the Pit 3 backfill, post-closure water quality, and will inform the rehabilitation and risk management of the site.

Contaminated sites have been identified across Ranger Mine since the early 2000s (Hollingsworth, 2006) and since then, a significant number of targeted contaminated land assessments have been undertaken previously on the RPA at known contaminated sites between 2006 and 2016. Although the focus of previous assessments was predominantly on 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 on the RPA.

The contaminated sites have been documented in a *Contaminated Land Risk Register* which has been developed and maintained by the site environment team at the Ranger Mine, in accordance with the operational *Hazardous material and contamination control plan* (ERA 2016). The *Contaminated Land Risk Register* identifies all sites where activities have occurred that have the potential to contaminate land. Section 9.4.1 describes the contaminated sites domain including the specific contaminated sites, grouped into major site areas, based on location and proposed remediation strategies. The major site areas are shown in Figure 5-91, Figure 5-92 and Figure 5-93.

As part of the feasibility study undertaken in 2018, a review of the *Contaminated Land Risk 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 knowledge based of site contamination. Sites were also classified according to risk (costs of remediation). Any new potentially contaminated land as a result of operational activities occurring after this review will be added to the *Contaminated Land Risk Register* by the site environment team and will be incorporated into closure investigations if required.

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 suitable, i.e. supported by outcomes of previous studies and outcomes of the feasibility study, and a gap analysis was completed. Areas identified during the gap analysis as having insufficient data to adequately determine a remediation treatment option were detailed, including depth and COPCs for further investigation.

Additionally, to support the post-closure solute transport modelling, an assessment of potential groundwater contamination sources is underway and will be detailed in the Pit 3 Closure application. These potential groundwater contamination sources are the Process Plant Area, TSF, LAAs, and the waste rock stockpile of the operational period.

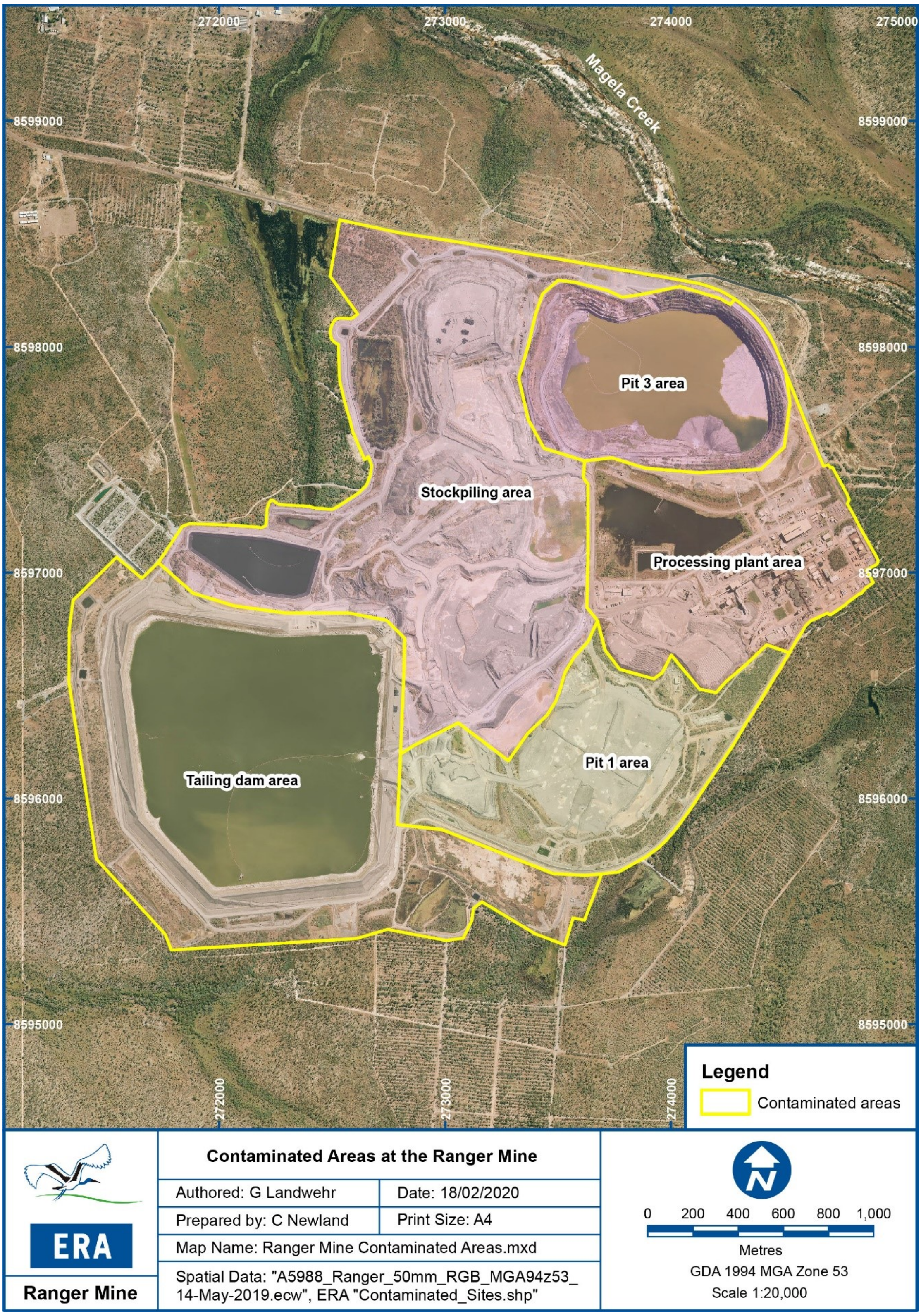


Figure 5-91: Ranger Mine area boundaries

ERA

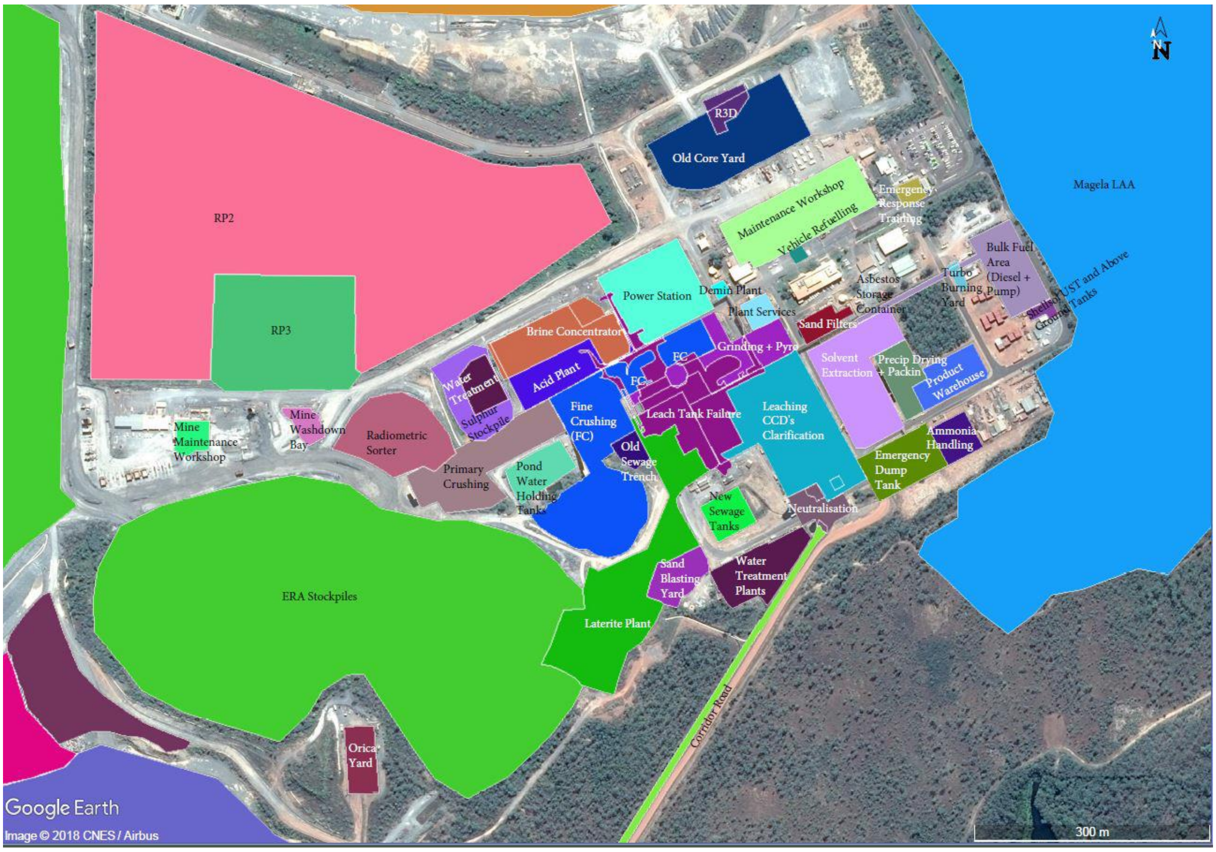


Figure 5-92: Processing plant area – contaminated sites register

Scope and approach– processing plant - soils

In order to understand the current state of the soils around the RPA, a contaminated sites drilling program was executed between November 2019 and January 2020 to sample soils, install groundwater monitoring wells and re-develop existing monitoring wells at targeted areas defined by the gap analysis undertaken in April 2019. A summary of knowledge gaps for the selected sites is summarised in Figure 5-37

The identified sites were sampled between November 2019 and January 2020 in accordance with the Australian Standards (AS 4482.2-1999 and AS 4482.1-2005). Soil samples were obtained using a drill rig equipped with a hollow stem augur. Soil conditions and descriptions were logged in the field and samples analysed for COPCs and other parameters of interest.

IN selecting the locations of the soil bores drilled as part of the drilling program (Figure 5-94 to Figure 5-100) ERA took into consideration, historical data and known gaps (as detailed in Table 5-35), nature and source of the contaminants and hydrogeology for each site.

A Sampling Analysis Quality Plan (SAQP) was developed to document the purpose and rationale of each location, target depth, sampling interval and COPCs of interest (ERA, 2020).

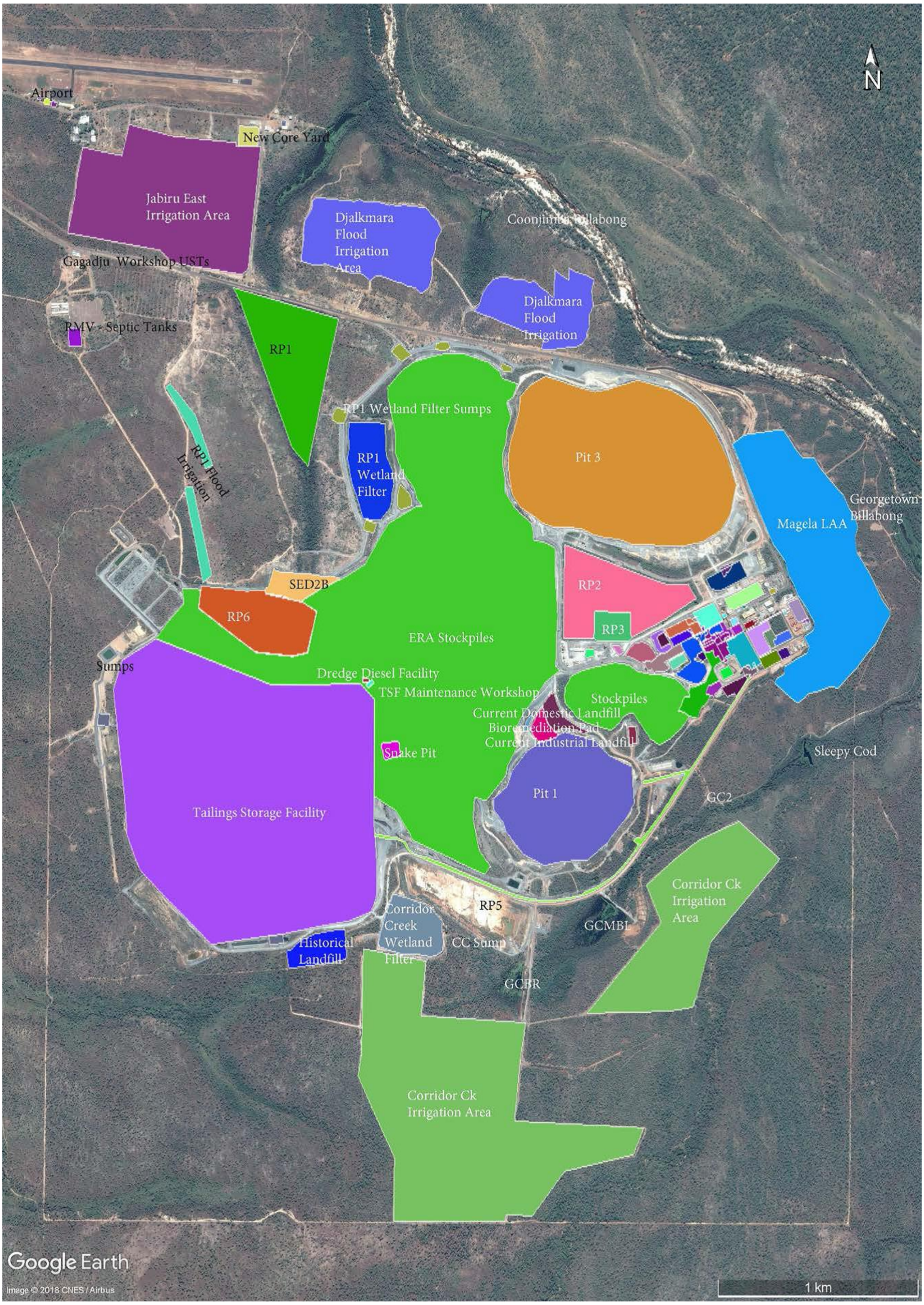


Figure 5-93: Major site area boundaries – contaminated sites register

Table 5-35: Summary of targeted Site Contamination Assessment of Knowledge Gaps.

Site	COPC	Knowledge Gap Actions
Historical Landfill	• TRH, BTEXN, PAH, Phenols, VOCs, Sulfate, Ammonia, Nitrate + Nitrite as N and Metals (Mn, U).	• Update data on current vertical extent of COPCs in soil. The primary depth of concern is within the top 4.5 m.
Emergency Dump Tank	• TRH, PAH, VOCs, Sulfate and Metals (Mn, U).	• Establish site-specific data to determine the vertical extents of COPCs in soil at the emergency dump tank. Depth of assessment up to 10 m BGL.
CCD Circuit	• Metals (Fe, U, Mn), pH, Sulfate, EC, TRH, cations and anions.	• Determine vertical extents of COPCs in soil beyond a depth of 3.65 m BGL.
Sulfur Stockpile and Acid Tank	• Metals (Mn, Cr, U, Fe), pH, sulfate and TRH.	• Determine vertical extents of COPCs in soil beyond a depth of 4 m BGL.
Power Station	• TRH, BTEXN, PAH, Sulfate, PCB, Metals (Mn + U)	• Determine vertical extents of COPCs in soil beyond a depth of 4.5 m BGL.
Shellsol Tank	• TRH, BTEXN, PAH and Phenols	• There is a limited data on vertical extents of COPCs in soil beyond a depth of 3.25 m BGL.
Bioremediation Pad	• TRH, BTEXN, PAH, VOCs and radionuclides	• There is currently a poor understanding of the vertical extent of COPCs in soil beyond depth of 0.4 m BGL.

Figure 5-94: Locations of soil bores drilled in the processing area at Ranger Mine

Figure 5-95: Locations of soil bores in the historic landfill, bioremediation pads and TSF walls at Ranger Mine.

Figure 5-96: Location of boreholes at the historic landfill area

Figure 5-97: Location of soil bores at the emergency dump tank and CCD circuit areas

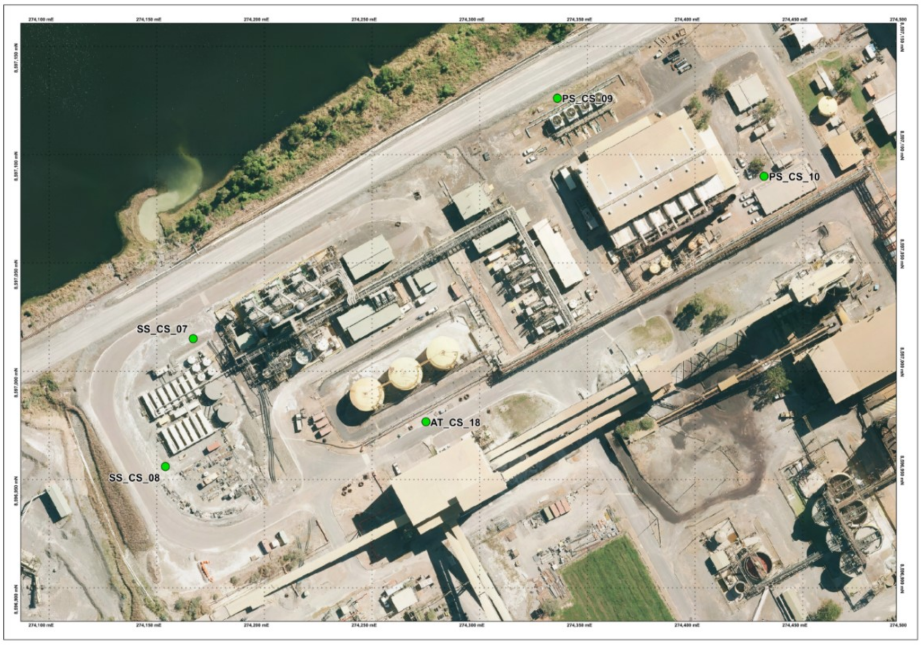


Figure 5-98: Location of soil bores at the former sulfur stockpile, acid tank and power station areas.

Figure 5-99: Location of soil bores at the Shellsol underground and above ground tanks

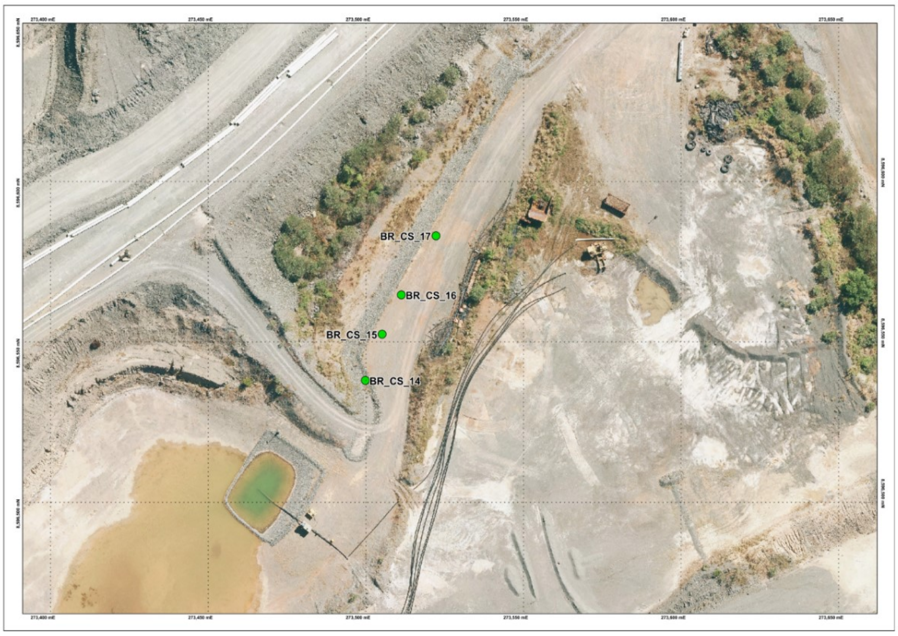


Figure 5-100: Location of soil bores at the bioremediation pad

Evaluation and reporting outcomes – processing plant: soils

Overall, contamination was found to be localised to infrastructure and top soils with limited groundwater impacts that are slow moving.

The following observations were made:

- Historic Landfill Area - Cr and Mn concentrations in LF_CS_01 showed increasing concentrations with depth with all other analytes displaying a decreasing or stable trend with increasing depth.
- Dump Tank Area - The profile was approximately linear in the area with no significant variation to the concentrations observed for most COPCs with increasing depth. An inverse relationship was observed between NH3-N and NO3-N indicating evidence of microbially mediated transformation processes in the soil.
- Counter Current Decanter (CCD) area - All COPCs concentrations except for those for NH3-N exhibit a decreasing trend down bore at the soil bores with the highest levels of contamination observed in the top 2.0 m of the soil profile.
- Former Sulfur Stockpile and Acid Tank – General decrease in COPC concentrations from surface to a depth of 5.0 m BGL with the steepest decrease observed at 1.5 m BGL. Cr trends increased with increased depth in SS_CS_07. At depths greater than 5 m BGL, Cu concentrations increased with depth in SS_CS_07 and Mn concentrations increased with depth in SS_CS_08.
- Power Station Area – Most of the COPCs that were analysed showed a sharp decrease at depths greater than 1.5 m BGL to stabilise at depths deeper than 2.0 m BGL. Hydrocarbon contamination was only detected in one soil bore at a depth of 0.1 m BGL in the power station area and in two bores to a depth of 1.5 m BGL at the former bioremediation pad area. There is no observable PCB contamination in the area.
- Shellsol Tank – There were no hydrocarbon impacts identified in the area and concentrations of COPCs were observed to gradually decrease with increased depth.
- Bioremediation Pad – Hydrocarbon impacts were identified at BR_CS_16, with a spike at 0.5 m BGL, persisting at low levels to a depth of 1.5 m BGL. Low level hydrocarbon contamination was detected at 0.1 m BGL in BR_CS_15. The contamination appears localised. No other impacts were observed at other bores sampled from this site.

Scope and approach– processing plant: groundwater

The Ranger Conceptual Model (INTERA 2016) noted that 38 contaminated sites have been identified in or near the processing plant area. Based on the dataset available, it appears that the majority of impacts to groundwater exist beneath the western portion of the process plant area, with lower levels of impact identified across the rest of the process plant and between the process plant and receptors to the south and east. The highest concentrations of sulfate in groundwater were identified in groundwater from bores 3B, 35 and 47 within the process plant area, extending to the south-east to OA09, OB241 and OB242; these concentrations are partially delineated by OA08, OA11, and OA10. The impacts of manganese in groundwater were not delineated between potential sources and receptors. Concentrations of COPCs above background in groundwater from bores towards Corridor Creek to the south and Georgetown Creek and GTB to the east are considered to be most likely to have been derived from irrigation activities in the former Magela LAA area (ERM 2020b).

Further review of the contamination extent and profile is underway to support the post-closure solute transport groundwater modelling for the Pit 3 closure application. This includes analysis and interpretation of all available groundwater laboratory analysis data from the processing area to support development of a three dimensional profile of contamination profile within the Leapfrog geologic modelling software that can then be incorporated into the solute transport modelling. Additionally, the contamination profile will be included within the uncertainty analysis of the groundwater modelling with results to be presented in the Pit 3 closure application and subsequent MCPs. A map showing all the bores with data that are being used to inform and develop the contamination profile for inclusion in the groundwater modelling is shown in Figure 5-101.

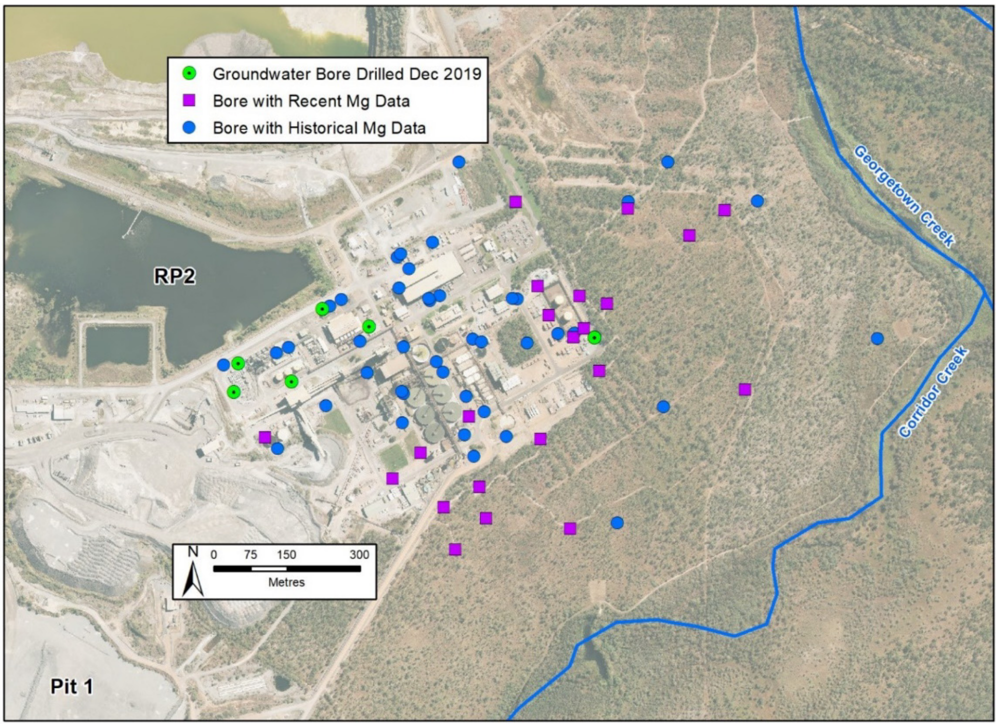


Figure 5-101 Monitoring bores used to inform development of groundwater contamination profile at the Processing Plant Area

Scope and approach– TSF

Gradual seepage from the TSF, 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 repeatedly over the years (Weaver 2010). Studies into the groundwater contamination below the TSF have been undertaken in order to support both the MTC application Ranger Mine Tailings Storage Facility – Subfloor Material Management and the Ranger Mine post closure solute transport modelling. The key elements of the studies involved sampling and analysis of the subfloor material below the TSF, a review of historical hydrogeological investigations, and a review of all available groundwater data surrounding the TSF.

To support the subfloor material management application INTERA (2020) modelled the extent and profile of the magnesium contamination below the TSF. This was undertaken by integrating and interpolating the available data within the Leapfrog geologic modelling software as shown in Figure 5-102.

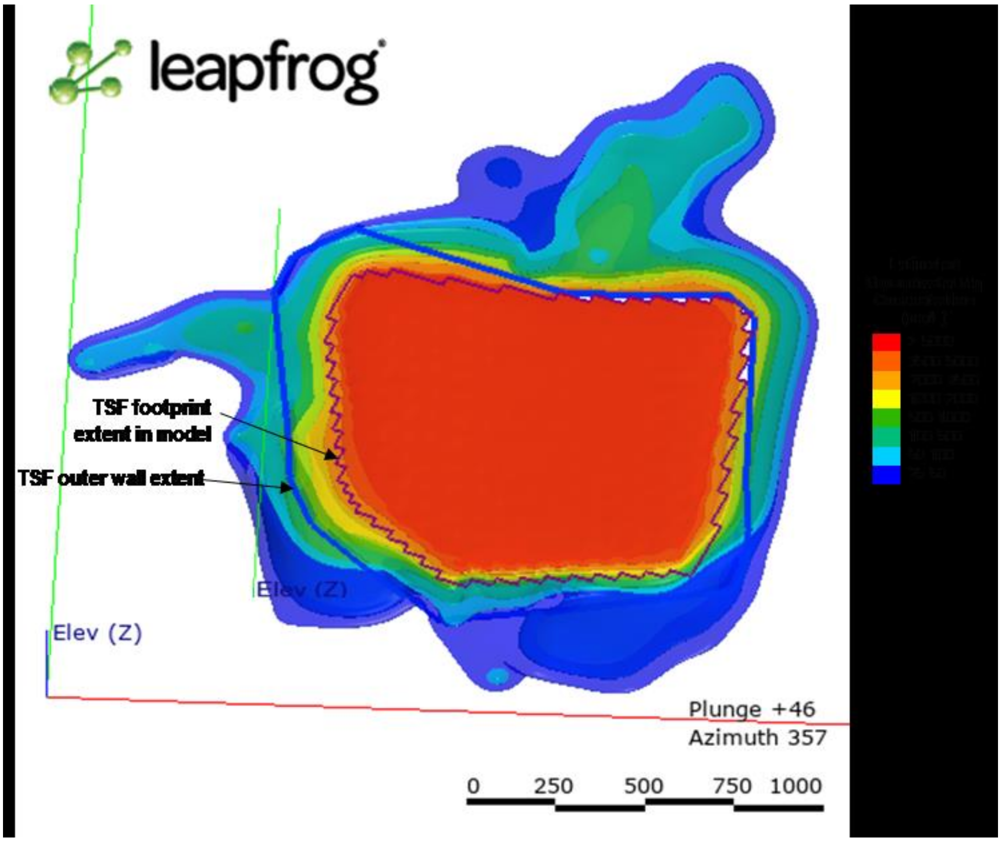


Figure 5-102 INTERA (2020) Leapfrog TSF Mg plume concentration and lateral extent

To support the post closure solute transport groundwater modelling with uncertainty analysis (section 5.5.2.10), the study to support the subfloor material management application was reviewed with the inclusion of more recent groundwater data, and laboratory analysis results from the subfloor-drilling program. The objective of this review is to include all COPCs required to be modelled to support assessment against the Ranger Mine closure criteria, and to define the uncertainty analysis parameterisation. The outcomes of this study will be detailed in the Pit 3 Closure application and future MCPs.

Scope and approach– Land Application Areas: soils

See section 5.5.2.4

Scope and approach– Land Application Areas: groundwater

Contamination that will be present in groundwater below the LAAs at closure is currently under investigation by INTERA. The purpose of this investigation is to define what COPCs will be above background concentrations in groundwaters proximal to the LAAs at closure. The results will be included as a source term within the post-closure solute transport modelling. Review of both historical and recent groundwater bore laboratory analyses is underway to identify what contamination has historically been present and to identify any trends in the groundwater COPC concentrations with consideration for both current and historical irrigation practices. The bores being utilised for this investigation are shown in Figure 5-103

Scope and approach– waste rock landform

To develop the post closure waste rock landform source term nine bores were drilled in December 2018 and January 2019 targeting groundwater below the waste rock stockpile. Monitoring of groundwater in these bores has been undertaken to quantify any contamination that may exist below the waste rock stockpile, and validate any geochemical modelling undertaken to inform the post closure waste rock landform source term. (Section 0) Analysis of the groundwater chemistry data is underway and will be presented in the post closure solute transport modelling to support the Pit 3 closure application as well as future MCPs.

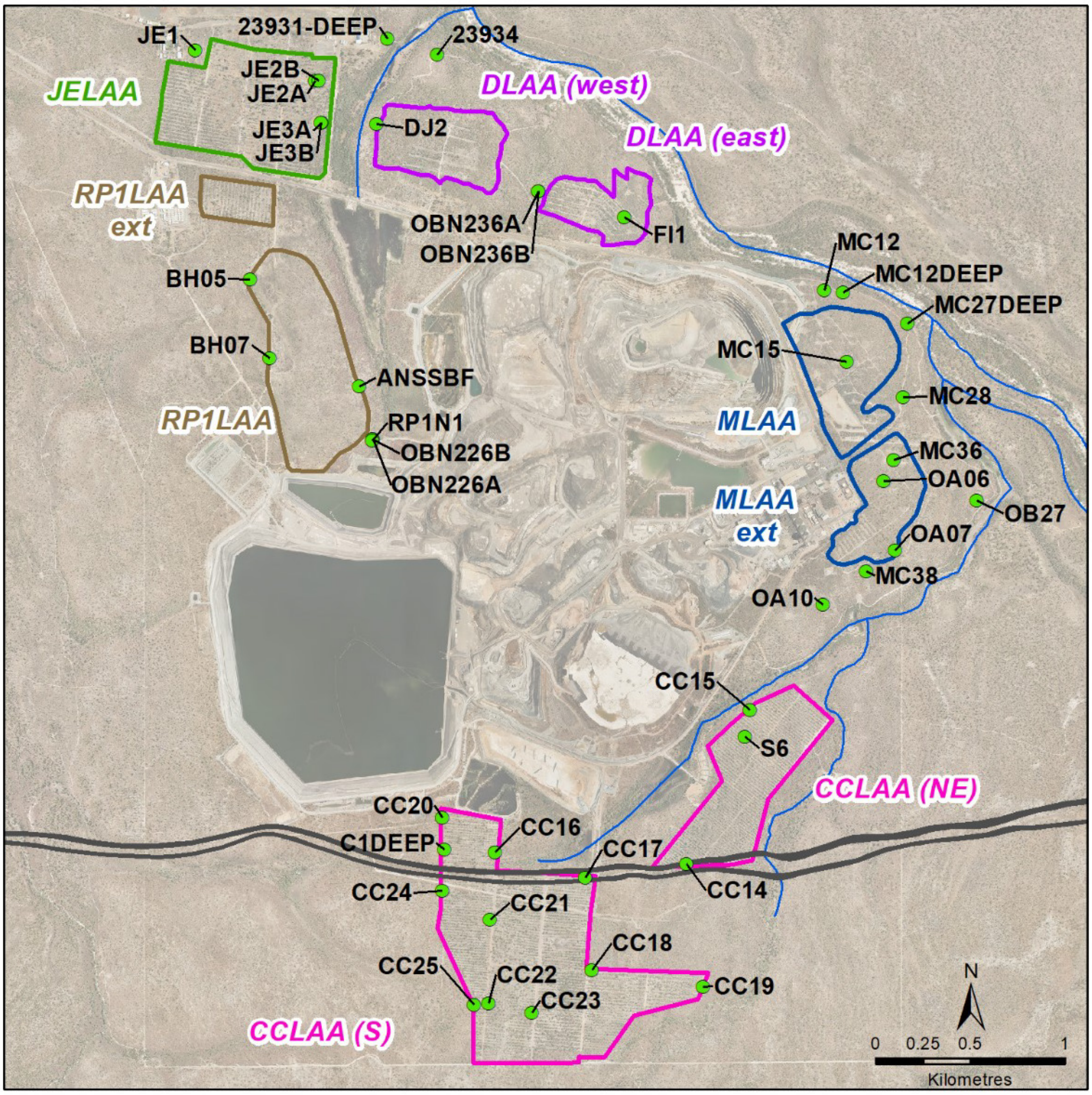


Figure 5-103 Land Application Area groundwater-monitoring bores for source term development

5.5.2.6 Stockpile drilling

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- WS2. Predicting transport of contaminants in groundwater

Monitoring of the bores, drilled as part of the stockpile drilling program, is required to inform the updated waste rock source term and subsequently the post-closure solute transport model with uncertainty analysis. The objective of this project is to collect groundwater level and chemistry data to inform the assessment of groundwater movement under the waste rock stockpiles and trial landform as well as support the validation of the waste rock source term for the post-closure solute transport model. See Section 0.

Scope and approach

This project required the regular collection of groundwater level and chemistry data from 9 bores drilled in the waste rock stockpiles and 1 bore in the trial landform (Figure 5-104). This project commenced after the completion of the bore drilling in January 2019. The project ceased mid 2020 once the data were collected.

Monitoring was undertaken by the site Water Management team on a monthly occurrence using their existing groundwater monitoring SAQPs.

Figure 5-104 Location of 9 stockpile bores and 1 TLF bore

Water level data will be provided to ERA's groundwater consultants on a regular basis when it is collected from the field. Details of the reporting outcomes will form part of the validation process for the post closure solute transport modelling with uncertainty analysis.

5.5.2.7 Solute source term update

This project relates to one KKN:

- WS1: Characterising contaminant sources on the RPA

A critical input to the post-closure solute transport modelling is the solute source term conceptual model. 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. The solute source term also includes reference to any geochemical processes that result in mobilisation of COPCs from the waste rock landform.

INTERA have previously developed a solute source term conceptual model for the major contaminant sources on the RPA for the 2014 and 2016 post closure solute transport modelling. The existing source terms within the solute source term conceptual model requires update following the availability of additional data. Additionally, new source terms are required to be developed for solute source areas not previously included in the post-closure solute transport modelling, these include the LAAs, processing plant area and TSF.

Solute source term conceptual model update in itself does not directly address any specific Environmental Requirements, however it does form a critical part in a number of groundwater and surface water studies that do.

The objective of this study is to define all sources of contamination on the RPA for inclusion in the post-closure solute transport modelling. Detail the COPCs present, the concentration or mass of the COPCs and any geochemical processes relevant to the mobilisation of COPCs.

The output of the study will feed directly into the post-closure solute transport modelling.

Scope and approach

INTERA have been engaged to update the existing solute source term for the post closure solute transport modelling. Additional scope has been included for the assessment of any new source terms that have not been previously included in the post closure solute transport modelling. These include the LAAs, processing area (mill, power station, CCDs, hydrocarbon storage, historic landfills, etc), TSF, and wetland filters.

The project consists of a desktop analysis of existing investigations, data and studies.

The scope of the source term work as a whole (original waste rock and tailings-derived materials scope and new additional scope) involves the following:

- update the conceptual understanding of concentrations of COPCs from waste rock
- update the conceptual understanding of concentrations of COPCs associated with tailings-derived materials
- update the INTERA (2016) conceptual understanding of groundwater impacts for the areas of interest/concern not associated with waste rock or tailings-derived materials

- estimate the COPC source concentrations suitable for use as inputs in simulating/calculating solute loading to creeks for waste rock, tailings-derived materials, and areas of interest/concern not associated with waste rock or tailings-derived materials
- draft and finalise a source term concentration report that will include all COPC sources at the minesite. The report will separate the COPC sources by the various primary materials/areas associated with the COPCs. For each material/area, descriptions of the data reviewed, assessments conducted, assumptions used, and results obtained will be provided.

5.5.2.8 Literature review on contaminant mobility

This project relates to multiple KKNs:

- WS1: Characterising contaminant sources on the RPA
- WS2. Predicting transport of contaminants in groundwater
- WS3. Predicting transport of contaminants in surface water

Factors influencing contaminant mobility in the sources and several pathways are covered by different KKNs. Details relevant to each KKN are described below.

Scope and approach

Undertake a desktop literature review summarising the site specific studies of contaminant mobility in water, sediment, soils, waste rock and tailings in the context of each KKN question and identify factors controlling mobility which need to be understood.

Results and conclusion

Literature reviews are attached to KKN closeout forms for review by relevant external stakeholders. Acceptance of the literature reviews results in KKN closeout.

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.	Literature review completed and attached to KKN closeout form for stakeholder review. Any further requirements for information can be addressed within projects against contaminant transport modelling. SSB feedback was to review need for additional information once final scenarios for predicting post-closure
WS2b	Groundwater pathway	Is conservative modelling or reactive modelling required? What factors are important?	
WS3c	Surface water pathway		

KKN	Compartment	Why factors controlling mobility need to be understood	Status
			surface water quality are completed. KKN closeout pending this.
WS3g	Surface water –sediment interactions	To determine if closure criteria will protect both environmental compartments	U & S identified as sediment CoPEC (contaminant of environmental concern). U rehabilitation standard protects both sediment and water. SO_4 rehabilitation standard derived to protect ASS forming.
WS3e	Groundwater – surface water interactions	Potential to limit or increase their concentrations from groundwater to surface water. Which could affect surface water quality predictions. *Note the KKN question focuses on physical influences, not chemical aspects. Jenny Stauber suggested including chemico-physical drivers at Nov 2019 meeting.*	KKN WS1b closeout covers the behaviour of contaminants in sediments (the interface) and the influence of factors such as pH, oxidation, secondary mineralisation etc at the source. Reactive transport drivers have been summarised in KKN WS2b & WS3c closeout. Reactive transport modelling discussed wrt WS2b includes the near surface layers.
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 is one of the sources reviewed in KKNWS1b closeout. Reports on U behaviour in sediments passed to SSB who are closing this KKN.
RAD9b	Concentration factors for bushfood	Quantify transfer from the environment (e.g. soil and water) to food items.	This is a SSB KKN.

5.5.2.9 Update groundwater solute transport modelling and conceptual model

This project relates to multiple KKNs:

- WS2. Predicting transport of contaminants in groundwater
- WS3. Predicting transport of contaminants in surface water
- RAD2. Radionuclides in aquatic ecosystems

Post-closure solute transport modelling is required to understand the mobilisation of COPCs from the RPA to the surrounding environment. This includes the mobilisation of contaminants from the storage of tailings, brines and contaminated material in the backfilled pits, from the landform waste rock, and from the LAAs located around the mine. The post closure solute transport modelling is split into multiple phases to support project execution.

The first phase of post closure solute transport modelling is to update to the Ranger conceptual groundwater model that was originally developed in 2014 (INTERA 2014a, 2014b) and then updated in 2016 (INTERA 2016).

In parallel to the update to the Ranger Conceptual Model, updates are required to specific inputs for the modelling, including 1250-01 Background COPCs, and 1250-08 Solute Source Area. The second phase is the 1250-11 post-closure solute transport modelling with uncertainty analysis.

The output of 1250-11 post-closure solute transport with uncertainty analysis is a key input to 1260-01 Surface Water Modelling.

Regular updates on the state and progress of the solute transport modelling are provided to stakeholders at MTC meetings and Ranger Closure Collaborative Forums. Further consultation is undertaken regularly with the SSB throughout the modelling process.

Solute transport modelling is required to directly address or support the Environmental Requirements (ER's).

The objective was to update to the Ranger conceptual groundwater model that was originally developed in 2014 (INTERA 2014a, 2014b) and then updated in 2016 (INTERA 2016). The update will be reviewed by stakeholders (SSB) prior to progressing the post closure solute transport modelling. This project is complete and an updated Ranger Conceptual Model is developed (INTERA 2019a). The outputs of the update of the conceptual model and solute transport modelling are required to support the Pit 3 backfill MTC application and address KKN WS2.

Scope and approach

The scope for the update to the Ranger conceptual groundwater model consisted of:

- review all available historical models, studies and projects on groundwater modelling, groundwater flow, and hydrogeological conceptualisations
- incorporate all recently available data, including groundwater monitoring, hydrogeological drilling
- review the exploration drilling data set to further refine the weathered zone and geological structures within the conceptual model
- update the Ranger Conceptual Model and undertake transient model calibration of the numerical model
- prepare a detailed report describing all updates and calibration of the Ranger Conceptual Model

- undertake head recovery modelling to predict when groundwater levels will recover to steady state across site. Include preliminary particle tracking modelling to understand solute transport pathways

Regular engagement was undertaken with stakeholders throughout the model update process and following completion. INTERA presented outcomes of the model update and calibration at ARRTC May 2019, follow-up review discussions occurred with the SSB. The revised report was issued in October 2019.

This project is complete and the updated Ranger Conceptual Model has been developed.

5.5.2.10 Post closure solute transport modelling with uncertainty analysis

This project relates to multiple KKNs:

- WS2. Predicting transport of contaminants in groundwater
- WS3. Predicting transport of contaminants in surface water

Post-closure solute transport modelling is required to understand the mobilisation of COPCs from the RPA to the surrounding environment. This includes the mobilisation of contaminants from the storage of tailings, brines and contaminated material in the backfilled pits, from the landform waste rock, and from the LAAs located around the mine. The post closure solute transport modelling is split into multiple phases to support execution.

The first phase of post closure solute transport modelling is to update to the Ranger conceptual groundwater model that was originally developed in 2014 (INTERA, 2014) and then updated in 2016 (INTERA 2016). The update to the groundwater solute transport conceptual model was completed in October 2019 by INTERA (Section 5.5.2.9).

Following the update to the conceptual model, multiple projects have commenced to support the update to the solute source area / conceptual model update, these including the Background COPCs in groundwater study and drilling campaigns (contaminated sites, TSF, stockpiles etc).

In parallel to the solute source area / conceptual model update, a study to develop a framework to link the outputs of the groundwater modelling, to the surface water modelling is underway. The aim is for a single report that summarises historical investigations, along with a review of more recent data to form a robust relationship for linking the two modelling packages together.

The post-closure solute transport modelling with uncertainty analysis forms the final step to predicting contaminant loadings from groundwater to the environment for 10,000 years post-closure. These loadings over time will then be evaluated through surface water modelling for assessment against closure criteria.

Key objectives of this project are to:

- develop probabilistic predictions of solute loading from Ranger Mine sources to Magela, Corridor, Coonjimba, and Gulungul creeks in the 10,000 years following mine closure

- calculate solute loads to the creeks for 20 COPCs: magnesium (Mg), 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

Scope and approach

INTERA has been engaged to undertake the post closure solute transport modelling. A scope of work has been prepared: *Scope of Work: Predictive Modelling of Ranger Post-Closure Solute Loading with uncertainty Analysis,* (INTERA 2019b). The scope of work (INTERA 2019b) outlines a two phase approach to the study including key deliverables and regular engagement with stakeholders.

Engagement with stakeholders is undertaken at approximately 6 weekly intervals, or when key milestones have been reached. These engagements are opportune times to discuss progress to date, clarify any concerns or comments, provide opportunity for feedback on the process and outline the tasks ahead.

Following completion by INTERA of the post-closure solute transport modelling with uncertainty analysis, the report will be provided to stakeholders for review and feedback.

5.5.2.11 Surface water modelling

This project relates to multiple KKNs:

- WS3. Predicting transport of contaminants in surface water
- RAD2. Radionuclides in aquatic ecosystems
- RAD9. Impacts of contaminants on human health

A surface water model of the RPA is required to predict concentrations of COPCs in surface waters present on the RPA and downstream of the post closure phase (Section 5.4.4).

The key objective of the study is to develop a surface water model that provides predictions of flow and COPC / sediment concentrations in Gulungul, Corridor, and Magela Creeks on the Ranger Project Area and downstream off the RPA after closure of the mine.

The output and results of the surface water model will form part of the Pit 3 backfill application.

Scope and approach

- Project start-up: collate and review all data pertaining to:
  - topographic information, landform profiles, LIDAR surveys, cross sections, billabong surveys.
  - review previously developed sitewide surface water models

  - local area surface water models, including OPSIM, rainfall runoff, 2D hydraulic models.
  - landform Evolution Modelling (LEM) for time series sediment loading to creeks.
  - erosion and sediment control features of the sites post closure
  - draft closure criteria
  - all available rainfall, flow, water quality data for the waterways of concern
  - rating curves for all waterways of concern
  - records of historical COPCs and sediment discharge from the site
  - aerial photographs
  - review previous studies and reports.
- Model conceptualisation
  - develop and refine the modelling framework for the study
  - develop modelling concept for each COPC and suspended sediment
  - develop Groundwater to Surface water model integration method
  - develop tech memo summarising the available data and proposed model concept.
  - update stakeholders in regard to surface water modelling progress
- Configuration and calibration of the surface water model
  - build the model in accordance with the framework
  - develop backwater billabong relationships
  - develop climatic sequences for calibration simulations
  - create COPC and sediment load inputs files
  - calibrate model to reasonably match recorded stream flows
  - develop modelling methodology for each COPC and suspended sediment
  - calibrate model to reasonably match recorded water quality data
  - undertake model verification
  - prepare Configuration and Calibration Report

  - update stakeholders in regard to surface water modelling progress
  - stakeholder review of surface water configuration and calibration
  - updates to address key/critical stakeholder feedback
- Application of surface water model
  - model agreed surface water model scenario cases
  - review results of model scenarios
  - prepare visualisation maps and graphics to effective communicate results
  - prepare surface water modelling results report
  - present modelling results to stakeholders
  - stakeholder review of surface modelling results
  - provide final report of surface water model results

Results and conclusion

The modelling was completed by Water Solutions in May 2020. A preliminary report has been provided which details the configuration and calibration of the model along with preliminary predictions. ERA has identified that further work is required to refine the model configuration and calibration. Additionally preliminary feedback from stakeholders is that further work is required on key elements of the model including downstream calibration and groundwater to surface water interaction. ERA is currently awaiting feedback from stakeholders on the scope of work of the final surface water model.

5.5.2.12 Surface water groundwater interaction

This project relates to KKN:

- WS3. Predicting transport of contaminants in surface water

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.

The objective of the study is to develop a report summarising the following:

- an understanding of the variations in groundwater discharge volumes into creeks over time relative to the surface water flow rates and volumes using a groundwater model that has greater refinement in spatial and temporal discretisation
- an evaluation of concentration data from groundwater bores and surface waters in conjunction with the model results to develop an improved conceptualisation of groundwater / surface water interaction and variation in surface water concentrations as surface water flows decrease when the wet season progresses into the dry season.

Scope and approach

The project requires the following:

- review historical studies into groundwater to surface water interactions, both regional and local scale
- review existing data sets including groundwater and surface water levels, and water chemistry to understand changes in hydraulic gradients adjacent creeks over the wet season
- review radon in groundwater studies to further support model conceptualisation and development
- develop updated groundwater to surface water conceptualisation utilising all available data
- test and validate updated conceptualisation within high spatial and temporal resolution numerical groundwater model
- develop a groundwater to surface water flow relationship that can be implemented in OPSIM to support the surface water modelling
- review and interpret data from the completed fieldwork
- multiple engagement sessions between groundwater and surface water modelling consultants have occurred to discuss and refine model integration linkage

5.5.2.13 Acid Sulfate Sediments management

This project relates to KKN:

- WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health
- RAD9. Impacts of contaminants on human health

Observed acidification events in Coonjimba Billabong (located on the RPA) during the early-wet seasons for the past several years indicate that on-site sediments may present a source of acidic water, metals and sulfate.

Assessment of recent water quality in Coonjimba Billabong, review of past studies of sulfate behaviour and acid sulfate soils (ASS) at Ranger and naturally in the Magela Catchment, and sediment studies were undertaken to understand the drivers and extent of the ASS issue in Coonjimba Billabong (Esslemont & Iles 2015, Esslemont, 2016). Baldwin (2017) reviewed these reports and other information, made several recommendations, and suggested a limit of 10 mg/L of sulfate in waters to protect against the development of ASS. The SSB adopted this value as the rehabilitation standard to apply at the mine lease boundaries.

Baldwin (2017) recommended a series of laboratory and modelling studies be undertaken to determine the persistence (and associated risk to the environment) of ASS at the Ranger Uranium Mining Site. This lead to the KKN question describing the need to predict sulfate budgets for the billabongs (i.e. Coonjimba, Georgetown, Gulungul) to assess the risk of acid sulfate sediment formation.

ERA contracted ERM to develop a preliminary conceptual model of ASS at Ranger (See 5.5.2.3)

ASS sediment sampling is planned for 2020 based on the conceptual model and Baldwin 2017 recommendations.

Scope and approach

Based on the results of the conceptual model and field assessments, a risk assessment of domains across the minesite will be undertaken to understand the future ASS occurrences/persistence in the billabongs. If the risk assessment indicates sulfate in water needs to be reduced or ASS sediments treated, trial mitigations and remediation options will be investigated.

5.5.2.14 Surface water pathway risk assessments (release pathways onsite)

This project relates to multiple KKNs:

- WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem health
- RAD9. Impacts of contaminants on human health

There is a need to assess what, if any, decommissioning/remediation is required for on site billabongs. The aim of any such work will be to minimise disturbance within the context of impacts that are ALARA-BPT.

Numerous studies have been completed, commenced or planned to understand what contamination exists, or is expected on the RPA following closure. The outputs of these studies will be used to understand the risks posed to the primary environmental objectives and the options for management of the risks.

This risk assessment of the surface water pathway on the RPA will use the results of projects against several KKNs, particularly those predicting contaminant concentrations in surface water and sediment (WS1, 2 and 3) and the effect of those concentrations to the ecosystem (WS5 & WS7) and human health (RAD9).

5.5.2.15 Eutrophication risk study

This project relates to KKN:

- WS6. Determining the impact of nutrients in surface water on aquatic biodiversity and ecosystem health

Sources of nutrients

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

The risk from nutrients has been low during the operational phase as waters are segregated and treated before directing to the release water circuit.

Load limits

Currently ERA must comply with Annual Additional Load Limits (AALL) for the discharge of NO_3-N (4.4 t/y) and PO_4-P (2.8 t/y) 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.

Brown *et al* 1985 refers to a study of ecological risk (no report cited) as the basis for the nitrate and phosphorous AALL. However, a review of the literature indicates that the AALL allow a doubling of the natural loads recorded in the 1982-83 wet season.

Scope and approach

Desktop review:

Phase 1: Review the AALLs for relevance and suitability for deriving an ammonia AALL:

- review the literature and basis of the current AALLs
- determine if the P and N AALL remain relevant and whether ammonia data are available and suitable to derive an ammonia AALL
- derive an AALL for ammonia if available data are suitable

Phase 2: Assess post-closure eutrophication risk

- compare surface water model predictions to national default guideline values (ANZECC & ARMCANZ, 2000) and background data (1st tier assessment)
- if these are exceeded conduct a higher level risk assessment in line with national guidance (ANZG, 2018)

Results and conclusions

Reports reviewed include:

- the body of work on nutrients in the Magela system, including those describing loads and concentrations of nutrients and eutrophication status of the floodplain billabongs (eg; Hart *et al* 1986b & 1987, Hart & McGregor, 1980, 1982; Walker & Tyler 1982 & 1983.)
- reports on additions of nutrients to natural waterbodies or wetland filters at Ranger Mine (Kessel, 1983; Overall 2001, 2003)
- the basis of the AALL and past nutrient concentration limits (Brown *et al*, 1985, Hart *et al* 1986b & 1987).
- national guidelines for nutrients (ANZEEC & ARMCANZ, 2000; ANZG, 2018).
- nutrient concentrations for waste rock, brines and tailings source terms (INTERA 2016).

Although cited as being based on ecological protection (Brown *et al* 1985) the basis of the current AALL appears to be a doubling of the annual loads of phosphorous-P and nitrate-N measured during the 1982-83 wet season (Hart *et al* 1986b and Hart *et al* 1987).

Ammonia was identified as a toxicant by Brown *et al* (1985) and OSS (2002) but not as a driver of potential eutrophication. Concentration limits were therefore developed for ammonia but not load limits. The addition of nitrate to the system was noted (in OSS, 2002) as not posing a risk to eutrophication yet nitrate load limits were set.

The SSB and ERA agree that the current AALL are not suitable for closure criteria and that KKN WS6b can be closed. Final documentation is being prepared for the KKN close-out relating to Annual Additional Load Limits (AALL) to be used to inform ammonia closure criteria (WS6b).

Eutrophication risk assessment (KKN WS6c)

The ERA literature review also showed that:

- the Magela Creek system is prone to natural eutrophication and is P limited, although P additions did not necessarily induce algal growth
- algae growth could occur depending on other factors such as nitrate availability, light, pH, and plant metabolism
- annual inputs of nutrients from the creek to the floodplain is very low compared to the load contained in the floodplain vegetation, benthic sediments and rain
- the trophic status of the floodplain is not greatly affected by inputs of N and P from the catchment
- the concentrations of nutrients in the waste rock source-term, the largest source of contaminants post closure are an order of magnitude lower than national guidelines for nutrients in the tropics (ANZEEC & ARMCANZ, 2000). Only ammonia in process water and brines, which make a very minor contribution to the creek waters, are higher than the default guidelines.

ERA is working with the 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.

5.5.2.16 Aquatic ecosystem assessment & framework development

This project related to multiple KKNs:

- WS7. Determining the impact of contaminants in surface and groundwater on aquatic biodiversity and ecosystem health
- CT1. Assessing the cumulative risks to the success of rehabilitation on-site and to the protection of the off-site environment.

Commonwealth ERs specific to the protection of water quality and the closure of Ranger Mine specify that:

- 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 as low as reasonably achievable (ALARA) (ER 1.2e).
- The RPA must be rehabilitated to a state to allow incorporation into Kakadu National Park (NP) (ER 2.1).

The SSB has set rehabilitation standards for water quality to provide high level ecosystem protection to protect biodiversity. These are based on ecotoxicity testing of local species, mesocosm studies and field macroinvertebrate and fish studies and are designed to protect 99% of species. These standards apply at the lease boundary (Supervising Scientist 2018).

Less conservative water quality objectives are required to support the RPA goal of impacts that are ALARA. ALARA allows for some change while still ensuring the primary environmental objectives off the RPA are not compromised and the RPA can potentially be incorporated into Kakadu NP in the future. The national Water Quality Management Framework (WQMF) (ANZG, 2018) will be followed and a number of assessments conducted to identify the ALARA option and water quality objectives for aquatic biodiversity and ecosystem health on the RPA.

An ecosystem vulnerability assessment is being developed as part of this project.

Understanding ecosystem response to mine effected water

An understanding of the potential impacts of mine-related stressors on aquatic biodiversity, and the endpoints representing the primary environmental objectives values of ecosystem processes, Kakadu NP World Heritage values (including culturally sensitive species) and Ramsar values is required. Biological indicators have been identified to reflect these primary environmental objectives. These biological components (species, communities, ecosystems) vary in their sensitivity to contaminants.

Solute transport modelling is currently underway to predict the concentrations of COPCs on, and downstream of, the RPA following closure. It is important to understand what type of change might occur at different contaminant concentrations to assess the suitability of the mine closure strategy, inform BPT/ALARA assessments to apprise the need for additional mine closure activities, and support the RPA on-site water quality objectives.

Scope and approach

BMT 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)
- develop a risk-based vulnerability assessment framework (VAF) 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 involved considering direct sensitivity to magnesium concentrations and indirect sensitivity via other factors affecting vulnerability, such as habitat, diet, reproduction and dispersion. (BMT, 2019).

Results and conclusions

This project is > 80 % complete. The vulnerability assessment has been conducted and a phase 3 draft report produced. New data which has since become available will be captured and considered in a re-assessment. The phase 3 report will then be updated with new biological effects information and a rescoring of vulnerability can then proceed.

Monitoring is recommended to address potential knowledge gaps identified in the aquatic ecosystem assessment & framework development. Monitoring will also provide information on the status of the aquatic ecosystem across a contaminated gradient at site to inform ALARA assessments and agreement for on-site water quality objectives/closure criteria.

The monitoring plan will be developed once the aquatic ecosystem assessment & framework development has been finalised.

5.5.3 Health impacts of radiation and contaminants

This section provides summaries of selected completed and ongoing KKN related studies linked to the theme of *health impacts of radiation and contaminants*. Some studies inform multiple KKNs and have only been included once to avoid repetition.

<table>
<tr><th>KKN title</th><th>Project title</th><th>Status</th><th>Section</th></tr>
<tr><td>RAD1 Radionuclides in the rehabilitated site</td><td>Radiological Impact Assessment</td><td>In Progress</td><td>5.5.3.1</td></tr>
<tr><td>RAD2: Radionuclides in aquatic ecosystems</td><td rowspan="3">Bushtucker Sampling Assessments</td><td rowspan="3">In Progress</td><td rowspan="3">5.5.3.2</td></tr>
<tr><td>RAD6: Radiation dose to wildlife</td></tr>
<tr><td rowspan="2">RAD7: Radiation dose to the public</td></tr>
<tr><td>Pit 1 Radiological Monitoring</td><td>In Progress</td><td>5.5.3.3</td></tr>
<tr><td>RAD8: Impacts of contaminants on wildlife</td><td rowspan="2">Human Diet assessment</td><td rowspan="2">Planned</td><td rowspan="2">N/A</td></tr>
<tr><td>RAD9: Impact of contaminants on human health</td></tr>
</table>

5.5.3.1 Radiological impact assessment

This project relates to multiple KKNs:

- RAD1. Radionuclides in the rehabilitated site
- RAD6. Radiation dose to wildlife
- RAD7. Radiation dose to the public

The preliminary radiological impact assessment, required to assess the radiological impact to members of public and terrestrial and aquatic wildlife is in progress and a draft report is currently under review (JRHC, 2020). The summary below provides information on the methodology followed in the assessment for members of the public and non-human biota.

Scope and approach

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,

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.

Recent preliminary surface water modelling results (Water Solutions 2020) provided the predicted concentrations of uranium, Ra-226 and Po-210 at a number of locations along the surface water pathways of the RPA for the years 1, 20, 270 and 10,000 post-closure. The likely concentrations of U-238, U-234, Th-230, Pb-210 and U-235, necessary for the dose assessment, were extrapolated from these predictions using equilibrium assumptions and the ratio of radionuclides reported in Murray (1992).

The potential concentrations of radionuclides above natural background levels were then calculated for Mudginberri, Coonjimba, Georgetown and Gulungal billabongs for the timeframes 1, 20, 270 and 10,000 years.

The outcomes from the atmospheric dispersion and surface water models were used as inputs into the radiation dose assessment. The assessment considered potential radiological impacts to members of the public, as well as terrestrial and aquatic biota.

Members of the public

The dose assessment for members of the public post-closure considered the following radiation 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.

Further information on post-closure landuse required for dose assessment is provided in Section 8.

Terrestrial and aquatic biota

The impact to specific terrestrial and aquatic species is based on changes in radionuclide concentrations of the media within which the species resides. For example; the media for fish is water. Therefore, determining the incremental changes in water radionuclide concentrations post closure is the basis for determining impact to fish. The method for determining the change in media concentration is via modelled dust deposition results and surface water solute transfer. The impacts to biota were then 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 were compared to the predicted changes in media concentrations for above background concentrations of Ra-226. Guidance values for Ra-226 concentrations in water and soils were not exceeded.

As the guidance values were not exceeded, a limited number of more targeted ERICA assessments were conducted:

- terrestrial species on the final landform at Closure
- freshwater aquatic species in the Gulungul Billabong at years 1, 20, 270 and 10,000
- freshwater aquatic species in the Coonjimba Billabong at year 270
- freshwater aquatic species in the Mudginberri Billabong at year 270

A number of representative organisms were considered in the ERICA assessment:

- freshwater fish (including benthic and pelagic species)
- molluscs (including bivalve and gastropod species)
- freshwater reptile
- freshwater vascular plants
- amphibian
- arthropod
- bird
- grasses & herbs
- mammal - large
- mammal - small-burrowing
- reptile

- tree

The outputs of the ERICA assessment, as dose rates to representative organisms, will be reviewed against closure criteria dose rates of 100 uGy / hr for the most exposed terrestrial species and 400 uGy / hr for the most exposed aquatic species.

Results of the radiological impact assessment will be preliminary as the water quality data used in this report are being updated in the final Surface Water Model (Section 5.5.2.11). The radiological impact assessment will be updated after water quality data is finalised. The complete dose assessment results will be included in the 2021 MCP.

5.5.3.2 Bushtucker sampling

An Independent Surface Water Working Group (ISWWG) conducted a review of the surface water management and monitoring associated with Ranger Mine in 2013. The ISWWG (Hart & Taylor, 2013a) recommended the re-introduction of the bush tucker monitoring program:

> *Recommendation 6: A routine 'metals (including radionuclides) in bush tucker' monitoring program be re-introduced, with ERA and GAC to provide details on the scope and objectives for such a program, and SSD to review existing 'metals in bush tucker' data base and provide advice on program design.*

Hart and Taylor (2013b) detailed the information and rationale that led to these recommendations.

The above recommendation was aimed at addressing concerns of the Mirarr Traditional Owners regarding the contaminant levels in bush tucker from Mudginberri Billabong by reintroducing a monitoring program for heavy metals and radionuclides in fishes and other freshwater biota.

The targeted species for the sampling program have been discussed in the Bush Food Diet section in the document *Post Closure Land Use* (Paulka 2016).

This study is undertaken in two phases. The first phase of this study is complete, and focussed on terrestrial fruit and vegetables collected from the Trial landform and other areas on the RPA. The second phase of this study will look at collecting and analysing a variety of terrestrial and aquatic fauna, to be undertaken in the second half of 2020.

Scope and approach

The aim of this project is to determine the bioaccumulation of heavy metals and radionuclides in traditional Bininj food and to interpret and communicate the results.

The first phase of the project assessed selected flora species. Flora, except for yams, have been sourced from the Trial Landform (TLF). Yams have been sourced from elsewhere on the RPA as they are not present on the TLF.

Fauna sampling and assessment will be completed as phase two. The fauna species selected will include a variety of introduced and native species found on the Ranger Project Area and surrounding Kakadu NP. Fish species will be sourced from Mudginberri and Georgetown billabongs. The locations for fauna sampling are shown in Figure 5-105.

All approvals will be sought prior to the commencement of works, including Charles Darwin University animal ethics approval, Parks Australia Approval, Fisheries Approval. The work will involve Traditional Owners where possible.

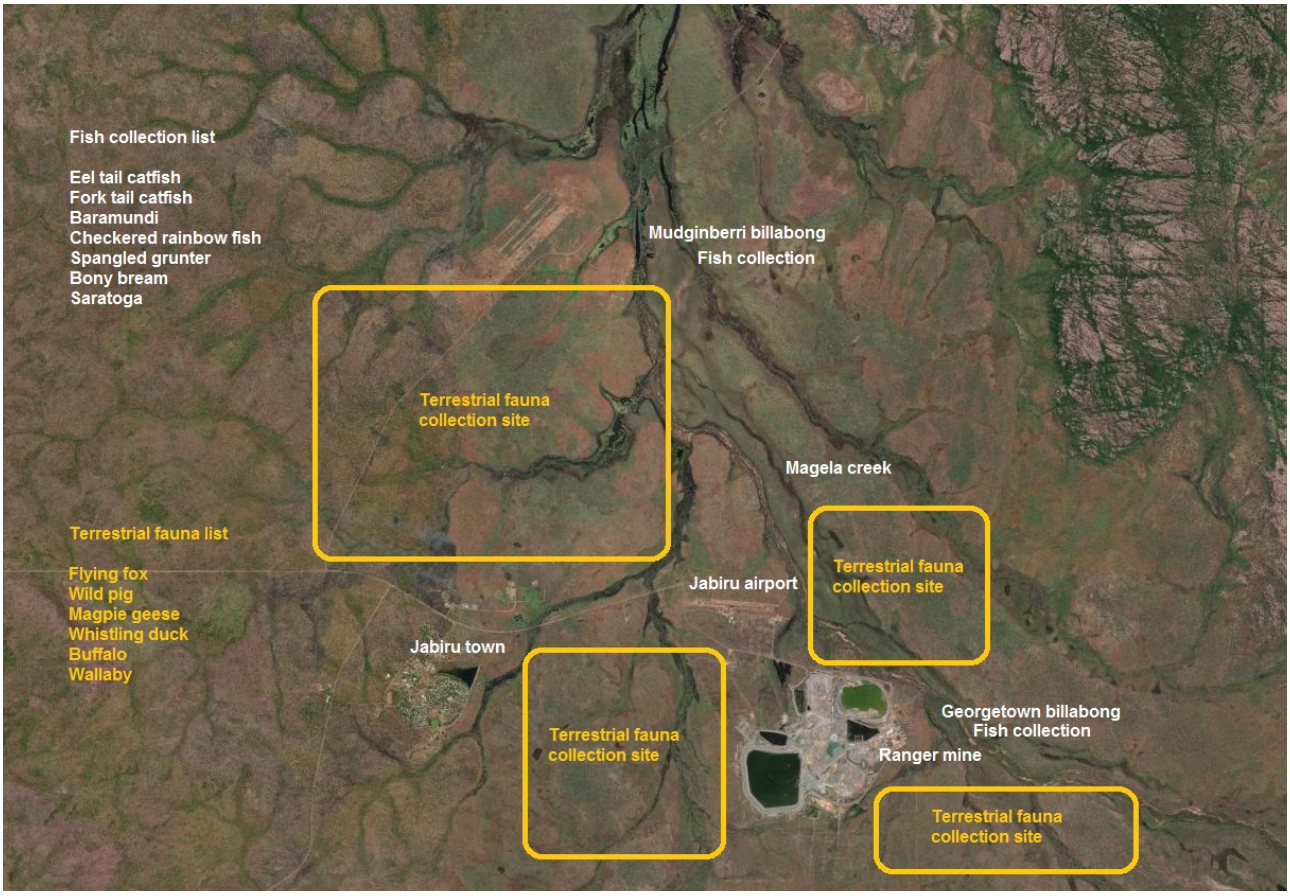


Figure 5-105 Fauna (bushfood) sampling locations within Kakadu National Park and the RPA.

5.5.3.3 Pit 1 radiological monitoring

ERA is currently finalising the scope of works to undertake radiological monitoring on the completed Pit 1 landform.

Scope and approach

A radiation survey and sampling program is to be undertaken and will consist of four components:

- Surface gamma survey
- Radon-222 exhalation flux density measurement

- Radium-226 waste rock substrate sampling
- Radon-222 in air measurement (passive)

The survey and sampling will be based on a systematic random sampling approach as shown in Figure 5-106 below (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).

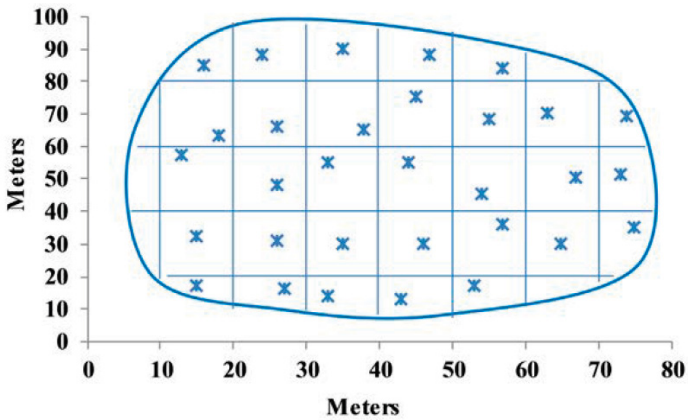


Figure 5-106 Systematic random sampling approach (IAEA 2019)

Gamma Survey

A gamma survey will be performed by competent trained personnel using a gamma detector in a regular grid pattern over the Pit 1 area. Absorbed gamma dose rates are to be measured at a height of 1m above the ground level and integrated over a 60 second time interval.

Radon-222 exhalation flux measurement

Brass canisters containing activated charcoal will be used to collect the exhaled Radon-222 from the surface waste rock. The canisters will be standard brass cylinders with an internal diameter of 0.007 m, depth 0.058 m and a wall thickness of 0.004 m, or other appropriate design proved suited for the purpose of the sampling program. The canisters will be prepared by heating (over 110 °C) over 48 hours (or other suitable method) to eliminate adsorbed substances prior to the measurement.

The mouth (face) of the canister will be put against the ground surface and sealed when necessary. Putty seal will be used to seal canisters on Pit 1 as it will be a waste rock surface. Areas of water inundation will be avoided. The canisters will be left for 3 days (72 hours) to secure the total adsorption of Radon-222 and the shorter-lived progeny radionuclides to the charcoal contained.

A number of sealed 'blank' canisters will be deployed in the field for background reference data and sent to the lab with the other samples for analysis. The decay of Radon-222 progeny will be measured with a NaI(TI) gamma detector calibrated for the respective cup geometry. The

Radon-222 exhalation flux density over the period of exposure of the charcoal canister on the landform will be estimated using published methodologies with Spehr and Johnston (1983) and Bollhöfer *et al*. (2005) as examples.

To assess seasonal variability, ERA will aim to undertake Radon-222 exhalation flux measurements at the end of dry-season in 2020 and at the end of wet season in 2021.

Radium-226 waste rock 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 Radon-226 in the sample.

Radon-222 in air measurement

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.

5.5.4 Ecosystem rehabilitation

This section provides summaries of the completed studies relating to the theme Ecosystem Rehabilitation as well as selected completed and ongoing KKN related studies. Some studies inform multiple KKNs and have only been included once to avoid repetition.

KKN title	Project title	Status	Section
ESR1. Determining the requirements and characteristics of terrestrial vegetation in natural ecosystems adjacent to the minesite, including Kakadu National Park.	Conceptual Model of Final Revegetation Reference Ecosystem/s	In Progress	5.5.4.1
ESR2. Determining the requirements and characteristics of a terrestrial faunal community similar to natural ecosystems adjacent to the minesite, including Kakadu National Park	Terrestrial fauna objectives & recolonisation strategy	In Progress	□
	Trial Habitat Creation on Trial Landform	In Progress	0

KKN title	Project title	Status	Section
ESR3. Understanding how to establish native terrestrial vegetation, including understory species.	Understorey nursery and TLF trials	In Progress	5.5.4.4
	Pit 1 Revegetation Studies	In Progress	9.3.1.3
ESR5. Develop a restoration trajectory for Ranger Mine	Evaluation of Key Attributes of Nutrient Cycling in Revegetated Waste Rock Landform of Ranger Uranium Mine	Complete	Appendix 5.1
ESR7. Understanding the effect of waste rock properties on ecosystem establishment and sustainability	Study of Root depth on TLF	Complete	Appendix 5.1
	Soil formation (PSD monitoring) on TLF at Year 10	Planned	0

5.5.4.1 Conceptual model of final revegetation reference ecosystem/s

This project relates to multiple KKNs:

- ESR1C. What values should be prescribed to each indicator of similarity to demonstrate revegetation success?
- ESR5B. What are possible/agreed restoration trajectories (flora and fauna) across the Ranger Minesite; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the minesite, including Kakadu National Park?
- ESR 8A. What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?

This project aims to review and compare industry best practice, ERA and the SSB approaches to reference site selection and flora and fauna closure criteria development. From this, ERA will develop the best approach for application at Ranger, including suitable reference ecosystems, justified closure criteria and complementary revegetation methods.

Scope and approach

The project is focussed on defining conceptual reference ecosystems and closure criteria for the post-mining Ranger landscape. Dr Libby Mattiske from Mattiske Consulting has been engaged to undertake this work, which requires the following:

- collate and analyse available baseline and rehabilitation datasets relevant to the Ranger Mine to develop a series of site specific reference ecosystems

- complete an assessment to identify the most suitable conceptual reference ecosystem for each domain, given specific constraints of the post-mining domains
- undertake an extensive benchmarking study to review and compare industry best practice for setting practical closure criteria
- develop closure criteria for each revegetation domain, including flora, fauna and other attributes that cover community composition, structure, and function (including resilience and sustainability

Progress

During 2019/2020 ERA and Dr Mattiske achieved a number of key steps, in consultation with key stakeholders, most of which is integrated within Appendix 5.1:

- completed the collation and analysis of available baseline data and proposed a series of potential conceptual reference ecosystems (Appendix 5.1)
- developed a package of technical information to inform future revegetation domain definition
- agreed on descriptive closure criteria with stakeholders (Section 8)

In 2020/2021, ERA shall continue working towards quantitative closure criteria through the following steps:

- review all available rehabilitation monitoring data from ERA including trial landform data, previous revegetation trials, and early results from Stage 13 and Pit 1 revegetation activities
- access relevant rehabilitation data from other sites, such as the *Eucalyptus tetrodonta* dominated revegetation at Gove and Weipa bauxite mines (over 40 years of knowledge)
- utilise the State-and-Transition model that has recently been developed (Richards et al. 2020 - in draft) to refine the trajectories for key parameters of the revegetation, to identify milestones and thresholds to inform the ERA Adaptive Management Plan
- review other trajectory study options as recently developed by Steedman et al. (2019) utilising species richness and density datasets to evaluate progress on rehabilitation areas
- propose quantitative closure criteria for the target 'close-out' timeframe expressed relative to the appropriate conceptual reference ecosystem
- undertake a statistical review and benchmarking exercise on how quantitative closure criteria should be monitored and assessed at Ranger Mine

5.5.4.2 Terrestrial fauna objectives & recolonisation strategy

This project relates to multiple KKNs:

- ESR2A. What faunal community structure (composition, relative abundance, functional groups) is present in natural ecosystems adjacent to the minesite, and what factors influence variation in these community parameters?
- ESR2C. What is the risk of feral animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?
- ESR5B. What are possible/agreed restoration trajectories (flora and fauna) across the Ranger Minesite; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the minesite, including Kakadu National Park?

Scope and approach

This project will identify the parameters required to identify the attributes of the terrestrial ecosystem that will enable recolonisation of the final landform with a diverse fauna community. This diversity includes the presence of invertebrate and vertebrate fauna (including consideration of richness, diversity, composition, occupancy and functional diversity), taxa of specific interest for their environmental and cultural significance and the management of exotic fauna.

This work will support the development and finalisation of fauna-related closure criteria, both direct and indirect measures. SLR has been engaged by ERA to undertake this project.

This project comprises two stages:

1. in consultation with key stakeholders, draft a report on the Ranger fauna closure criteria.
2. in consultation with key stakeholders, develop a recolonisation plan and monitoring program to facilitate fauna return.

Note: The project “Trial habitat creation on the TLF” is related to, and will inform, this larger project.

Progress

In 2020, SLR developed an updated suite of terrestrial fauna closure criteria based on scientific publications and informal consultation with key stakeholders. The closure criteria comprised a combination of metrics that assess attributes of the ecosystem to facilitate the recolonisation of a diverse fauna community, the presence of fauna, taxa of specific interest for their environmental and cultural significance and the management of exotic fauna. A draft report is currently under review and will be made available to stakeholders for consultation once it is finalised. A set of proposed draft closure criteria have been provided in Section 8.

5.5.4.3 Trial artificial habitat creation on trial landform

This project relates to multiple KKNs:

- ESR2B. What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?
- ESR5. Develop a restoration trajectory for Ranger Mine.

This project will identify the types of artificial habitat options available, and test their effectiveness in facilitating the utilisation by native species on the trial landform, and also suitable bushland sites.

Scope and approach

The presence of suitable habitat is an essential precursor to fauna recolonization. The development of mature vegetation communities correlates with increased faunal diversity. The presence of vegetation communities has frequently been used as an indicator of fauna recolonisation in mine closure (see reviews by Cross *et al*., 2019, Cristescu *et al*., 2012). Vegetation features that have been considered as indicators of the development of suitable fauna habitat for a diverse range of fauna include:

- tree hollows
- edible fruit-bearing trees and shrubs
- leaf litter and woody debris

Tree hollows provide important habitat for amphibian, bird, mammal and reptile species, including many species which are hollow-dependent (Taylor *et al.* 2003, Goldingay 2009, Goldingay 2011, Lindenmayer *et al.* 2014). Individuals of hollow-using and dependent species 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 mammal dens (including those in the NT) were >100 years of age.

Leaf litter and coarse woody debris (generally fallen timber >10 cm diameter) provide habitat for fauna species, including some specialists, in tropical savanna ecosystems such as at Ranger Mine. However, ground cover is highly variable depending on fire regimes and detritivore activity. One opportunity for increasing the diversity of species able to colonise the waste rock final landform would be the establishment of fresh litter islands.

This project will trial the use of artificial nest boxes on the trial landform to expedite the colonisation of the landform by fauna. ERA will deploy a variety of nesting boxes on the TLF, and also suitable bushland sites, to determine their effectiveness. Nesting boxes for arboreal mammals, bats and birds have been procured and safety and logistic arrangements for installation are currently underway. Other habitat methods relating to the provision of artificial ground cover (e.g. pipes, boards, rock piles) will also be trialled. Further details on litter islands has been provided in Section 3.3.3.3 of Appendix 5.1.

Evaluation and reporting outcomes

- regular updates to stakeholders as the trials progress.
- outcomes will be included in the Ranger Mine Closure Plan.

5.5.4.4 Understorey nursery and TLF trials

This project relates to multiple KKNs:

- ESR3A. How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?
- ESR7D. Are there any other properties of the rehabilitated site that could be attributed to any observed impairment of ecosystem establishment and sustainability, including vegetation and key functional groups of soil fauna?

Scope and approach

ERA need to demonstrate the ability to establish the full range (or an appropriate complement) of native vegetation species from the reference ecosystem. While this has been shown in initial trials for key overstorey species, there is far less available evidence for the successful establishment of a diverse suite of understorey species. This study will test a large suite of understorey species under trees in the TLF, site 1A and also on bare waste rock landform.

This project includes a number of trials including:

- 2020-21 TLF ‘secondary’ introductions trial
- 2020-21 TLF ‘secondary’ introductions: Understorey direct seeding trial
- ongoing monitoring of 2018 understorey trial
- nursery trials

These trials are discussed in Appendix 5.1

5.5.4.5 Soil formation (PSD monitoring) on the TLF at Year 10

This project relates to KKN 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?

Scope and approach

The TLF was constructed in 2009 from waste rock materials (100%) in TLF, sections 1A and 1B. The waste rock material was from Pit 3 run-of-mine which has a low content of fines (particle size < 2 mm). The fines content in TLF 1A ranges from 39 % to 27 % with an average of about 33 %. Plant available water can only be held in fines of the waste rock substrate. Low fines content results in a low plant available water capacity of the landform. The WAVES model demonstrated that a waste rock landform of 4-6 m will be able to support a woodland vegetation that is similar to that at the Georgetown creek reference sites 30 and 21 (Lu *et al* 2019). It is anticipated that as the waste rock weathers through physical/chemical and biological weathering processes the fines content in the substrate shall increase, thereby increasing the plant available water in the landform.

This project involves the collection and analysis of PSD in the top 10 cm of section 1A and 1B of the TLF. Results will be compared to previous results to demonstrate the degree of increase in fines content in the substrate after 10 years since construction of the landform.

Samples have been collected and analysis is underway.

5.5.5 Cross theme

KKN title	Project title	Status	Section
CT1. Assessing the cumulative risks to the success of rehabilitation on-site and to the protection of the off-site environment	Climate change and mine closure	Completed	5.5.5.1

5.5.5.1 Climate change and mine closure

A staged approach is recommended in which a first pass risk screening is first undertaken to understand how direct and indirect pressures from climate change may affect all aspects of the closure plan. The first pass assessment includes undertaking a review of any previous climate change considerations in the Kakadu NP and in relation to the mine (including by the SSB).

The approach will enable the climate change for the closure of Ranger Mine to be framed appropriately, something which is critical for the longer-term success of adaptation planning. The risk screening enables a more detailed, targeted approach towards understanding and managing climate risk, to be scoped. This will also identify any further studies or analyses that may be required and assist in the minimisation of unnecessary expenditure whilst ensuring that any studies and analysis will fill gaps and add value to mine closure adaptation.

The approach aligns with the ISO31000 Risk Standard and with leading practice in climate adaptation risk assessment framing, including guidance from ICMM on considering climate change for closure.

Scope and approach

This project was initiated to identify how climate change is likely to affect the plan for the closure of Ranger Mine and to determine any additional investigations or actions that are required to help address any challenges. The project aims to:

- understand how direct and indirect pressures from climate change may affect all aspects of the closure plan and the risks it may create
- understand climate change predictions of rainfall, temperature, cyclones, sea level change etc. for the region surrounding Ranger Mine during the decommissioning at post closure periods
- understand how the climate change predictions are likely to affect rehabilitation of the Ranger Mine and the surrounding environment and ecosystem
- screen risks to identify high risk issues
- identify if additional studies or processes are needed to underpin further risk assessment or management
- identify scenarios for modelling of high risk issues

Results and conclusions

Climate change descriptions for Kakadu NP have been completed and a stakeholder inception meeting for context setting, information availability, method and project planninga was undertaken in 2019.

A stakeholder workshop was held in ERA's Darwin office conference room on March 2020 to undertake a first pass assessment of climate change risk to the closure of the mine. The assessment was undertaken by subject matter experts from within and outside of ERA. A further on-line workshop was conducted with bushfire experts to gather additional expert input into this critical aspect.

The process included delivery of a briefing on climate projections for the target area, based on available information obtained from reliable resources including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Bureau of Meteorology (BoM) and the National Climate Change Adaptation Research Facility (NCCARF). Additional information was drawn from published peer reviewed literature.

An overview of the risk assessment process was presented and included discussion on the likelihood and consequence tables to underpin the risk analysis and ensure that all participants were comfortable with the approach. Stakeholders reaffirmed the outcomes for the project from the Inception Workshop, including the areas that should covered by the assessment and the projected timeframes that should be covered in the assessment. It was agreed that Jabiru and the airport were not to be included in the assessment and that the main timeframes to be considered were 2030 (initial post-closure planting and maintenance period), 2050 (planned post-closure monitoring end date), and 2100 (best available long-term projections). A mid-range climate change scenario of RCP4.5 was selected and a business as usual climate change scenario of RCP8.5. Using these two possible futures would help to determine when any major risks were likely to occur. There is little difference between the climate change projections of the two scenarios until after 2050.

In assessing risk, the current management plans and activities relating to the mine closure were discussed. Their role in addressing relevant climate change risks was assessed to enable any residual risk to be identified.

Discussion took place regarding the assessment of climate related risks for longer time periods associated with mine closure including the 10,000 year time period to be consistent with regulatory conditions. There are few climate change data available for those periods and the uncertainties associated with them is extreme. Accordingly, it was agreed that there was little merit in including these risks in the risk assessment activity.

The approach was then used to work through risks associated with: heat, sea-level rise and salinity, rainfall and drought, cyclones, and bushfire.

Thirty-seven potential risks were discussed and assessed. Risks were classified into four key areas

(1) onsite activities (management and monitoring)

(2) vegetation

(3) onsite and receiving water quantity, quality and ecology

(4) erosion and sediment.

In general, the relatively short period (compared to climate change timeframes) of active onsite management and monitoring, expected before the site stabilises and meets close-out conditions, meant that the risk profile for the mine closure was fairly low.

A full report of the risks assessed and recommendations has been finalised and shared with stakeholders.

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APPENDIX 5.1: REVEGETATION KNOWLEDGE BASE

REVEGETATION KNOWLEDGE BASE

Issued date: October 2020
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Cover photograph: *Cochlospermum fraseri* (native Kapok) on Trial Landform

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1 REVEGETATION OBJECTIVES, GUIDELINES AND STANDARDS

1.1 Objectives

The revegetation objective for ERA Ranger Mine is stated in the *Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine* (1999), which sets out the overarching environmental management at Ranger (referred to as the 'Environmental Requirements' or 'ERs'). Of direct relevance to this revegetation strategy are the following clauses:

> *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.*
>
> *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.*

Relatively high-level rehabilitation objectives, including the required post-mining land use, must be further developed and translated, through consideration of physical, chemical and other constraints of the altered conditions, into clear qualitative and/or quantitative targets (criteria) (e.g. Young *et al*. 2019c). This is necessary for rehabilitation planning and execution, subsequent monitoring and management of the developing ecosystem, and final assessment and sign-off (relinquishment) of the mature rehabilitated ecosystem. The following diagram represents the approach taken at ERA and indicates the process of refinement of objectives considering post-mining conditions, conceptual reference ecosystems, closure criteria, monitoring and management.

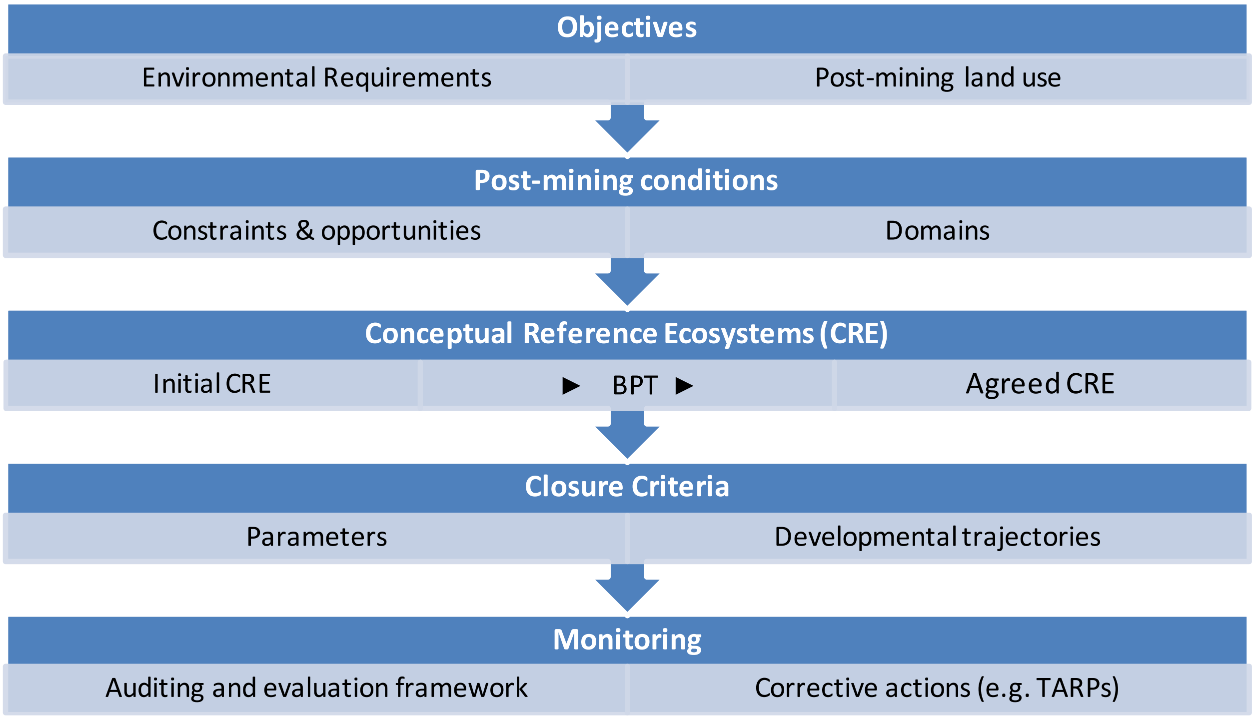


Figure 1-1: Process flow diagram (consistent with Young *et al*. 2019c).

Such an approach reflects the ongoing maturation of industry standards, which now recognise the need for all operators and stakeholders alike to have a clear understanding of the legal commitments and target end land uses, including specifics on the anticipated closure and rehabilitation challenges and opportunities with an emphasis and commitment to the process of continual review and improvement.

Of particular importance is the need to clearly differentiate between the ideal of 'restoration of the ecosystem to its pre-existing state' and the practical and feasible, given the often significantly altered post-mining site conditions. Different mines have very variable site conditions that need to be rehabilitated after mining and associated activities. For example, revegetation practices at large, progressive shallow mining operations such as bauxite mining or sand mining (where it may possible to replace topsoil and overburden directly during operations) are not feasible at open pit operations where minimising the disturbance footprint has been a priority, such as Ranger.

The Australian federal government's '*Leading Practice Sustainable Development Program for the Mining Industry'* series (Australian Government 2016b) uses the following distinction:

> ***Rehabilitation*** - *The return of disturbed land to a stable, productive and self-sustaining condition, after taking into account beneficial uses of the site and surrounding land. Reinstatement of degrees of ecosystem structure and function where restoration is not the aspiration.*
>
> ***Restoration*** - *Re-establishment of ecosystem structure and function to an image of its prior near-natural state or replication to a desired reference ecosystem.*

The National standards for the practice of ecological restoration in Australia (SRG SERA 2017) uses a similar, but slight different definition, namely:

> ***Rehabilitation*** *- reinstating some form of ecosystem functionality without seeking to also recover a substantial proportion of the native biota found in an appropriate native reference ecosystem. (Note: Such rehabilitation is especially encouraged and valued where it: (i) improves ecological condition or function and (ii) is the highest standard that can be applied.)*
>
> ***Ecological restoration*** *- the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. (Note: Single species restoration can be considered complementary and an important component of ecological restoration.)*

This differentiation between restoration and rehabilitation is important as it directly relates to the setting of realistic rehabilitation objectives and targets as well as the development and execution of appropriate, successful rehabilitation programs. Due to the significantly altered post-mining landscape at Ranger Mine, ERA uses the term rehabilitation to describe the overall closure program, including revegetation and subsequent ecosystem development.

To identify and accommodate this situation, an understanding of the ecosystem functions on both the native environments and their relevance to the post mining conditions is required, in particular a clear and definitive understanding of the constraints imposed on rehabilitation processes by the post-mining engineered landforms and site conditions.

In recent times the approach of designing ecosystems that have values in common with the native ecosystems in the local or regional context has become widespread (Mattiske & Meek 2020). At Ranger this is particularly evident in the language of the Environmental Requirements and also industry, community and stakeholder expectations. Whilst similarity and alignment of rehabilitation areas with the local native ecosystems is a reasonable goal, the influence of constraints and threats (e.g. seasonal establishment and growth conditions, site physical and chemical constraints, water availability, fires, weeds and exotic fauna) must be factored in. This may restrict the ability of a site to achieve a high degree of similarly to the reference ecosystem, at least within the timeframes normally available for revegetation establishment, management and site relinquishment (e.g. decades compared to centuries or more for achieving a mature, reference ecosystem). This does not necessarily mean that current rehabilitation and relinquishment timeframes are inappropriate (in fact, the timely return of land to post-mining landholders is often another rehabilitation driver), but that measures of success must take this into consideration and effort must be put into providing a sufficient level of confidence for the ongoing development of the relinquished rehabilitation towards the final, mature end state over time.

These concepts and how they are applied at ERA Ranger Mine are covered in more detail in Section 2 below.

1.2 Guidelines and standards

There are numerous Australian and international sources of guidance on the process and management of rehabilitation and closure in the mining industry including:

- 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)
- Integrated mine closure – good practice guide. Second edition. (ICMM 2018)
- National standards for the practice of ecological restoration in Australia. Second Edition. (SRG SERA 2017)
- Guidance for the assessment of environmental factors – rehabilitation of terrestrial ecosystems. No. 6. (WA EPA 2006)
- Statutory Guidelines for Mine Closure Plans (WA Department of Mines, Industry Regulation and Safety 2020)
- Completion criteria framework: an overview. (Young *et al.* 2019a)
- Completion criteria framework: endorsed by the Department of Mines, Industry Regulation and Safety. (Young *et al.* 2019b), and
- Project report: a framework for developing mine-site completion criteria in Western Australia. (Young *et al*. 2019c).

The current standards associated with baseline studies and rehabilitation studies has progressed significantly in the last few decades in line with increasing community expectations and also increasing industry standards associated with ecological rehabilitation and restoration programs (SRG SERA 2017; ICMM 2018; WA EPA 2016a, 2016b; Australian Government 2016b; Kragt *et* al. 2019).

In 2018, the SSB drafted an "*Ecosystem Restoration – Rehabilitation Standard for the Ranger uranium mine*" that aims to describe the requirements for restoring the terrestrial ecosystem of the Ranger Project Area (including riparian areas) in the Alligator Rivers Region of the Northern Territory (Supervising Scientist, 2018). This standard is considered by ERA, along with the overarching Environmental Requirements and corporate standards, to determine the desired outcomes for environmental protection at Ranger Mine.

2 REFERENCE ECOSYSTEMS AND CLOSURE CRITERIA

As prescribed in the ERs, ERA must establish an environment using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park.

At Ranger Uranium Mine, the waste rock final landform is dramatically different to pre-mining conditions and, although ERA has shown that this material can support development of a native woodland ecosystem (on the Trial Landform and other trials – see Section 3), there will likely be a degree of difference in these revegetated ecosystems to those that were there previously. The specific physical and chemical constraints (if any) of the rehabilitated landform must be considered (in the form of 'revegetation domains') and appropriate reference sites chosen representing native ecosystems likely to be suited to the post-mining conditions (SRG SERA 2017).

In the absence of a natural reference ecosystem with a similar topography and substrate as the final landform, a nearby natural reference ecosystem can be adopted but "adjusted to accommodate changed or predicted environmental conditions" (SRG SERA 2017). The reference ecosystem in the case of Ranger Mine will be a conceptual model synthesised from appropriate reference sites chosen considering, and/or adjusted for, the permanent and irreversible changes to the site based on research, trials, experience, benchmarking, and historical and predictive records.

Closure criteria are the qualitative or quantitative standards of performance used to measure the achievement of the rehabilitation closure objectives for the closure of the site and needed for the relinquishment of the mining lease (WA EPA 2006). They are usually expressed relative to a reference ecosystem (Young *et al.* 2019b) and a key principle of completion criteria development is that the change in the nature of the site as a result of mining is acknowledged (Young *et al.* 2019c).

ERA has developed a set of descriptive closure criteria, agreed with key stakeholders (SSB and NLC) in 2020. This is seen as a positive and important step on the journey towards developing quantitative criteria against the full suite of conceptual reference ecosystems suited to the revegetation domains of the rehabilitated mine site.

Figure 2 indicates the relationship between reference ecosystems (on the longer time frame), closure criteria (eg. after 25 years) and the revegetation domains associated with the post-mining site conditions in the rehabilitation areas.

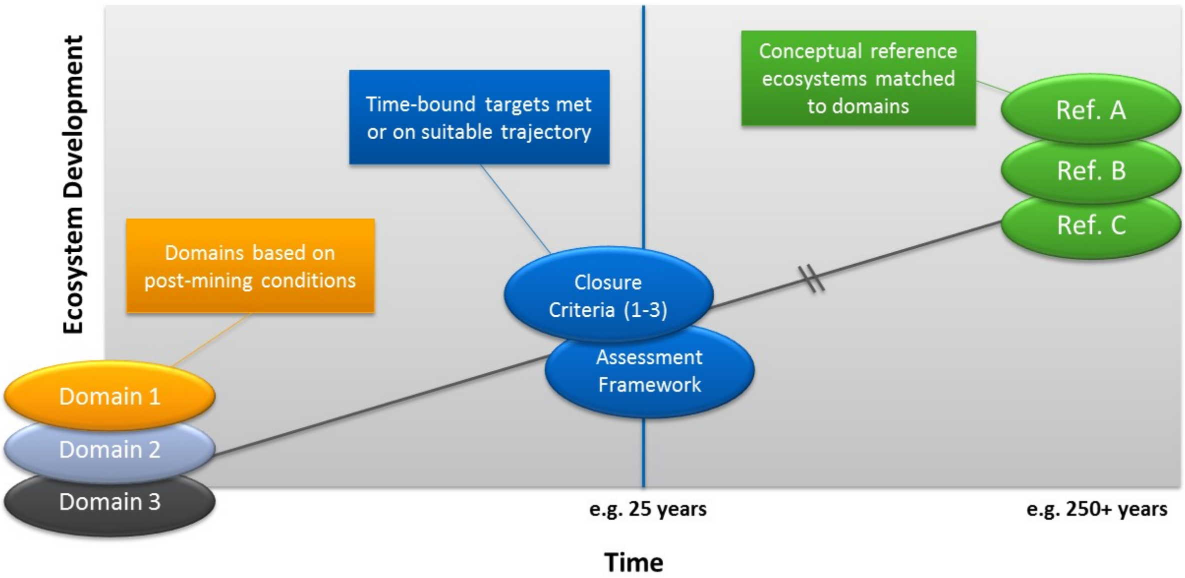


Figure 2-1: Relationship between domains, trajectories and (conceptual) reference ecosystems.

2.1 Reference site selection at Ranger Mine

A key element of the Ranger Revegetation Strategy (Reddell & Meek 2004; Section 1) 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. The identification of suitable reference vegetation types has mainly been based on ERA surveys in the surrounding natural landscapes that are potential geomorphic analogues of those formed on the final landform (based on the reasonable assumption that many of the environmental determinants of vegetation distribution will be similar in these settings). The intention is to revegetate the majority of the landform post mining with open eucalypt-dominated woodlands similar to the native vegetation typical of the surrounding areas near Ranger and within Kakadu National Park.

As work on this has progressed, including collaboration with key stakeholders, a clearer pathway towards development of an agreed conceptual reference ecosystem model for Ranger Mine revegetation has appeared, as outlined below:

- Ensure a shared understanding of clear and specific objectives (Section 1).
- 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.
- Understand any constraints (and opportunities) to revegetation establishment imposed by the post-mining conditions (Section 2.1.1).

- Identify and characterise a series of natural reference sites including common vegetation found in nearby areas, and/or vegetation likely to be suited to the different conditions in each revegetation domain (Section 2.1.2).

- Review and modify the natural reference sites based on research, trials, experience, benchmarking, and historical and predictive records (Section 2.2).

The following sections cover the final three stages of this approach.

2.1.1 Influence of post-mining conditions

A primary objective for rehabilitation of the Ranger Project Area is to return a native ecosystem similar to those in nearby Kakadu National Park. To ensure that the specific goals underpinning this objective are realistic and achievable, it is important to take into consideration all elements that may constrain or favour the various options (Young *et al.* 2019a-c; McCullough 2016).

At Ranger Mine, there are a range of physical constraints that may affect our ability to achieve the objective at a species level, community level, structurally, and also with regard to spatial distributions across the landscape (the final landform is an engineered landform and the locations or extents of the various constraints will not necessarily occur in a 'natural' distribution).

A preliminary approach to assessing the potential of post-mining landscapes is to undertake a landscape capability assessment (Young *et al*., 2019c). In 2020, ERA commissioned 2rog Consulting to assess and describe the land capability of the proposed final landform (2rog Consulting, 2020).

Also 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 constraints are discussed below, 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

- slopes and aspect

The extent and influence of these constraints was used in the following sections to develop a series of revegetation domains across the post-mining land form and then on the basis of these match each domain to a suitable reference ecosystem considering relevant environmental conditions (Section 2.1.2).

2.1.1.1 Land capability assessment

In 2020, ERA commissioned 2rog Consulting to assess and describe the land capability of the proposed final landform (2rog Consulting, 2020). The project was to consider the land capability of the final landform and place this landform capability within context of a broader regional area. Spatial data from existing sources including site-based mapping and modelling and regionally available data were to be used in conjunction with the NT guidelines for land capability assessment. A summary of the assessment outcome is provided below.

Land capability assessment in the Northern Territory is included within the land clearing and native vegetation management guidelines (DoENR, 2019). Land capability and land suitability assessments are used to determine if a soil and land resource is appropriate for the intended post-clearing land use. Land capability assessments evaluate the key soil and land resource parameters recorded in a land type map against a defined set of criteria to determine an overall land capability class. There are four land capability classes, Class 1 is the most versatile resource with Class 4 the most constrained.

Resulting from the 2rog assessment, almost 90% of the final landform (including some of the natural surrounds) was found to be classed as ‘marginal’ (land with severe constraints and requires considerable management practices) or ‘not recommended’ (land with extreme constraints too severe to develop. Can only be overcome with major management and/or engineered solutions).

Table 2-1 Classes resulting from the land capability assessment (2rog 2020).

Capability Class	Regional		RPA		Final landform & surrounds	
	ha	%	ha	%	ha	%
1 - High		0%		0%	53	3%
2- Moderate	18,444	2%	453	6%	184	11%
3 - Marginal	136,277	18%	2,260	29%	369	22%
4 - Not recommended	597,406	79%	5,196	66%	1,112	67%
TOTAL	752,127		7,908		1,665	

2.1.1.2 Material Type

The characteristics of the waste rock being used to construct the final landform have been documented in MCP Section 5.5.1.2 The key aspects of waste rock impacting vegetation establishment relate to plant water availability (PAW) and rooting depth.

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. For example, Section 1a of the Trial Landform (TLF) was constructed of material with an average of 33% fines and has been able to successfully establish a native woodland ecosystem; although some specific species have struggled (e.g. *Eucalyptus miniata* and *Acacia mimula*) and adjustments in species mix may be required to ensure the functionality of the target ecosystem is achieved (e.g. using *E. phoenicea*, *E. tintinnans* and *Acacia latescens*).

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.

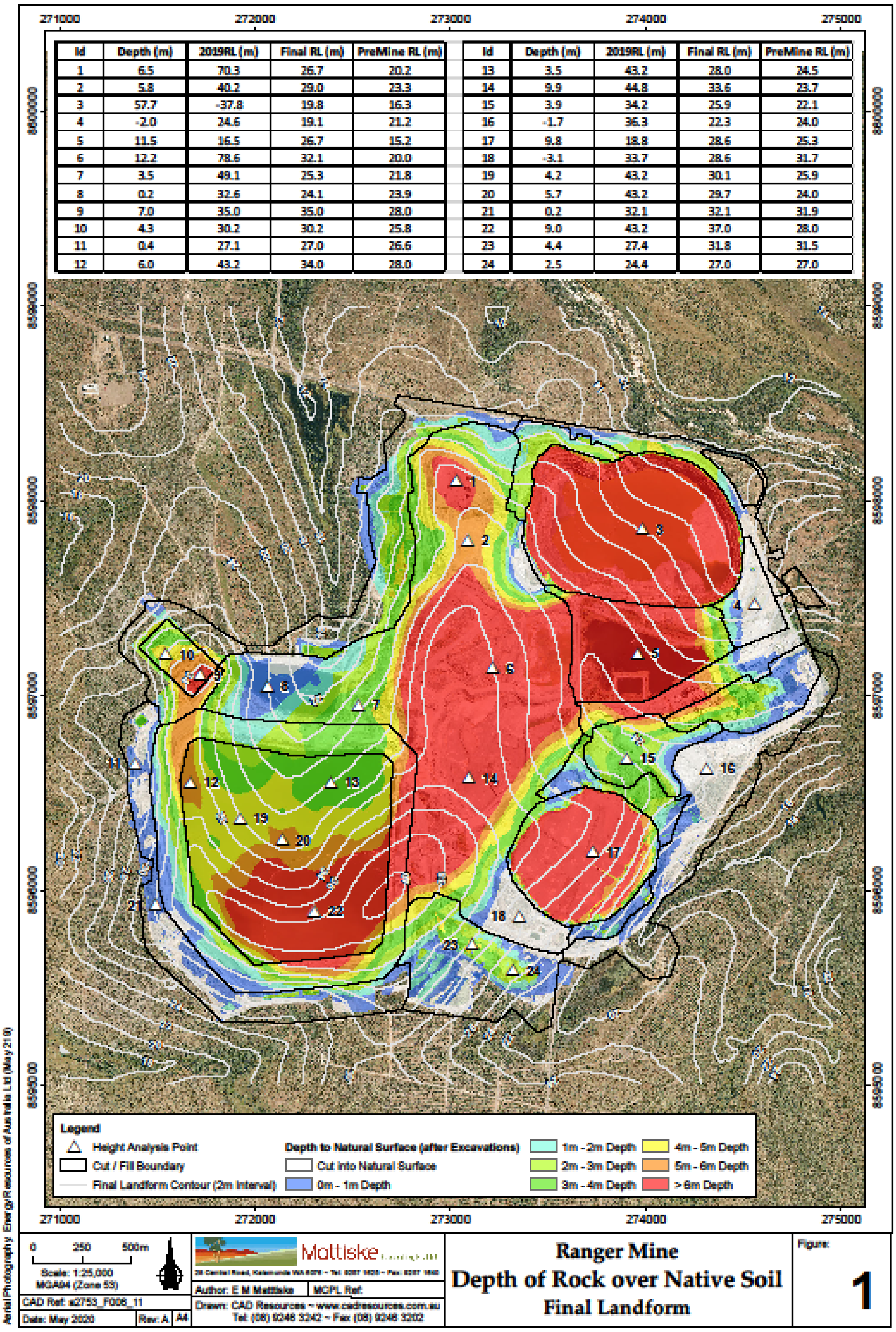
Particle size distribution (PSD) analysis of waste rock in stockpiles indicates that the waste rock ranges between 10%-60% fines (Section 4.1). Mine planning and bulk earthworks processes have been developed to ensure that the material to be placed in the surface growth layers (e.g. up to 6 m depth) of the final landform (FLF) is not below 15% fines and, wherever possible has more fines to optimise PAW.

Whilst it is not possible to exactly predict the PSD of all construction materials and therefore the occurrence of the different PAW 'zones' across the final landform surface, ERA has implemented an execution methodology that will ensure that the nature of the material in the 6 m growth layer is understood prior to final revegetation planning and execution. 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.

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 (Figure 2-2 and Figure 2-2). This means that plants in these areas, particularly larger plants with greater rooting depths, will likely be able to access any PAW in these soil and have improved plant-water relations in the late dry season when seasonal stresses are greatest. Plants on the other 38% of the FLF 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).

Table 2-2: Depth of waste rock over natural soils.

Depth	Area (ha)
Cut into Natural Surface	65
0m - 1m	73
1m - 2m	52
2m - 3m	59
3m - 4m	86
4m - 5m	72
5m - 6m	57
> 6m	283
Total	747



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

Id	Depth (m)	2019RL (m)	Final RL (m)	PreMine RL (m)
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 2-2: Depth of rock over natural soil.

2.1.1.3 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 2-3). 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. Suitable reference ecosystems will be further investigated and a suitable revegetation plan developed.

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 FLF 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. It is likely that alternative reference ecosystems will required for these areas, however that is outside this current scope of work.

Similarly, the nature of the subsurface hydrogeology in the area of the Tailings Storage Facility (TSF) will likely be an influence on what vegetation can establish. As agreed through stakeholder consultation, further investigations into these constraints, and identification and collection of suitable reference baseline data, will be conducted.

Emergent vegetative features in constructed waterbodies

The RPA has two wetland filters: the CCWLF (currently in operation) and the RP1 wetland filter (currently removed from operational use).

Valdron Clark (2011) describes the dominant vegetation species in the RP1 wetland filter, describing previous studies of the species on and off the RPA, the historical distribution and abundance of the species in the wetland filters, propagation methods, and their tolerances to environmental factors including water quality and hydrological regimes.

A series of four reports were prepared between July 2013 and November 2014 to chronicle the emergent vegetative features in the two artificially constructed waterbodies and water management sumps on the RPA (Valdron Clark 2013a, 2013b, 2014a, 2014b).

Water quality within the RP1 wetland filter is of pond water quality and water levels closely resemble seasonal cycles (Valdron Clark 2014b). The CCWLF has received inputs of varying water quality since its construction, including rainfall and surface water intercepts from the Southern Stockpile and Corridor Road, pond water permeate, and minor inputs from the TSF and Brine Concentrator (BC) distillate. The influx of distillate into the wetland in October 2013 resulted in recorded temperatures of between 45 and 55 ºC contributing to the dieback of aquatic plants throughout two of the wetland cells. However, aquatic flora species recovered, particularly *Eleocharis* species which demonstrated recruitment of new culms protruding from dead *Eleocharis* beds. For the most part, the wetland has continued to demonstrate resilience, in terms of vegetation establishment, as a response to wet/dry hydrological cycles (Valdron Clark 2014b).

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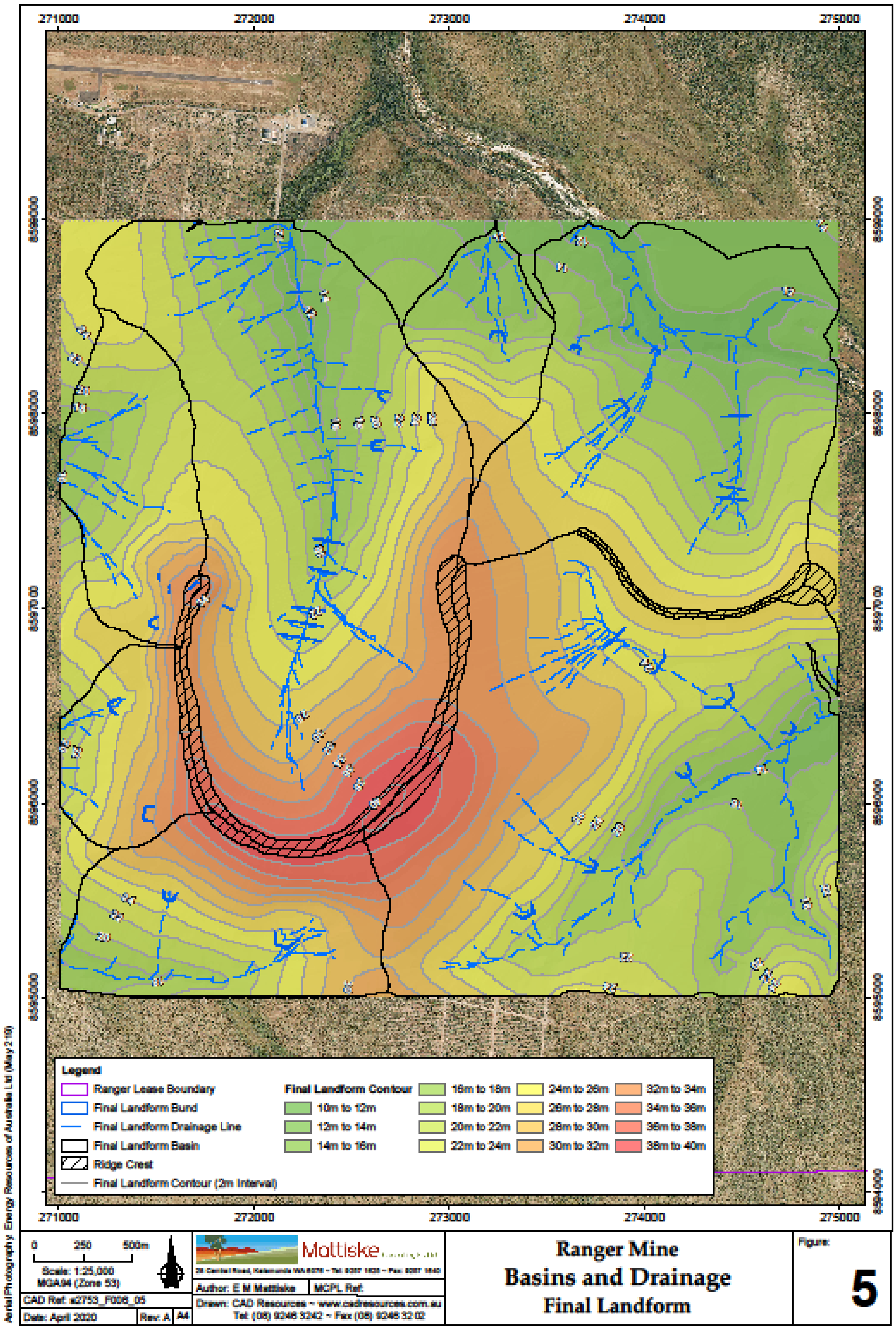


Figure 2-3: Basins and drainage features of the final landform.

Acidic conditions have been recorded in both the RP1 and CCWLF; however, recruitment of new plants and viability appear to have been unaffected by acidic conditions (Valdron Clark 2013b). In addition, frequent sightings of water monitors in the vicinity of both wetland filters suggest these artificial wetland ecosystems in the RPA are functional to some degree (Valdron Clark 2013b).

These reports provide evidence of the natural colonisation and successful establishment of aquatic vegetation habitats within constructed waterbodies on the RPA and an understanding of environmental conditions to support sustainability of these habitats.

2.1.1.4 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. The ecological risk assessment found that risks to revegetation from mine-derived chemicals is assumed zero (Bayliss 2018).

The TLF showed successful vegetation establishment and development with a methodology including application of fertiliser. The current ERA revegetation method also includes provision of a suitable fertiliser upon tubestock planting with a follow-up application in the subsequent wet season.

As part of the technical constraints review, it was identified that areas of potential acid sulfate soils 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.

2.1.1.5 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. The Ranger Mine rehabilitation plan allows for surface ripping of areas with steeper slopes, which should mitigate against any potential erosion risks.

2.1.2 Identify suitable natural reference sites

2.1.2.1 Targeted surveys of natural ecosystems

A description of the natural vegetation communities and flora and fauna of the region is provided in MCP Section 5.3.3. This section below shall cover surveys undertaken specifically to support development of a conceptual reference ecosystem for Ranger Mine rehabilitation.

The final landform at Ranger Mine 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. 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 Ranger Mine final landform and Project Area. 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). Understanding environmental features that are associated with the normal range of native vegetation community types (including PAW) informs the design and construction of the Ranger Mine final landform.

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 expect on the Ranger waste rock final landform.

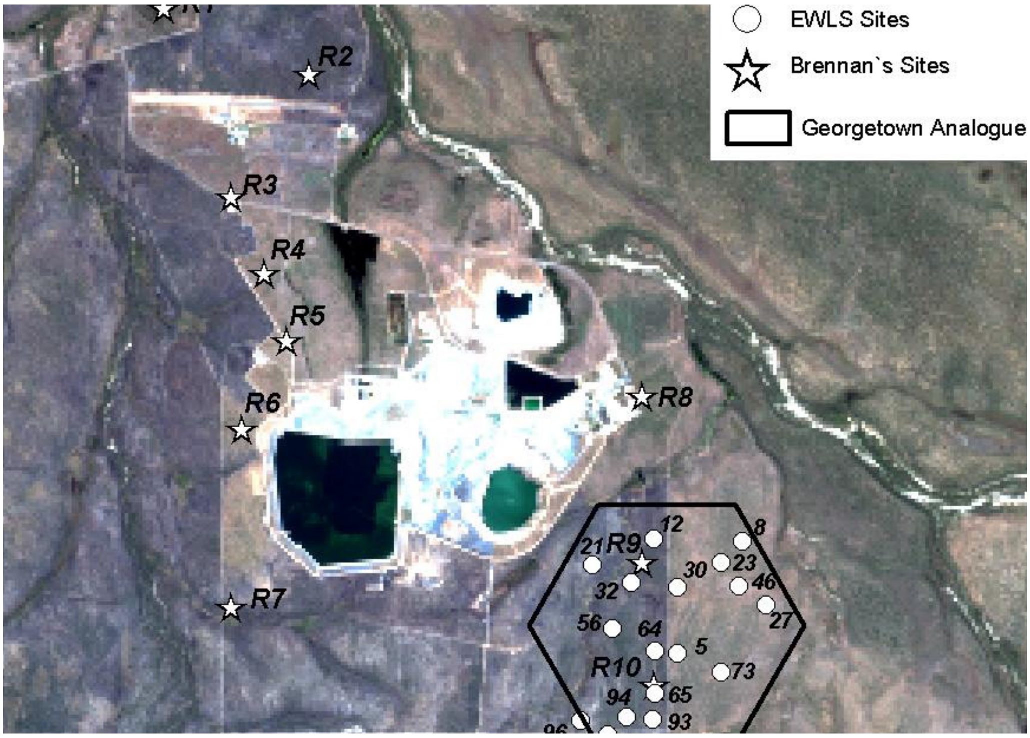
A Supervising Scientist study by Brennan (1995) compared vegetation found at areas adjacent to the Ranger site and those further afield (but within KNP) with a substrate likely to be more similar to the Ranger waste rock final landform. A key finding was that floristic heterogeneity (among the hill sites) was due to the dissimilarity of their substrates or parent-rock types. As Brennan (1995) 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.*

The RPA and surrounding areas of Kakadu NP have been studied extensively over the last sixteen years by ERA and ERISS to obtain information from appropriate reference sites to inform revegetation planning, management and performance objectives and assessment methods (in terms of closure criteria) (eg. 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 2-3).

Table 2-3: Vegetation Survey Data collected in the Alligator Rivers Region (adapted from Erskine *et al*. 2019).

Reference	n	Date Surveyed	Design	Plot Size and Methods	Plots within 10km radius of Ranger Mine
Conservation Commission (White *et al*. 1985)	77	1979-1981	Unknown	Vegetation present within 50m radius of soil sampling sites. 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 5m quadrats (400m^2) 25 understorey (0.71m x 0.71m (12.5m^2)	35%
EWLS (Hollingsworth & Meek (2003)	20	2002	Stratified Systematic	For trees and shrubs >2m; 320m x 20m plots (total of 1200m^2) at each site stratified by ecosystem types. 10 understorey x 1m x 1m (10m^2)	100%
Cyclone Monica (Saynor *et al*. 2009)	31	2006	Stratified Random	For trees & shrubs >2m 30m×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×20m plots (400m2) plots except site A53 (25m x 20m). Understorey not collected.	100%
2019-2020 (SSB 2019a)	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%



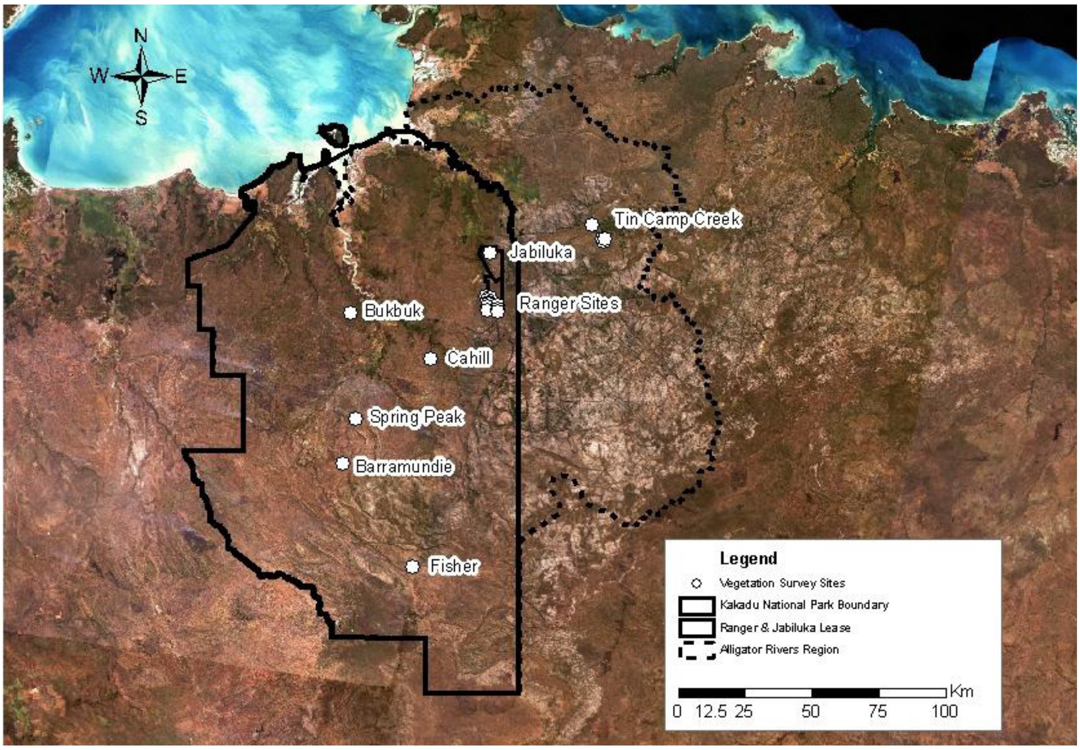


Figure 2-4: Maps of plant analogue sites surveyed by Brennan (2005) (top and bottom) and (Hollingsworth *et al.* 2003a) (bottom) (source Humphrey *et al.* 2006).

An area of focus has been the 'The Georgetown Creek Reference Area' (the hexagon in Figure 2-4), 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.* 2003, Hollingsworth & Meek 2003).

Extensive surveys of Georgetown Creek Reference 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 2-5). Monitoring plots in Figure 2-5 are coloured according to vegetation type:

- Pink: Tall *Eucalyptus tetrodonta* open forest
- Yellow: Tall *E. 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*, *E. setosa*, and *E. porrecta* open forest
- Brown: Tall *E. foelscheana, E. tetrodonta* and *E. confertiflora* mixed open woodland
- Red: Mid-high *E. confertiflora, E. tectifica* and *E. foelscheana* open woodland

The soils in the Georgetown Creek Reference 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 Creek Reference 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.) are also 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, and often localised, disturbance events.

Given the variation in PSD of the TLF (as discussed in Section 4.1) some degree of variation in PSD is expected in the source rock for the Pit 1 final landform cover and therefore the surface layer. The environmental characteristics that influence variation in plant communities, as discussed above, are likely to also vary across the Pit 1 final landform cover and result in the heterogeneous combination of vegetation communities observed in Ranger reference sites.

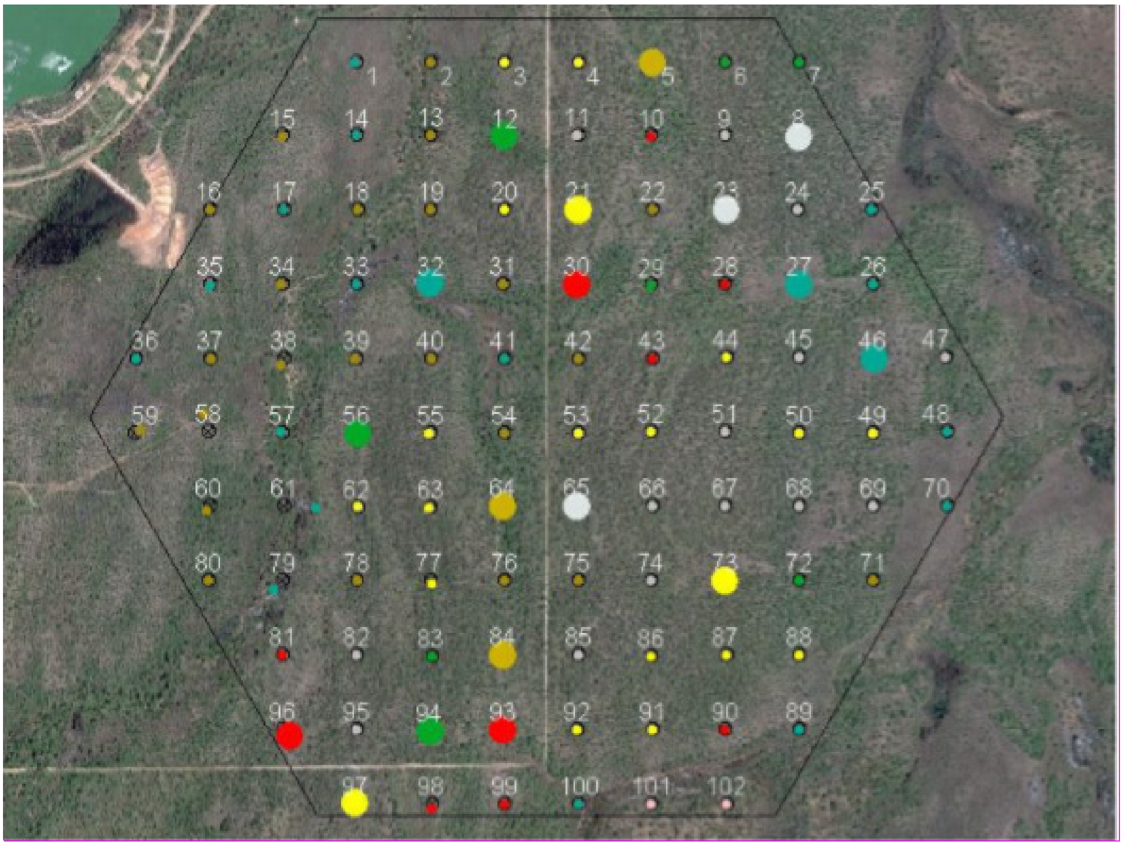


Figure 2-5: Georgetown Creek Reference Area vegetation type variation across monitoring sites

Multivariate classification of the vegetation communities surveyed in Georgetown (Hollingsworth & Meek 2003) and by Brennan (2005) resulted in four broad vegetation types based (Humphrey *et al.* 2012) (Figure 2-6).

Gardener *et al*. (2007) has described ecological attributes of each of the three community groups using species phenology, including growth form, life history, time to maturity, response to fire, type of re-sprouting and deciduousness. In general, all three communities have similar attributes, i.e. an even mix of tree and shrub species, comprising mostly long lived perennials and able to re-sprout after fire. The only attribute that differed was the relative contribution of deciduous species, with the drier community having a greater proportion of deciduous species.

This finding agrees with other studies in KNP; for example as part of the long-term, Kapalga experiment, Cook (unpublished data) demonstrated that soil depth, most likely through the mechanism of water availability during the dry season, is a major driver of tree stand structure (Cook 2020 *in draft*). The data show that evergreen trees increased in basal area as soil depth increased, but deciduous trees showed no significant variation with soil depth (Figure 2-7).

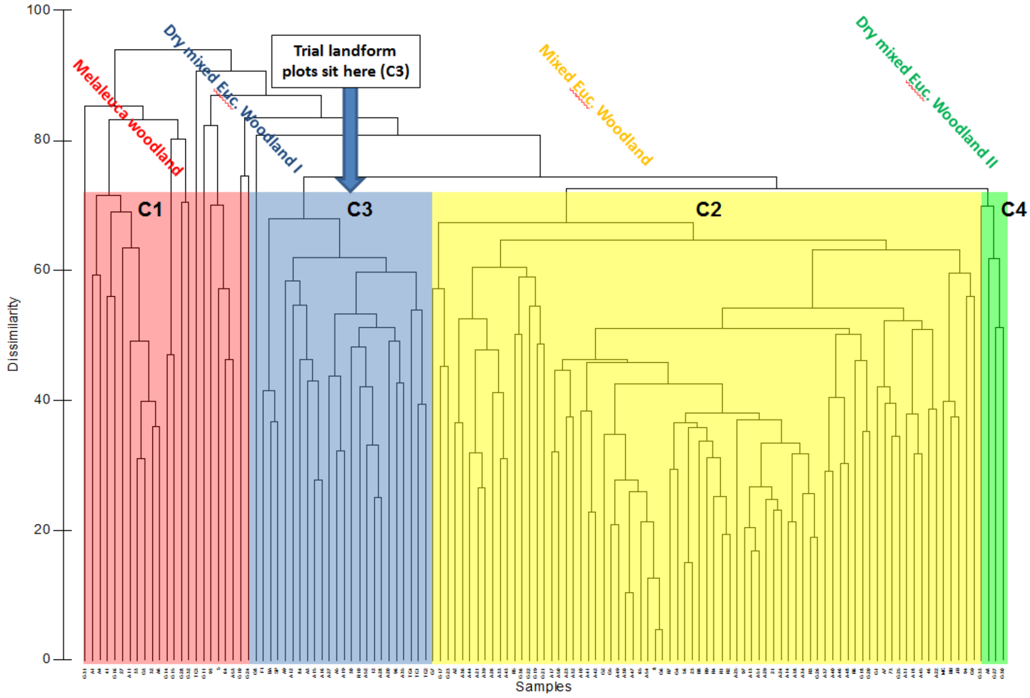


Figure 2-6: Cluster analysis (group average linkage) of trees and shrubs data for Alligator Rivers Region vegetation analogue sites. [Vegetation data log transformed density/ha units (Humphrey *et al.*, 2012).]

Table 2-4: Descriptions of the Ranger Mine analogue communities

Broad vegetation community	Dominant and/or distinguishing tree or shrub species	Classification unit[1]
Melaleuca woodland	*Melaleuca viridiflora, Pandanus spiralis, Planchonia careya*	C1
Mixed eucalypt woodland	*Acacia mimula, Eucalyptus tetrodonta, Corymbia porrecta, E. miniata, Xanthostemon paradoxus, Terminalia ferdinandiana*	C2
Dry mixed eucalypt woodland: Type 1	*Corymbia foelscheana/latifolia, X. paradoxus, T. ferdinandiana, P. careya, Cochlospermum fraseri*	C3
Dry mixed eucalypt woodland: Type 2	*Terminalia pterocarya, Acacia mimula, X. paradoxus, C. disjuncta, E. tectifica*	C4

[1] Humphrey *et al.* (2012); Figure 2A

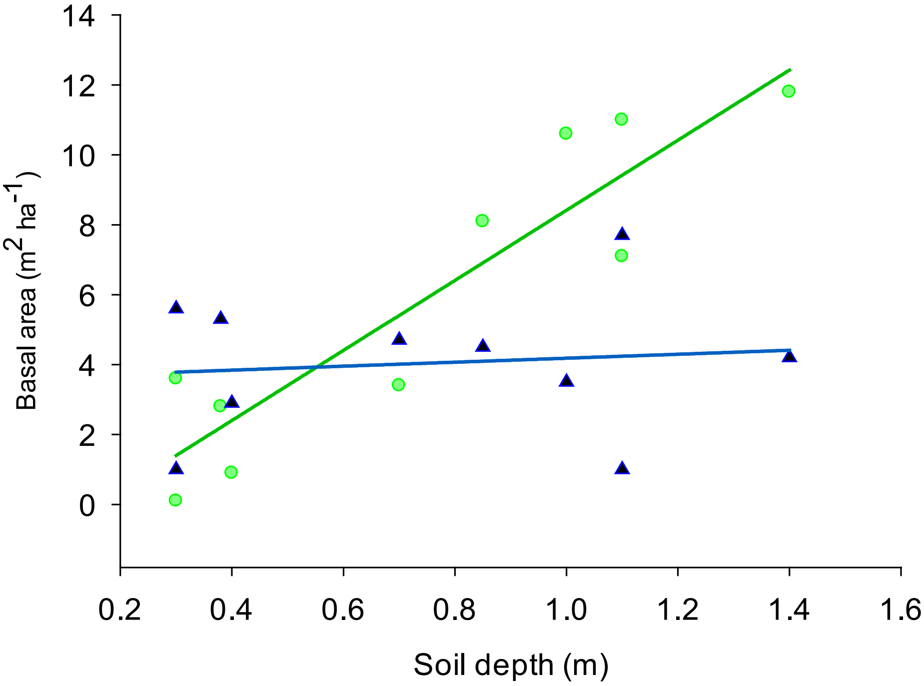


Figure 2-7: Variation in the basal area of evergreen trees (●) and deciduous trees (▲) in relation to soil depth along downslope catenary sequences at Kapalga in Kakadu National Park (Cook 2020).

In 2018/19, SSB surveyed 12 new one-hectare vegetation reference plots (including 2 sites within the Georgetown Creek Reference Area) from within a 10 km radius of the mine site. Multivariate ordination of overstorey cover data showed that nine of the sites (and ten sites if using overstorey stem densities) classified (in cluster analysis) with the dominant savanna woodland type for the local lowlands (SSB 2019a), termed 'mixed eucalypt woodland' *sensu* Humphrey *et al*. (2012). Data from these sites are interim, pending acquisition of data from larger scales, and will be useful to informing ongoing refinement of closure criteria and assessment by ERA.

2.1.2.2 Fauna baseline monitoring

A variety of flora and fauna studies in the RPA and surrounds have been conducted for purposes not specifically related to mine closure. Flora and fauna surveys conducted prior to 2012 were reviewed by ENV Australia Pty Ltd (Firth 2012) during the PFS for the Ranger 3 Deep mine development. Firth (2012) reviewed 18 flora survey reports, 26 fauna survey reports, three aquatic flora and fauna survey reports and seven reviews of previous terrestrial and aquatic flora and fauna work.

The establishment of habitats on the final landform that support fauna assemblages similar to Kakadu NP and contain culturally important fauna species is predominantly dependent on the success and final composition of the revegetation. Monitoring of the final landform and reference sites will provide data to determine trends in the composition and abundance of fauna.

Colonisation of revegetated areas by fauna of all trophic levels is critical for the healthy functioning of the ecosystem and its long-term self-sustainability (Corbett, L 1999). Successful fauna recolonisation primarily depends on the proximity to the source of the fauna and availability of suitable habitats within revegetated areas. The final landform will be surrounded by relatively healthy woodland and is therefore close to the source of native fauna. The vegetation will be established to a standard similar to the surrounding natural woodland, therefore the habitats are expected to not prohibit the natural colonisation of fauna.

Extensive fauna studies on historical revegetation trial areas on waste rock dumps in the RPA (Corbett, L 1999) 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 and that the density of frogs, native mammals and invertebrate groups was generally higher on the waste rock dumps than in similar habitats in Kakadu NP. One exception was the absence of possums and other arboreal groups on the waste rock dumps, which was probably due to the absence of extensive stands of mature trees with hollows. Such habitats will develop with further time. L. Corbett (1999) concluded that the prognosis for the Ranger Mine is that rehabilitated landforms are likely to be recolonised with representative populations of vertebrates and many invertebrates within five years of decommissioning. 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."*

In 2011 ERA initiated and implemented a long-term fauna and flora monitoring program (Zimmermann 2013a) on the RPA and, in agreement with Mirrar Traditional Owners and Kakadu NP Management, in adjacent areas of Kakadu NP. The primary objective of the program was to provide crucial information about the natural woodland ecosystem (potential revegetation target habitats) for the development of realistic closure criteria. The fauna and flora monitoring program aims to establish baselines of the long-term dynamics, seasonal fluctuations and responses to natural disturbances such as fire or cyclone. This will provide the closure criteria with the spatial and temporal variations that can be expected in the natural woodland ecosystems. It also provides valuable information about ecosystem resilience, natural recruitment, self-sustainability, the relationship between habitat complexity and fauna, impact of weed incursion and many other factors crucial for the assessment of revegetation success.

Future monitoring was committed to be undertaken in close collaboration with SSB/ERISS, just as monitoring site selection had been. The site selection process, criteria of the monitoring program and initial site survey were detailed in Zimmermann (2013a).

Site selection criteria were developed to ensure that monitoring objectives are met, and data are comparable and meaningful. The criteria for site selection included: vegetation community (similar to those to be established on the final landforms), fire regime (captures variability of vegetation communities under different fire regimes), surface geology/soils (similar to those identified in the final landform vegetation communities), position in the landscape (captures the variability in crest, upper/mid/lower slope vegetation communities), cultural heritage (no impact on cultural heritage), access (easy access during all seasons and in the long term) and weed status (weed free at time of establishment). The criteria were consulted with relevant stakeholders and experts.

Based on the above criteria, suitable areas were identified on the RPA and in adjacent Kakadu NP. Approval (Kakadu NP permit) was granted from ERA for the RPA and from Traditional Owners and Kakadu NP Management for Kakadu NP to inspect these pre-selected areas and select suitable monitoring sites within them. The monitoring program and the pre-selected areas in Kakadu NP were presented to the Gunjeihmi Aboriginal Corporation (GAC) as part of the approval and consultation process.

A total of 17 monitoring sites were selected for the Ranger Mine long-term fauna and flora monitoring program, with 11 sites located on the RPA and six in the surrounding Kakadu NP (Figure 2-8). The sites fulfil all selection criteria.

The monitoring sites provide a good representation of the fire frequencies of the region. On the RPA two sites have experienced a high, three a low and six a low to medium fire frequency in the last 10-12 years. In the surrounding Kakadu NP four sites have had high and two sites low fire frequencies. Of the two broad vegetation communities identified as target habitats for the Ranger Mine revegetation, 14 monitoring sites were Mixed Eucalypt Woodland and three were Dry Mixed Woodland. The latter was not found outside of the RPA Georgetown area.

The sites are positioned on the crest, mid and lower slope representing the variation in vegetation communities derived from position in the landscape. All selected sites are weed and disturbance free, accessible and do not impact on cultural heritage and Kakadu NP values.

In 2016, Eco Logical Australia (ELA) was engaged by ERA to undertake the first full flora and fauna survey of the above monitoring sites (S. Smith 2016)

The 2016 data provided an indicative assessment of the condition of native woodland in the areas surrounding the mine footprint. The results indicated natural variability in undisturbed sites resulting from seasonal changes and in some cases fire. No other disturbances (e.g. cyclones) impacted sites between surveys.

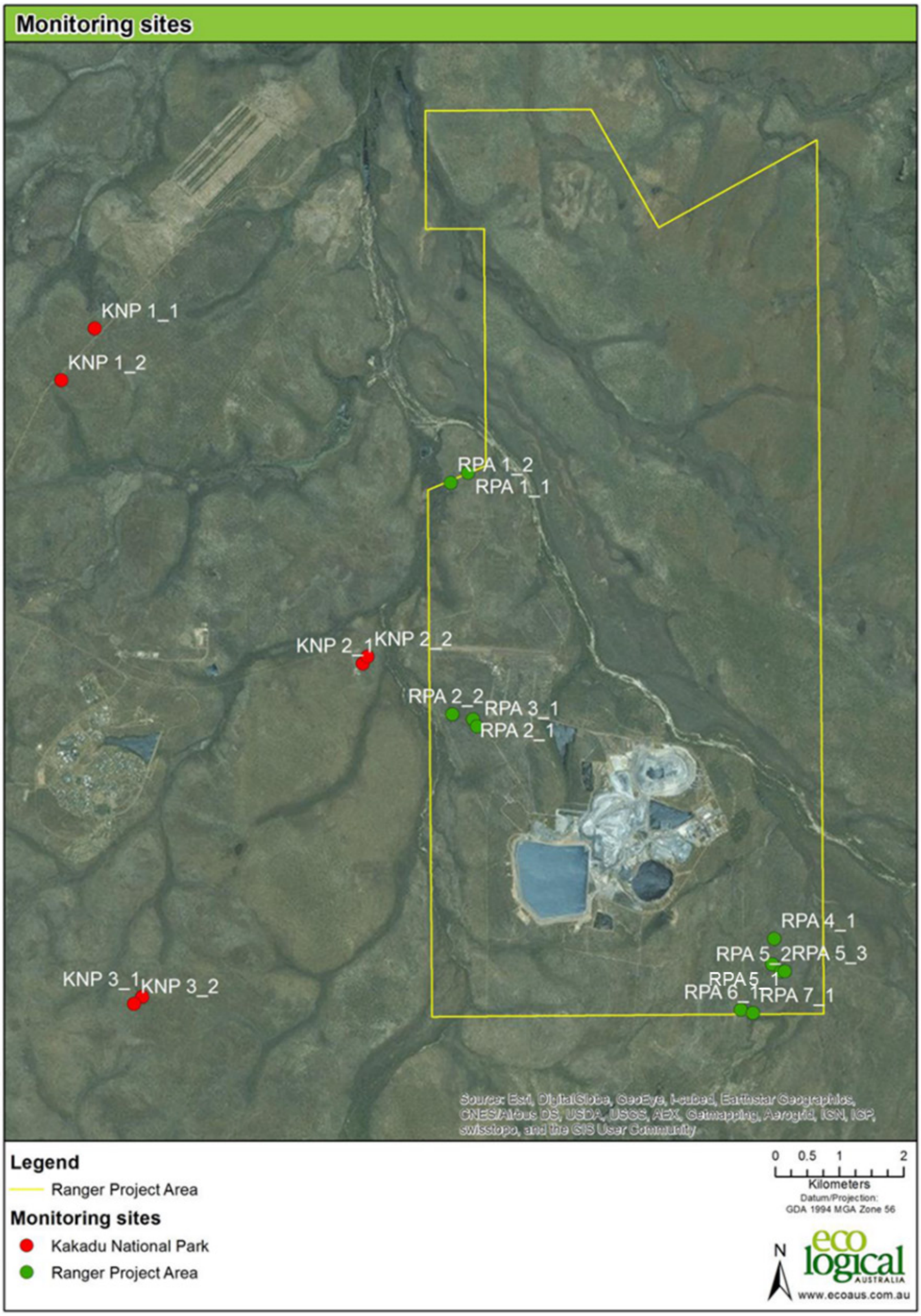


Figure 2-8: Survey sites

2.1.3 Proposed conceptual reference ecosystems for ERA Ranger Mine

ERA is collaborating with key stakeholders to define appropriate conceptual reference ecosystems and develop agreed closure criteria for the rehabilitation of Ranger Mine. Ten of the SSB 2018/19 surveyed woodland sites have been nominated as representing the 'Initial Conceptual Reference Ecosystem' (ICRE), based on which ERA may further develop additional (or alternative) 'Agreed Reference Ecosystems' (ACREs) that take into account the various constraints of the final landform.

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 data for Ranger Mine, compare these to benchmarked approaches from other operations and jurisdictions, and recommend an updated approach to developing conceptual reference ecosystem/s and resultant closure criteria for ERA. The resultant report (Mattiske & Meek 2020 *in draft*) is summarised in the following sections and covers the integration of available datasets, the results of analyses undertaken, and presents the proposed descriptive closure criteria, supported by a benchmarking exercise and other information. This work builds 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 places 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 but also to refine the suitable species and community structural and floristic combinations that might assist in the revegetation assessments and adaptive management programs.

The survey data was integrated with a reliance particularly on stem numbers of the overstorey and midstorey species in line with the initial emphasis on the key framework species of the ecosystems in the Ranger area. Although some analyses were initially undertaken on the presence/absence datasets, this report concentrates on the key 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 avoids the constraints of variations in seasonal conditions at the time of samplings and the complexity of different lifeforms as evident in the summary of the flora (Mattiske & Meek 2020 *in draft*).

From an initial review of dominant tree species for the SSB sites 1 to 10, it was apparent that there was significant variation in the number of stems for the respective overstorey species, Figure 2-9. This supports the degree of local variation in the sites and communities near the Ranger operations that have been apparent in previous studies. Whilst to date there has been an effort to concentrate on the dominant *Eucalyptus tetrodonta* and *Eucalyptus miniata* tree species, the results as illustrated in Figure 2-9 reflect variations in these species alone, let alone some of the other overstorey and midstorey species.

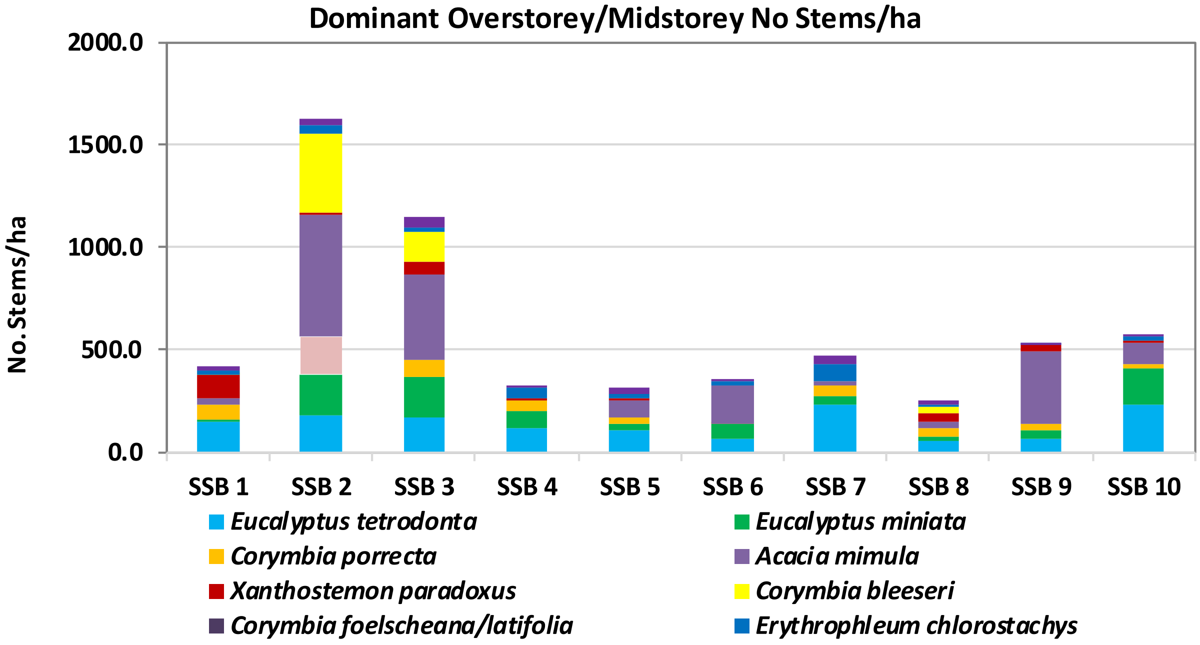


Figure 2-9: Review of Total Stem Numbers / ha on the SSB sites near Ranger (2019/2020 data).

The following dendrogram summarises the results from the analysis using Clarke and Gorley (2015) Primer version 7.0.13 with a Bray Curtis similarity of all overstorey and midstorey stems for the ten SSB sites which concentrated on the *Eucalyptus tetrodonta-Eucalyptus miniata* woodland communities which is proposed by SSB as the ICRE (Initial Conceptual Reference Ecosystem), Figure 2-10. This approach supports the trends in the dominant overstorey/midstorey species as summarised in Figure 2-9 and reflects the subgroups of these woodlands based on all stems of overstorey and midstorey species.

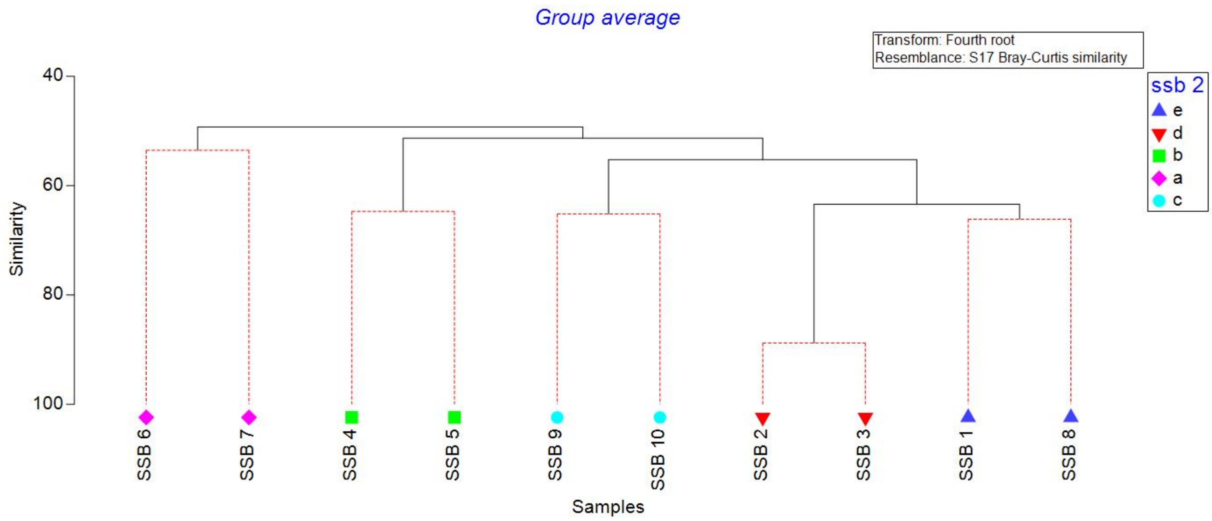


Figure 2-10: Dendogram illustrating similarity of subgroups from SSB sites near Ranger (2019/2020 data) utilising stems/ha of overstorey/midstorey species.

The data was then analysed using Clarke and Gorley (2015) Primer version 7.0.13 using Bray –Curtis similarity using the combined data from SSB (2019/2020), Humphrey *et al.* (2012) (A1 to A54 – designated as GTX A1 to GTX A54), Georgetown sites by Hollingsworth and Meek (2003) (H1 to H97, see E sites in Hollingsworth *et al.* (2007a)) and nearby sites of Saynor *et al.* (2009) (G1 to G36 noting that a few sites were missing in the series of 31 sites). Brennan (2005) sites were excluded due to the variation noted in Hollingsworth *et al*. (2007a); although these should be considered in future variations for potential extreme and localised site conditions that might arise on the RPA.

As indicated in the dendrogram (Figure 2-11) the data from some Georgetown woodland sites align with the SSB Eucalypt woodlands. Consequently these results support the combination of the SSB sites with other sites to broaden the coverage and also to allow for variations on site conditions on the RPA which may not support selected species (e.g. *Eucalyptus miniata*, due to lack of soil water holding capacity) and may support other species (e.g. *Eucalyptus tectifica* that are more drier site tolerant). The results from this modified combination as a subset of the large set of sites is summarised in Figure 2-12. These results enabled the refinement of 4 possible groupings of the Eucalypt woodland communities (ICRE based on SSB 1 to 10). A slightly modified ICRE (ACRE v1) and a modified ACRE v2 which supports species and a community that is wider in representation and ACRE v3 which includes species that may be more tolerant of drier site conditions on the RPA.

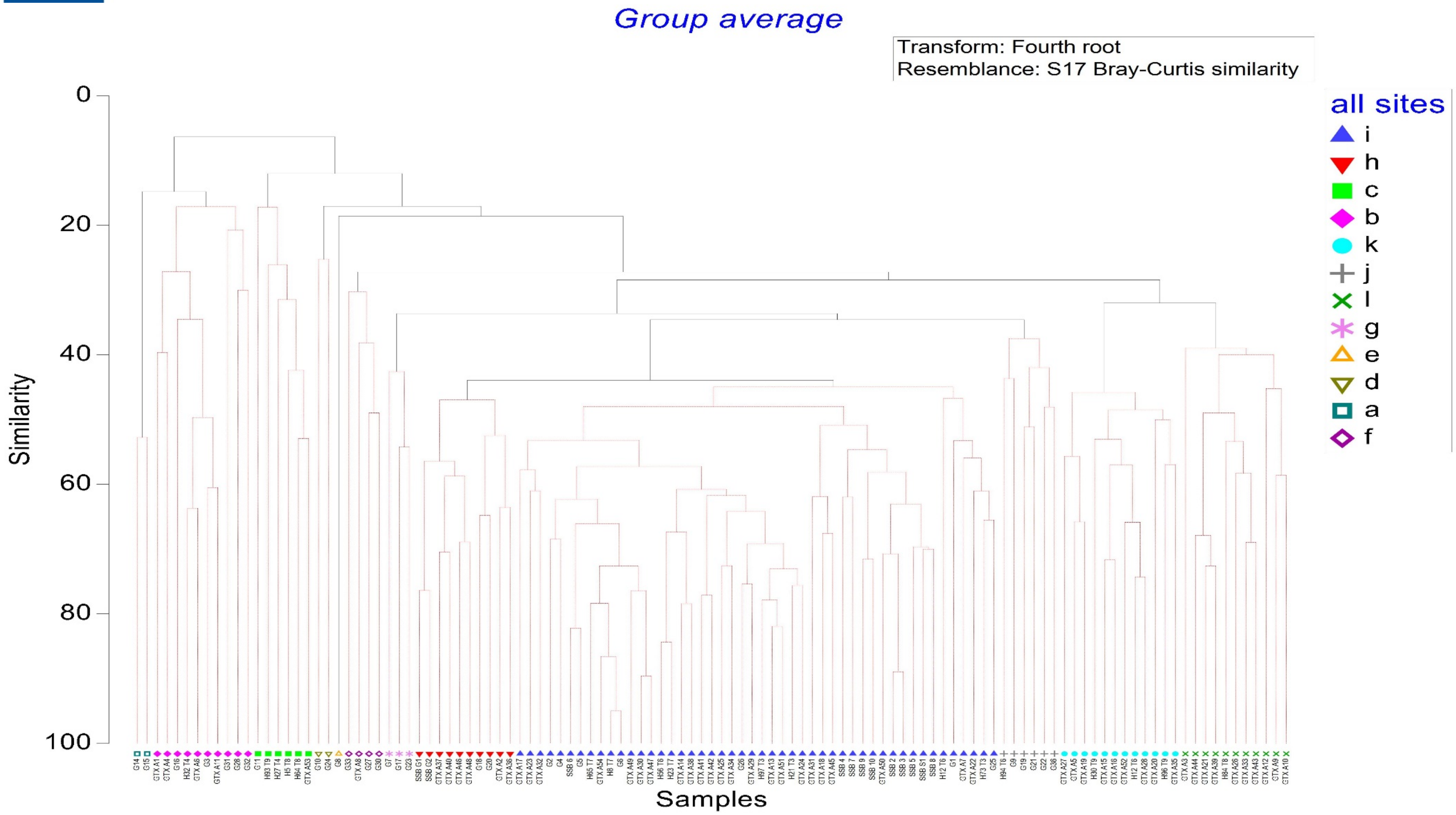


Figure 2-11: Dendogram illustrating similarity of SSB sites near Ranger (2019/2020 data) and all of Saynor et al. (2009) and Georgetown (Hollingsworth & Meek 2003, Humphry et al (2012) using stems/ha overstorey/midstorey species (Mattiske & Meek 2020).

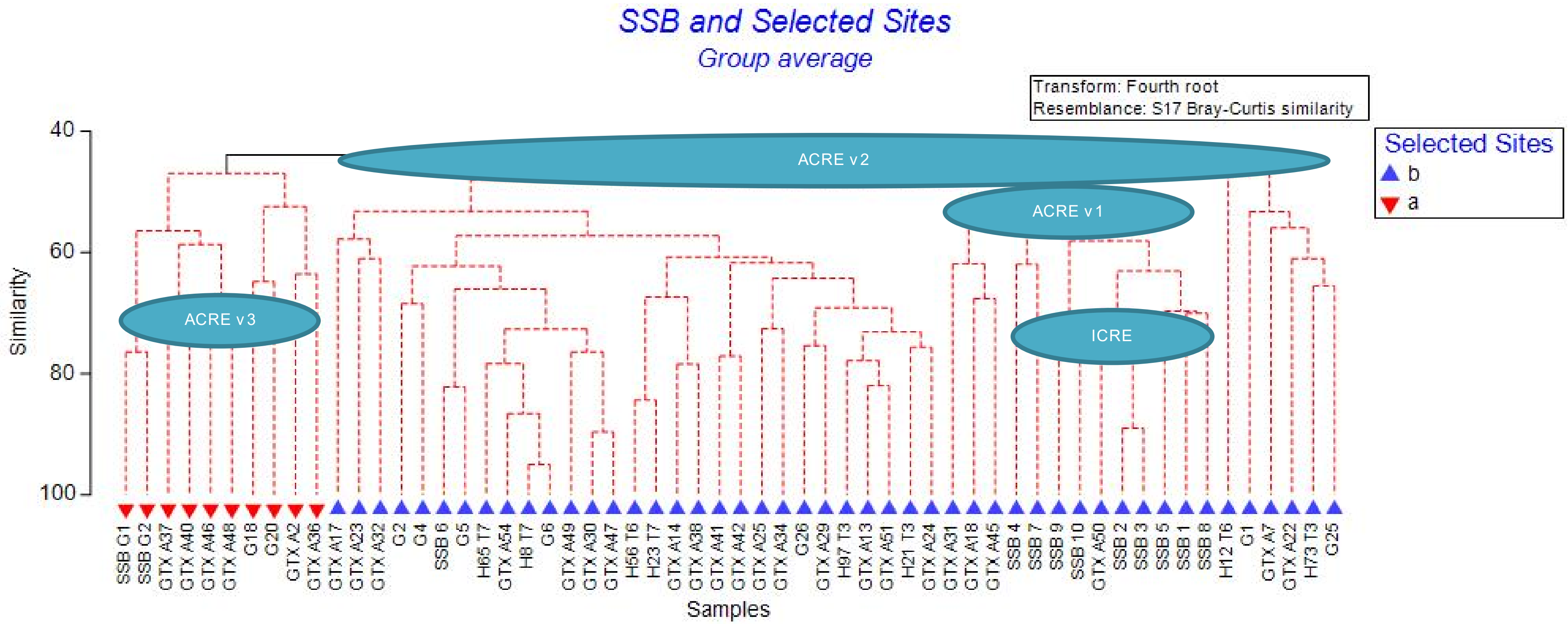


Figure 2-12: Dendogram illustrating similarity of a subset of SSB sites near Ranger (2019/2020 data), Saynor et al. (2009) and Georgetown (Hollingsworth & Meek 2003, Humphry et al (2012) using stems/ha of overstorey/midstorey species (Mattiske & Meek 2020).

These results support the approach of combining the SSB sites with selected sites from within and near the RPA. This has led to a modified list of framework species for the Eucalypt woodlands as proposed to align with the ICRE (SSB 1 – 10) dominant species; IRCE slightly modified (ACREv1) (species from grouping within the “b” group) on Figure 2-11, a modified ACRE v2 which supports species and a community that is wider in representation and a ACREv3 which allows for the inclusion of species that tolerate drier sites (a modification of group a), see Table 2-5. The lower contribution of *Eucalyptus miniata* and the contribution of *Eucalyptus tectifica* are within the ACREv3 potential option.

Such an approach can be used to refine and adapt the framework overstorey and midstorey species following rehabilitation trials. As such it can also be used to delineate and refine completion criteria from other datasets associated with the different lifeforms, midstorey and understorey species.

The inclusion of a wider range of sites is beneficial in view of the variation within the local woodland which is evident from the initial analyses on the SSB sites 1 to 10 as well as on the wider area within RPA and KNP. The inclusion of Georgetown and other sites near the RPA have assisted in the process to date and as more site specific conditions necessitate a similar approach could be undertaken for the other parameters.

ERA will take the opportunity of the 2021 Pit 1 revegetation trial to plant out areas with these different CREs as detailed in Section 6.1 below. This will enable monitoring for their suitability for revegetating waste rock landforms and also provide an opportunity to visually demonstrate the different ecosystem types to Traditional Owners and external stakeholders.

Table 2-5: Dominant Overstorey and Midstorey species for the ICRE and proposed ACREs (species order by descending mean stems/ha ± SE) (Mattiske & Meek 2020 – *in draft*).

ICRE (SSB Sites 1 – 10)		**ACREv1 (13 sites)**		**ACREv2 (48 sites)**		**ACREv3 on drier sites (10 sites)**	
Acacia mimula	182.8 ± 64.8	*Acacia mimula*	174.6 ± 60.4	*Acacia mimula*	393.4 ± 53.1	*Acacia mimula*	304.1 ± 72.4
Eucalyptus tetrodonta	140.1 ± 21.3	*Eucalyptus tetrodonta*	125.8 ± 18.9	*Eucalyptus miniata*	106.0 ± 21.6	*Eucalyptus tetrodonta*	188.8 ± 65.1
Eucalyptus miniata	86.6 ± 23.9	*Corymbia porrecta*	77.5 ± 19.8	*Eucalyptus tetrodonta*	103.3 ± 10.0	*Corymbia foelscheana/latifolia*	150.5± 57.5
Corymbia bleeseri	57.6 ± 39.3	*Livistona humilis*	67.8 ± 28.4	*Xanthostemon paradoxus*	76.7 ± 15.8	*Xanthostemon paradoxus*	137.6 ± 41.6
Corymbia porrecta	56.2 ± 15.6	*Eucalyptus miniata*	65.0 ± 20.9	*Corymbia porrecta*	75.2 ± 9.6	*Terminalia pterocarya*	115.6 ± 23.66
Livistona humilis	50.6 ± 32.8	*Xanthostemon paradoxus*	58.8 ± 16.0	*Corymbia bleeseri*	28.7 ± 10.2	*Corymbia porrecta*	59.8 ± 19.6
Xanthostemon paradoxus	28.9 ± 10.4	*Corymbia bleeseri*	46.2 ± 30.5	*Terminalia ferdinandiana*	28.1 ± 4.9	*Terminalia ferdinandiana*	41.0 ± 15.2
Erythrophleum chlorostachys	28.3 ± 7.5	*Erythrophleum chlorostachys*	41.0 ± 11.3	*Livistona humilis*	20.7 ± 8.6	*Corymbia disjuncta*	40.5 ± 15.3
Terminalia ferdinandiana	22.9 ± 4.8	*Terminalia ferdinandiana*	38.3 ± 10.2	*Erythrophleum chlorostachys*	18.0 ± 4.8	*Eucalyptus miniata*	24.1 ± 15.0
Persoonia falcata	15.7 ± 5.3	*Planchonia careya*	12.0 ± 6.6	*Melaleuca viridiflora*	10.4 ± 10.4	*Buchanania obovata*	22.4 ± 6.2
Acacia aulacocarpa	8.7 ± 8.3	*Buchanania obovata*	11.7 ± 3.8	*Planchonia careya*	10.3 ± 3.1	*Corymbia bleeseri*	18.9 ± 14.8
Buchanania obovata	7.9 ± 1.9	*Persoonia falcata*	10.5 ± 4.5	*Corymbia foelscheana/latifolia*	7.8 ± 2.8	*Calytrix exstipulata*	14.5 ± 14.4
Acacia oncinocarpa	5.4 ± 5.0	*Acacia aulacocarpa*	6.7 ± 6.4	*Corymbia dunlopiana*	7.3 ± 5.1	*Cochlospermum fraseri*	14.3 ± 10.2
Brachychiton megaphyllus	3.7 ± 2.0	*Syzygium eucalyptoides bleeseri*	6.4 ± 4.1	*Persoonia falcata*	6.6 ± 1.7	*Eucalyptus tectifica*	11.9 ± 7.1
Pandanus spiralis	3.3 ± 2.2	*Brachychiton megaphyllus*	4.8 ± 2.3	*Syzygium eucalyptoides bleeseri*	6.4 ± 4.8	*Pouteria arnhemica*	10.8 ± 5.8
Cochlospermum fraseri	3.1 ± 2.0	*Acacia oncinocarpa*	4.1 ± 3.8	*Calytrix exstipulata*	5.9 ± 4.7	*Gardenia megasperma*	10.6 ±5.1
Planchonella arnhemica	3.0 ± 1.2	*Jacksonia dilatata*	3.8 ± 3.8	*Corymbia setosa*	5.7 ± 3.7	*Planchonia careya*	9. 4 ± 5.1
Stenocarpus acacioides	3.0 ± 1.2	*Planchonella arnhemica*	3.8 ± 3.8	*Buchanania obovata*	4.6 ± 1.4	*Grevillea mimosoides*	8.0 4 ± 5.5

Table 2-6: Selection of Overstorey and Midstorey Stems/ha and Species Richness data of each Reference Ecosystem (Mattiske & Meek 2020 – *in draft*).

	Summary Data					
ICRE	**n**	**MIN**	**MAX**	**MEAN**	**MEDIAN**	**SE**
TOTAL Stems / ha	10	304	1954	725	511	167
Framework stems/ha	10	147	989	369	278	85
No. OS/MS framework spp.	10	4	5	4	4	0
No OS/MS spp.(all)	10	10	22	17	18	1
ACREv1						
TOTAL Stems / ha	13	304	1954	783	648	13
Framework stems/ha	13	147	989	356	299	13
No. OS/MS framework spp.	13	3	5	4	4	13
No OS/MS spp.(all)	13	9	22	15	17	13
ACREv2						
TOTAL Stems / ha	38	354	2100	993	900	79
Framework stems/ha	38	50	950	321	275	31
No. OS/MS framework spp.	38	2	5	3	3	0
No OS/MS spp.(all)	38	3	10	8	8	0
ACREv3						
TOTAL Stems / ha	10	500	2200	1219	1056.5	200
Framework stems/ha	10	50	1475	499	440.5	134
No. OS/MS framework spp.	10	1	8	4	4	1
No OS/MS spp.(all)	10	6	30	13	11	2

2.2 Development of Closure Criteria

Closure criteria are the qualitative or quantitative standards of performance used to measure the achievement of the rehabilitation closure objectives for the closure of the site and needed for the relinquishment of the mining lease (WA EPA 2006). They are usually expressed relative to a reference ecosystem (Young *et al.* 2019b) or, as has been covered in the preceding sections, a series of appropriate conceptual reference ecosystems adjusted to account for the known, or anticipated, constraints of the post-mining landscape.

The process of developing closure criteria is underpinned by the analyses of both analogue sites in appropriate reference ecosystems as well as the analysis of rehabilitation data sets during the initial and ongoing phases of rehabilitation activities with the continual need for adaptive management at different phases from initial establishment and growth to achievement of trajectories of key parameters towards specific closure criteria.

As part of the 2020 review, Mattiske & Meek undertook a benchmarking exercise of the approach to reference site selection and derivation of qualitative and/or quantitative closure criteria at other mining operations and jurisdictions. Utilising the reference site analyses presented earlier and the benchmarking outputs, suitable floristic parameters (or attributes) and preliminary descriptive closure criteria are proposed.

2.2.1 Benchmarking of other operations and jurisdictions

There are many guidelines and frameworks for setting and assessing mine closure objectives (Section 1.2); however the majority of closure criteria are based on processes and qualitative parameters. A review and benchmarking exercise was undertaken to identify best practices in relation to more detailed closure criteria, focussing on areas where the intention was mainly concentrated on re-establishing native vegetation. In addition, the review concentrated on previous practice in the Australian mining industry due to current standards in local and national context.

To extract this information it was necessary to rely on specific and publicly available licences, closure plans and environmental plans. Not all of details by many mining companies are explicit in public documents and there is a reliance on process rather than detailed closure criteria. In many instances there are more generic statements related to outcomes such as the re-establishment of sustainable ecosystems with similarities without specific targets or metrics to achieve such outcomes.

The pattern of increasing expectations on the industry and the studies undertaken internationally are on a similar trajectory towards greater certainty on outcomes. Criteria, where they are defined, tend to be qualitative rather than quantitative criteria. There has been a greater reliance on measurements of particular parameters that are key to re-establishing the native ecosystems. The latter include parameters such as use of local flora species, selection of key, dominant or framework species, selection of species that are known to establish and some quantitative data on species richness, density and cover. Fauna species are less regularly assessed with the exemption of a greater coverage of invertebrate species such as ants and bird species in the early phases. The more detailed best practices concentrate on process, internal outcomes and external outcomes; with clear triggers on adaptive management needs and actions. These will be discussed further for each specific parameter in the Closure Criteria (Section 8).

2.2.2 Key floristic parameters

These floristic parameters (Table 2-7) reflect current local and international industry guidelines (SRG SERA 2017), and as such reflect consistency in current operations and are in many instances comparable to those used internationally (Ruiz-Jaen & Aide 2005; Wortley *et al.* 2013).

Table 2-7 Key Attributes for assisting in alignment from local and international guidelines for rehabilitated and restored ecosystems (extracted from SRG SERA 2017)

SER (2004) Restoration Attributes (^^)	WA EPA (2006) Rehabilitation Criteria	SERA (2017) Restoration Attributes (^^)
1. Structure 3. Functional groups	9. Abundance or density 12. Canopy and keystone species 16. Habitat diversity	Community structure
1. Structure 2. Indigenous species 3. Functional groups	8. Species diversity 10. Genetic diversity 11. Ecosystem diversity **13. Effective weed control 15. Animal diversity	Species composition
Resilient Self-sustaining 5. Function	**6. Soil structure and function 7. Self-sustaining and resilient	Ecosystem function
Landscape integration External threats	**13. Effective weed control 14. Pest and disease control	External exchanges Absence of threats

** criteria repeat over different attributes; ^^ – SER (2004 and SERA (2017 use the terminology attributes rather than parameters.

One of the keys to selecting and refining the selection of attributes for the closure criteria include including key parameters (or attributes as used by some authors) that reflect and support the assessment for outcomes, be easily and consistently sampled by different researchers, are reliable indicators in line with key attributes of ecosystems, have clear and consistent analytical methods available to a wide range of technical and professional skill levels, be appropriate to time frames and be clear to assessors and those reviewing progress.

The Society for Ecological Restoration (SER 2004) recommended nine ecosystem attributes to measure restoration (rehabilitation in the mining industry context):

- similar ecosystem diversity and community structure to those of the reference sites
- the presence of indigenous (native) species
- the presence of functional groups necessary for long-term stability

- the capacity of the physical environment to sustain reproducing populations
- normal functioning
- integration within the landscape
- the elimination of potential threats
- resilience to natural disturbances
- self-sustainability

The SER Primer underpins key ecosystem attributes to formulate goals for restoration (SRG SERA 2017). Recent reviews reveal seemingly infinite numbers of indicators that have been used or could be used to reflect the ecosystem attributes in different areas and ecosystems (Ruiz-Jaen & Aide 2005; Wortley *et al.* 2013). These studies have reflected the dominance of species diversity, abundance, structure and ecological processes as key attributes. The range of possible attributes is summarised in the document by Kragt *et al.* (2019) and includes an extensive range of abiotic, biotic indicators. In Western Australia, recent standards on baseline studies has led to more consistency in approaches (WA EPA 2016a, 2016b).

The initial focus is concentrated on the dominant Eucalypt and *Corymbia* woodlands near the RPA with a view towards following a similar approach for other ecosystems associated with other post-mining conditions (e.g. riparian areas and seasonally wetter sites). The development of the concepts of domains in the pre-mining and post-mining areas has been commenced and as such relies on the underlying information on the baseline environmental values and research associated with understanding these values and how these values could be restored on highly disturbed environments.

In line with the end land use and proposed outcomes at Ranger the emphasis in the revegetation planning and processes relies on an understanding of the constraints and where these can be addressed and minimised to return the local flora and fauna species, the structure and function of the communities and the associated values on a trajectory towards such an end land use. Other mine sites have addressed some of these short-term gaps through the introduction of the following procedures:

- Selection of engineering designs (landforms, soils and drainage) that may facilitate the species and ecosystem functions.
- Selection of alternative species that may be known to prefer specific site conditions.
- Placement of values such as surface soils or logs and hollows in local scattered areas to assist with progression of species re-colonisation.
- Avoidance of some treatments (e.g. avoidance of soils that may introduce competitive native species or weed species that may increase fire risks in the early phases of the rehabilitation of the post mining sites).

In assessing the values there has been a reliance on most recent mine site rehabilitation activities to use indicators such as use of local provenance seed and seedlings, plant species richness, plant cover and plant density. Of the range of indicators these were the most commonly used to evaluate the progress of restoration programs (Ruiz-Jaen and Aide 2005).

The following parameters have been agreed by ERA and the Supervising Scientist Branch (Table 2-8). The development of the parameters and descriptive completion criteria are summarised in MCP Section 8.

Table 2-8: ERA Agreed Objectives, Outcomes and Parameters.

Objective	**Outcome**	**Parameter**
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	Revegetate the disturbed sites of the RPA using local native plant species.	Provenance
	Species composition and community structure is similar to adjacent areas of Kakadu NP	Species composition (tree and shrubs) and relative abundance
		Canopy architecture
		Canopy cover index, ground cover index
		Tree distribution**
	Long term, viable ecosystem requiring maintenance similar to adjacent areas of Kakadu NP	Reproduction (flowering and seeding)
		Recruitment / regeneration
		Nutrient cycling
		Fire resilience
		Resilient to wind and drought
		Weed composition and abundance
		Native fauna
		Exotic fauna

**Tree distribution is covered separately in the Cultural Criteria.

2.2.3 Future development of quantitative closure criteria

The proposed qualitative criteria are currently focussed on derivations of the local woodland ecosystems, anticipated to be suitable for the bulk of the final landform and land application areas at Ranger Mine. However, as indicated in the technical review of constraints, there are scenarios predicted that may require additional reference ecosystems to be identified, such as riparian, sedgeland and grassland, or shrubby ecosystems. This will then require the gathering of data from suitable analogue sites, which may take some effort (and time) and is required to inform revegetation activities. Refinement of qualitative and/or quantitative closure criteria and monitoring and assessment methods shall follow the process outlined below.

Following the agreement of the proposed qualitative criteria, ERA shall continue working towards quantitative closure criteria through the following steps:

- Review all available rehabilitation monitoring data from ERA including Trial landform data, previous revegetation trials, and early results from Stage 13 and Pit 1 revegetation activities.

- Access relevant rehabilitation data from other sites, such as the *Eucalyptus tetrodonta* dominated revegetation at Gove and Weipa bauxite mines (over 40 years of knowledge).

- Utilise the State-and-Transition model that has recently been developed (Richards *et al*. 2020 - in draft) to refine the trajectories for key parameters of the revegetation, to identify milestones and thresholds to inform the ERA Adaptive Management Plan.

- Review other trajectory study options as recently developed by Steedman *et al*. (2019) utilising species richness and density datasets to evaluate progress on rehabilitation areas.

- Propose quantitative closure criteria for the target 'close-out' timeframe expressed relative to the appropriate conceptual reference ecosystem.

- Undertake a statistical review and benchmarking exercise on how quantitative closure criteria should be monitored and assessed at Ranger Mine.

Once draft quantitative closure criteria are proposed, these will be reviewed by key stakeholders and key researchers in line with adaptive management of options for progressing the ecological restoration on a trajectory to meet the proposed outcomes. In view of the limitations associated with limited trials on the revegetation areas, it is important the proposed assessment methodologies and studies are developed and refined to enable ongoing testing and adaptive management and strategies for continual improvement (Mattiske & Meek 2020).

In developing these quantitative measures it is important to undertake data gathering which is scientifically rigorous without the complexity that restricts effort and coverage.

As part of the development of potential quantitative closure criteria, there is a need to review former and proposed monitoring methods to enable not only comparisons with reference ecosystem values but also with proposed closure criteria which can vary in their trajectories in the initial phases of rehabilitation. In the context of mine closure there may be leading indicators and lagging indicators. An example of using initial indicators at Alcoa of Australia Ltd bauxite mines illustrates this approach with selected indicators which has enabled remediation and supplementary treatments to be undertaken in a timely manner.

As discussed in Section 2.2.2, there are a range of options for metrics for different parameters over time. The options include, for example, means or medians with standard errors, or a range of data within the bounds of that in the appropriate reference ecosystem, or the use of percentiles within set bounds (e.g. 10% to 90% or 20% to 80%). Consideration of the interaction of post-mining conditions and the selection of appropriate closure criteria have been taken into account initially in the selection of potential descriptive qualitative criteria (MCP Section 8) and as such will require further refinement for the 2021 ERA MCP.

The rate and predicted direction of change in environmental metrics will vary between parameters over time, and will be reflected in the different rehabilitation trajectories. At ERA these components will be addressed as part of the quantitative review; however at this juncture and considering the industry benchmarking exercise, it is expected that the initial planting of seedlings of the framework species will encourage rapid growth and a range of other attributes associated with colonisation and dispersion, and litter accumulation will result. Amongst the lagging indicators will be a range of fauna species that rely on soil development and also values that will take some time to establish. This latter aspect will require further investigations in 2020/2021.

The additional key component in developing suitable quantitative closure criteria is a clear way forward on methodology of assessments, analysis and interpretation of the findings on future rehabilitation areas. The critical aspect of the latter is the need for consistency and coverage of key attributes in a scientifically rigorous approach.

3 REVEGETATION STUDIES AND KNOWLEDGE AT RANGER MINE

Over more than thirty years, a large number of small-scale revegetation trials have been undertaken at Ranger Mine by the CSIRO, ERISS, ERA and other parties in relation to final landform (FLF) morphology, revegetation and ecosystem establishment (Section 3.1). All this research has culminated in an extensive body of applied techniques, designed to give confidence that the revegetation strategy proposed for the closure of the RPA will result in a self-sustaining, long-term ecosystem. These practical techniques are summarised in MCP Section 9.4.6.

3.1 Early revegetation establishment trials at Ranger Mine

A myriad of revegetation trials were undertaken at Ranger Mine between 1982 and 2002 (refer Table 3-1 and Figure 3-1). Almost all of these trials were discontinued at various stages, due to the need by operations for additional waste rock storage areas as mining of the pits 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 and the establishment of a dedicated waste rock revegetation research facility – the Trial Landform (TLF).

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 related key issues that are highly relevant to ERA's revegetation strategy.

In more recent years, investigative studies have been undertaken on local seed provenance for revegetation, and species composition and community structure. The outcomes of these studies are described in the following sections.

Table 3-1: 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

Project	Location	Date
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* and *Azolla*)	RP1 wetland filter	1991-1992
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

Project	Location	Date
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
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

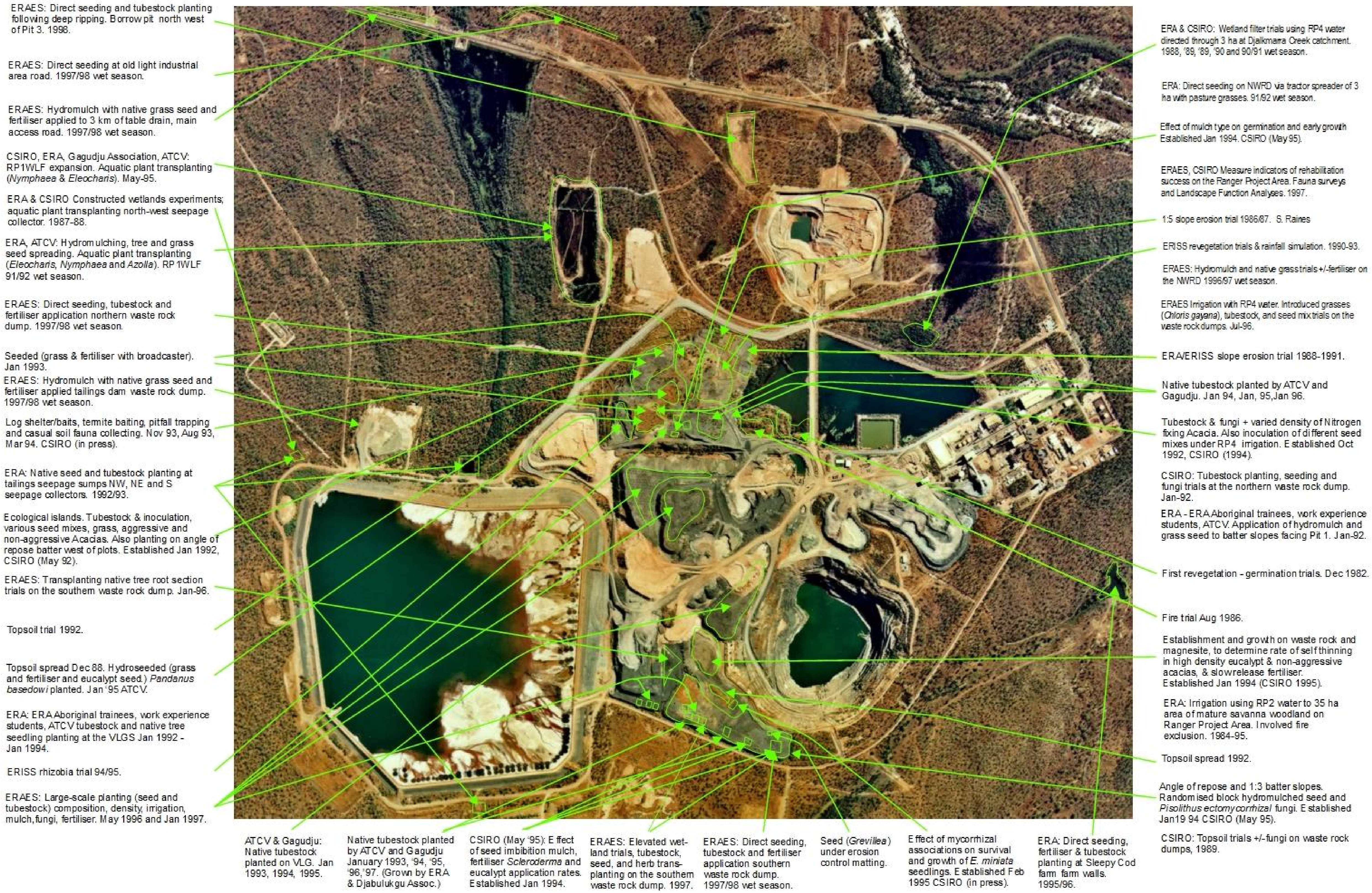


Figure 3-1: Revegetation conducted on Ranger Mine (1982 – 1998)

3.2 The Trial Landform: An ongoing (11-year long), large-scale field test of the Revegetation Strategy

The 8 ha TLF, situated near the north-western corner of the TSF (Figure 3-2), was constructed in 2008/2009 to allow for testing of landform design, substrate types, and revegetation strategies (Daws *et al.* 2009). It also has provided the opportunity to investigate and implement adaptive-management during ecosystem establishment (Humphrey 2013). An extensive monitoring system was installed to assess the soil water holding capacity, runoff and infiltration of the landform (Daws *et al*. 2008, Shao 2015) as well as the revegetation performance.

The TLF has enabled the Ranger Revegetation Strategy to be tested and refined. It has also informed many of the physical and biophysical features of the FLF design, including but not limited to: its waste rock construction, erosion, bedload, stability, water management, radiological aspects, revegetation and ecosystem development.

The following sections provide an overview of the construction and purpose of studies to date on the TLF.

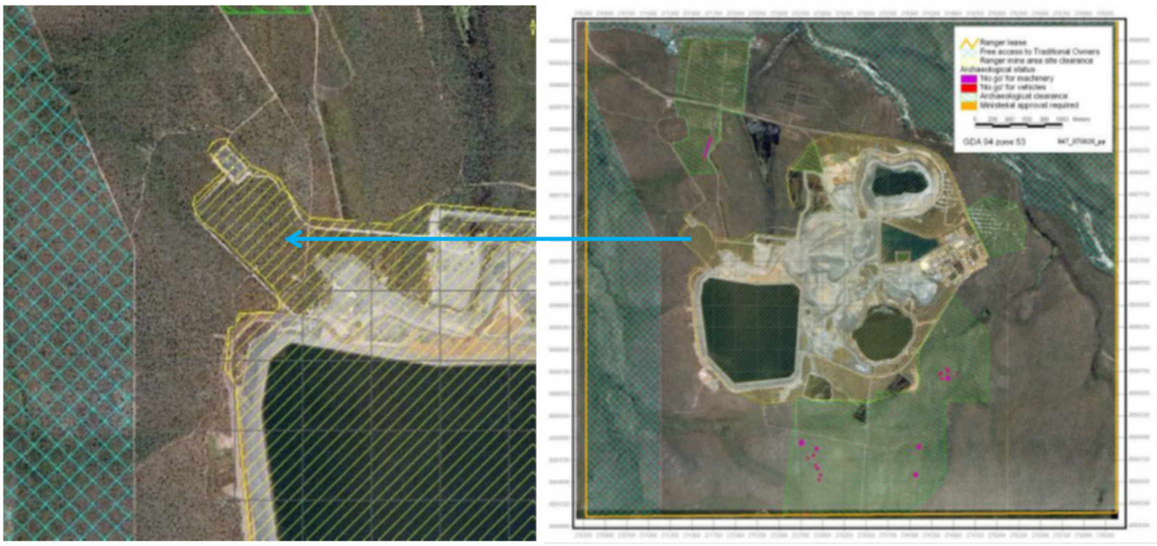


Figure 3-2: Location of the trial landform, north-west of the TSF (Pugh *et al.*, 2008)

3.2.1 Design and construction

The TLF was designed based on studies undertaken by ERA and ERISS on analogue sites and previous revegetation work conducted at Ranger Mine. It stands four to seven metres above the original natural ground surface and was constructed using 800,000 tonnes of primary and weathered waste rock and laterite material. The design has allowed testing of the performance of different types of surface substrates, different depths of mixed materials over the waste rock only layer, different planting methods and different irrigation regimes (Figure 3-3; adapted from Pugh *et al* 2008).

The TLF 1A 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. 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.

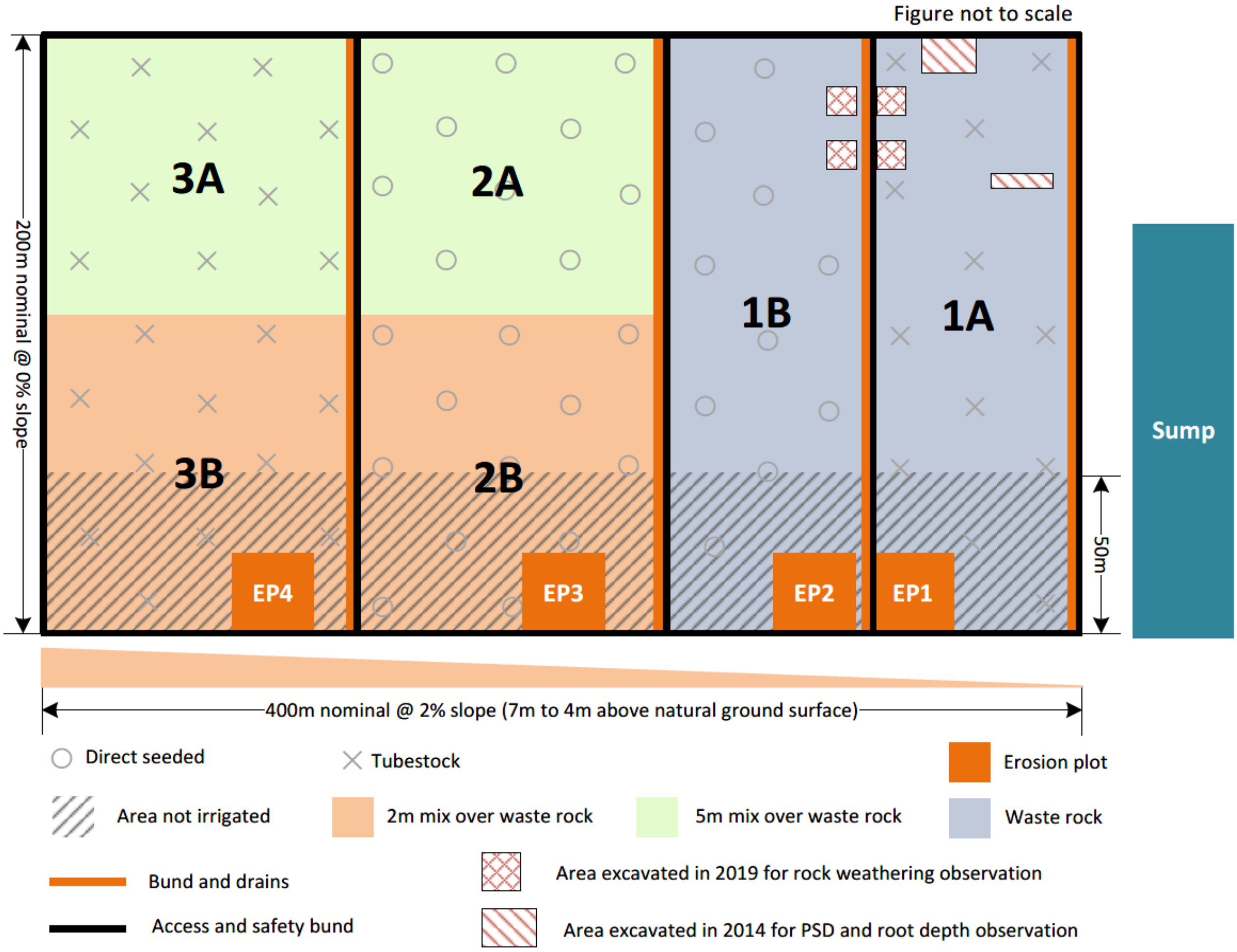


Figure 3-3: Trial landform – treatment design and associated infrastructure

The three main rock types in Ranger waste rock stockpiles are primary, weathered and laterite materials, all of which were used in the construction of the TLF. Primary material 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 generally still low in clay content. Laterite is a near surface, highly weathered and sometimes reconsolidated material that is generally high in iron and aluminium clays (ERA 2018). Photos of the 1s primary material and weathered rock used for construction of the TLF are shown in Figure 3-4.

The surface substrates trialled on the TLF were: waste rock only; and waste rock blended with 30 percent volume/volume of laterite rock. To facilitate treatments, the trial landform was divided into several areas according to treatment (Daws & Poole 2010). The Area 1A and 1B of the TLF were constructed with the waste rock only. Areas 2(2m) and 3(2m) were constructed as a two-metre thick layer of laterite /waste rock mix over a base of 1s rock 3 to 5 metres thick. Areas 2(5m) and 3(5m) were constructed as a five-metre thick layer of laterite/waste rock mix over a 1's rock base 0 to 2 metres thick. The Ranger FLF surface layer will be primarily constructed with primary and weathered waste rock without purposely mixing in laterite. This design and construction is similar to the waste-rock only section of the TLF (i.e. section 1A), presented in Figure 3-5.

Bulk density of the substrate layer of the TLF is estimated at about 2.0 t/m^3, with a specific gravity of solids of 2.65 t/m^3 (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.

The TLF was constructed with a 2% slope and was ripped at 2 metre intervals down to approximately 0.5 m deep.

Vegetation establishment commenced in March 2009 and an area 50-metres wide on the front, north-eastern side of the TLF was left unirrigated; this is further described in Section 3.2.3 below.

(source: Daws & Poole 2010)

Figure 3-4: Rock types used to construct the trial landform

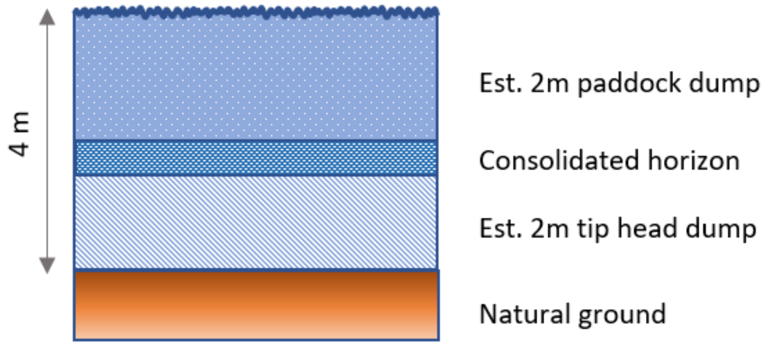


Figure 3-5: Profile of the waste-rock only section 1A of the TLF

3.2.2 Instrumentation

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

- 66 soil moisture probes.
- A weather station.
- Four erosion plots (Supervising Scientist, 2010), featuring:
  - A tipping bucket rain gauge.
  - A primary shaft encoder with a secondary pressure transducer to measure stage height.
  - A turbidity probe.
  - Electrical conductivity probes located at the inlet to the stilling basin and at the entry to the flume to provide an inferred measure of the concentration of dissolved salts in 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.

3.2.3 Vegetation establishment trials

A range of trials have been undertaken on the TLF (Table 3-2). Overstorey (OS) and midstorey (MS) species were initially introduced in 2009 in both the waste rock and laterite mix areas of the TLF; tubestock planting was conducted in March and direct seeding occurred in July. This resulted in the entire TLF being revegetated except for a 40 - 50 m strip along the northern edge of the direct seeded areas, which was not seeded since it was outside the irrigated zone. This area was direct seeded when rainfall commenced in December 2009 (Daws & Poole 2010). In January 2010, additional tubestock was planted in the tubestock areas to fill gaps left by an initial high mortality (Daws & Gellert 2011). In January 2011, tubestock was planted in the direct seeding areas to increase plant density and correct for the skewed species composition due to the low success rate of some of the species (Gellert 2012). In February 2020, additional tubestock were planted to increase OS and MS diversity, to trial species that hadn't been grown in waste rock before, and to trial 'secondary' introductions for species that failed to establish during the initial revegetation.

There have been multiple attempts to establish understorey (US) species on the TLF. Grass seeds were sown in January 2011 on the tubestock areas and in November 2012 on the waste rock tubestock section, both times without fertiliser or irrigation. In 2018, a comprehensive research project was undertaken to investigate optimal protocols for establishing native US grass and legume species on waste rock (Parry 2018). Both direct seeding and tubestock planting were trialled on sections 1A and 1B of the TLF, which by then had considerably different stem densities and canopy covers. In addition, five different amelioration treatments to the waste rock were investigated with the direct seeding trials. A well-watered shade house trial was also conducted in 2018 investigating the same waste rock amelioration treatments. In January 2019, the US plants left over from the shade house trial were planted in 'islands' on the waste rock section. Lastly, in February 2020, a mixture of grasses, legumes, shrubs and herbs were planted and sown to increase US diversity and to trial 'secondary' introduction methods.

Controlled burns were performed in May 2016 (Wright 2019a) and June 2019 (Wright 2019b) on the laterite mix areas of the TLF as a means of weed management and to measure the resilience of the established vegetation.

Table 3-2: Vegetation establishment activities conducted on the Ranger Mine TLF, 2009 – 2020

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 21g slow release fertiliser tablet	2
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	3
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	4
January 2010	Infill tubestock planted	699 tubestock planted in section 1A, 1317 planted in section 3 – each with 21g slow release fertiliser tablet	3
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	3
January 2011	Infill tubestock planted	1449 tubestock planted in section 1B, 2432 planted in section 2 – each with 21g slow release fertiliser tablet	5
January 2011	Understorey trials	Five grass species were sown in section 1A and 3	6
January 2012	*Xanthostemon* tubestock planted	Approximately 300 planted in the track between sections 1A and 1B; 75 planted in section 3	7
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	8, 9 6
May 2016	Weed management	Cool burn of the laterite mix sections (2 and 3)	10
April 2018	Understorey direct seeding trial	Five understorey species were sown in sections 1A and 1B with six WR amelioration treatments	11

[2] Daws and Gellert (2010) Initial revegetation monitoring on the trial landform
[3] Daws and Poole (2010) Construction, Revegetation and Instrumentation of the Ranger Uranium Mine Trial Landform: Initial Outcomes
[4] Daws and Gellert (2011) Ongoing revegetation monitoring on the trial landform
[5] Gellert (2012a) Ongoing revegetation monitoring on the Trial Landform 2011
[6] Gellert (2012b) Establishment trials for five native grasses on the Ranger Trial Landform
[7] Gellert (2013) Ongoing revegetation monitoring on the Trial Landform 2012
[8] Gellert (2013) Ongoing revegetation monitoring on the Trial Landform 2012
[9] Gellert (2014) Ongoing revegetation monitoring on the Trial Landform 2013
[10] Wright (2019a) Effects of the 2016 prescribed fire on revegetation at the trial landform (2016 and 2018 surveys)
[11] Parry (2018) Treatments to improve native understorey establishment in mine waste rock in northern Australia

June 2018	Understorey tubestock trial	Five understorey species were planted in sections 1A and 1B	11
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	Weed management	Cool burn of the laterite mix sections (2 and 3)	12
February 2020	'Secondary' introductions	Eighteen species tubestock planted (10x US and 8x MS/OS), and seven understorey species seeded in patches with and without added mulch (21 species total, mostly 1A and 1B)	13
February 2020	Understorey direct seeding trial	Twelve understorey species were sown in section 1A in plots with and without naturally occurring organic matter	14

3.2.4 Ecosystem monitoring programs on the TLF

The TLF has been continually monitored over the last decade to assess revegetation performance and ecosystem development.

In September 2009, five 15 x 15 m Permanent Monitoring Plots (PMPs) were established in each of the different sections of the TLF; a further 15 PMPs were established in February 2011 after infill planting was performed in 1B and 2 (Figure 3-6 and Table 3-3). The OS and MS plants inside the PMPs have been monitored annually (excluding 2017) for survival, growth, and density. In addition to the PMPs monitoring, two large-scale surveys measuring every single OS and MS plant on the TLF have been conducted, once in 2009 and again ten years later in 2019.

From 2010 to 2014, TLF monitoring also included Landscape Function Analysis (LFA) to measure stability, infiltration and nutrient cycling.

Starting in September 2018, regular walk-throughs have been performed in every section of the TLF to opportunistically capture and/or monitor patterns and changes. Some of the observations include whether established plants are flowering, fruiting and recruiting, and whether new species have been able to naturally colonise the TLF from external sources.

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[12] Wright (2019b) Technical Memo: TLF (laterite mix areas) weed control burn – June 2019

[13] Trial Landform Research and Monitoring Plan 2020 – 2026 (in draft)

[14] Parry (2020) Project plan for 'secondary introduction' understorey direct seeding trials on TLF – in draft

Figure 3-6: Permanent Monitoring Plot Locations on the Ranger Mine TLF

Table 3-3: 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

3.3 Species establishment research program

The ERA revegetation strategy is to initially establish framework overstorey species along with a subset of important and predictable midstorey and understorey species (Section 1). Once these species have established, they will control much of a site's nutrient and water resources, and will provide many of the core habitat values for other plants and animals to colonise (Reddell & Hopkins 1994). Based this approach, the species establishment research program (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 at the Ranger Mine.

The SERP will undertake 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. Priority will be placed on framework species that are required for initial introductions as this will result in the majority of species and stems per hectare in the revegetation program. Other species, particularly understorey species, will be progressively tested in small trials (e.g. pot trials or small-scale field trials) due to very limited seed.

The SERP is continuously working to increase the number of species included in the revegetation implementation program (either as initial or secondary introductions), through improved understanding of practical aspects such as seed collection, storage and usage strategies, propagation tactics, planting and irrigation methods, and species-specific ecological characteristics in terms of substrate, water availability and competition.

3.3.1 The SERP species list

Plant species composition and relative abundance based on appropriate reference sites (Section 2.1.3) was used to develop a revegetation species list with relative density for the revegetation of the TLF in 2007 by ERA in collaboration with ERISS 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 (TWG) reached a consensus on a Ranger Mine revegetation tree and shrub species list (MCP Section 9.4.6.1) This revegetation species list was developed based on:

- previous analogue vegetation studies in undisturbed RPA and surrounding areas by ERISS and ERA (125 studied analogue sites, including 10 sites from Kakadu NP with a land surface similar to the Ranger Mine final landform) (Section 2.1.3, Figure 2-4);
- 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.

The current SERP species list (Table 3-4) comprises 121 species, including 17 overstorey tree species, 61 midstorey tree and shrub species, and 43 understorey species. All species are initially assessed as framework or 'other', and likely suited to an initial or secondary introduction strategy. The list is based on the 2016 agreed revegetation tree and shrub list and expanded with the addition of understorey species based on early surveys by Brennan (2005) and further modified after consultation with Peter Christophersen (*pers comm.*, 2019) and Dr Sean Bellairs (Lu *et al.* 2017; *pers comm.* 2019).

The species included in this list will continue to be refined as outcomes from ongoing reference site survey and data analysis (e.g. Mattiske & Meek 2020 – *in draft*), revegetation trials (e.g. TLF, Stage 13 and Pit 1), risk assessments and further stakeholder consultations are completed (including appropriate formal review by stakeholders).

3.3.2 Culturally significant plant species

A number of species have been included in the agreed revegetation list following cultural consultation with the Mirarr Traditional Owner group (Garde 2015). While fifteen species identified by Garde (2015) do not occur in any of the historically surveyed reference sites (e.g. Georgetown, Brennan, OSS surveys; Section 2.1.2.1), their cultural significance warrants inclusion in the revegetation list. An additional eight species are on the list that were identified as culturally important plant species by the Mirarr Traditional Owners, however these are out of scope or of taxonomic uncertainty. In this context, it is acknowledged by the Mirarr that it may not be possible to propagate and establish all species. Nevertheless, the intention is to plant as many species identified by the Mirarr on the final landform as practicable, to address cultural and other values such as aesthetics.

Table 3-4: The SERP revegetation species listed with framework status and potential introduction strategy

Species	Framework / Other	Initial / Secondary Establishment
Overstorey trees		
Corymbia bleeseri	Framework	Initial
Corymbia chartacea (setosa)	Framework	Initial
Corymbia dichromophloia	Other	Initial
Corymbia disjuncta (confertiflora)	Framework	Initial
Corymbia dunlopiana (setosa)	Other	Initial
Corymbia foelscheana	Framework	Initial
Corymbia latifolia	Framework	Initial
Corymbia polycarpa	Other	Initial
Corymbia polysciada	Other	Initial
Corymbia porrecta	Framework	Initial
Corymbia ptychocarpa	Other	Initial
Erythrophleum chlorostachys	Framework	Initial
Eucalyptus miniata	Framework	Initial
Eucalyptus phoenicea	Framework	Initial
Eucalyptus tectifica	Framework	Initial
Eucalyptus tetrodonta	Framework	Initial
Eucalyptus tintinnans	Other	Initial
Understorey		

Species	Framework / Other	Initial / Secondary Establishment
Midstorey trees and shrubs		
Acacia aulacocarpus	Other	Secondary
Acacia difficilis	Other	Initial
Acacia dimidiata	Other	Initial
Acacia hemignosta	Other	Initial
Acacia lamprocarpa	Other	Secondary
Acacia latescens	Framework	Initial
Acacia mimula	Framework	Initial
Acacia oncinocarpa	NA	
Allosyncarpia ternata	Other	Secondary
Alphitonia excelsa	Other	Initial
Antidesma ghesaembilla	Other	Secondary
Asteromyrtus symphyocarpa	Other	Secondary
Banksia dentata	Other	Secondary
Brachychiton diversifolius	Other	Initial
Brachychiton megaphyllus (paradoxus)	Other	Initial
Buchanania obovata	Framework	Initial
Calytrix achaeta	Other	Secondary
Calytrix exstipulata	Other	Secondary

Species	Framework / Other	Initial / Secondary Establishment
Overstorey trees		
Acacia gonocarpa	Framework	Initial
Alloteropsis semialata	Framework	Initial
Ampelocissus acetosa	Other	Initial
Aristida holathera	Other	Secondary
Aristida inaequiglumis	Other	Secondary
Chrysopogon fallax	Framework	Initial
Crotalaria brevis	Other	Secondary
Cymbopogon refractus	Other	Secondary
Ectrosia leporina	Other	Secondary
Eragrostis rigidiuscula	Other	Secondary
Eragrostis schultzii	Other	Secondary
Eriachne armittii	Other	Initial
Eriachne avenacea	Other	Secondary
Eriachne basedowii	Other	Secondary
Eriachne obtusa	Other	Initial
Eriachne schultziana	Other	Secondary
Eriachne sulcata	Other	Secondary
Eriachne triseta	Other	Secondary
Ficus aculeata (opposita)	Other	Initial
Fimbristylis caloptera	Other	Secondary

Species	Framework / Other	Initial / Secondary Establishment
Midstorey trees and shrubs		
Clerodendrum floribundum	Other	Secondary
Cochlospermum fraseri	Other	Initial
Coelospermum reticulatum	Other	Initial
Dodonaea hispidula	Other	Secondary
Elaeocarpus arnhemicus	Other	Secondary
Ficus racemosa	Other	Initial
Gardenia fucata	Other	Initial
Gardenia megasperma	Other	Initial
Grevillea decurrens	Other	Initial
Grevillea dryandri	Other	Initial
Grevillea goodii	Other	Secondary
Grevillea pteridifolia	Other	Initial
Hakea arborescens	Other	Initial
Hibbertia dealbata	Other	Secondary
Jacksonia dilatata	Other	Secondary
Livistona humilis	Framework	Initial
Livistona inermis	Framework	Initial
Lophostemon lactifluus	Other	Initial
Melaleuca argentea	Other	Initial
Melaleuca cajuputi	Other	Initial

Species	Framework / Other	Initial / Secondary Establishment
Overstorey trees		
Fimbristylis sp.	Other	Secondary
Flemingia parviflora	Other	Secondary
Galactia megalophylla	Other	Secondary
Galactia tenuiflora	Framework	Secondary
Haemodorum coccineum	Other	Initial
Heteropogon triticeus	Framework	Initial
Indigofera saxicola	Framework	Secondary
Marsdenia sp.	Other	Initial
Mnesithea formosa	Other	Secondary
Panicum mindanaense	Other	Secondary
Schizachyrium fragile	Framework	Secondary
Sehima nervosum	Other	Secondary
Senna leptoclada	Other	Secondary
Sorghum intrans	Other	Secondary
Tephrosia nematophylla	Other	Secondary
Tephrosia polyzyga	Other	Secondary
Tephrosia remotiflora	Other	Secondary
Tephrosia reticulata	Other	Secondary

Species	Framework / Other	Initial / Secondary Establishment
Midstorey trees and shrubs		
Melaleuca dealbata	Other	Initial
Melaleuca leucadendra	Other	Initial
Melaleuca nervosa	Other	Initial
Melaleuca viridiflora	Framework	Initial
Owenia vernicosa	Other	Initial
Pandanus spiralis	Framework	Initial
Persoonia falcata	Other	Secondary
Petalostigma pubescens	Other	Initial
Petalostigma quadriloculare	Framework	Initial
Planchonia careya	Framework	Initial
Stenocarpus acacioides	Other	Initial
Sterculia quadrifida	Other	Secondary
Syzygium eucalyptoides subsp. bleeseri	Other	Initial
Syzygium eucalyptoides subsp. eucalyptoides	Other	Initial
Syzygium suborbiculare	Framework	Initial
Terminalia carpentariae	Framework	Initial
Terminalia ferdinandiana	Framework	Initial
Terminalia pterocarya (canescens)	Other	Initial

Species	Framework / Other	Initial / Secondary Establishment
Overstorey trees		
Thaumastochloa major	Other	Secondary
Themeda triandra	Other	Secondary
Uraria lagopodioides	Other	Secondary
Vigna lanceolata	Other	Secondary
Vigna vexillata	Other	Secondary

Species	Framework / Other	Initial / Secondary Establishment
Midstorey trees and shrubs		
Verticordia cunninghamii	Other	Initial
Vitex glabrata	Other	Secondary
Wrightia saligna	Other	Initial
Xanthostemon eucalyptoides	Other	Secondary
Xanthostemon paradoxus	Framework	Secondary

3.3.3 Trial establishment methods

Compared to most surface mining operations where topsoil return followed by broadcasting of seed during rainy seasons is standard, a non-typical range of establishment options is available in Ranger Mine rehabilitation. A few key options are described below, and additional revegetation methods or tactics for investigation are included within the description of each particular trial, e.g. Stage 13.1 (Section 3.4).

3.3.3.1 Topsoil return and direct seeding

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 framework 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 an appropriate seed mix dominated by framework species, good early establishment results have been obtained.

In contrast, on some hard-rock mines direct seeding has been more problematic and unreliable for establishing framework species (Reddell & Zimmermann 2002). Reddell and Hopkins (1994) found that tubestock planting was more successful than direct seeding, and follow-up trials confirmed that the reliability and predictability of vegetation establishment was very low with direct seeding (Reddell & Spain 1995, Gordon *et al* 1995), likely due to the extreme and variable climatic condition on the waste rock surface. Amelioration using mulch treatments were also unsuccessful and results suggest that the interaction between high ambient temperature and fluctuating moisture levels were probably critical factors affecting the success of vegetation establishment from seed. 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. The revegetation of the Ranger Mine is limited to seed from local provenance, therefore commercial supply of seed is extremely limited.

Although experience shows that direct seeding is not suitable for initial establishment of framework species, it is still an option in some situations (e.g. later establishments with the substrate conditions have improved) due to its:

- potential high cost effectiveness, and
- operational simplicity for 'broad scale' application.

Investigations are underway and shall continue into the environmental conditions and species best suited to this method of establishment.

3.3.3.2 Establishment from tubestock

Based on experience cited above, the Ranger revegetation has (since e.g. Reddell & Meek 2004) focussed on establishment via tubestock. Based on current technology tubestock planting will:

- significantly reduce the risk of planting failure associated with erratic rainfall and extreme temperatures
- accelerate the speed of vegetation development
- overcome the poor predictability of establishing a final revegetated landform from direct seeding techniques

This strategy has proven to be the most cost-effective method for the initial establishment of framework species at the Ranger Mine and is reasonable given the constraint imposed by greatly limited seed availability within Kakadu NP. However, where reliable and predictable direct seeding success can be achieved for some species, such as Pandanus and Kapok *(Cochlospermum* spp.*)*, this method will be used.

Whilst tubestock planting has proven very successful for a range of overstorey and midstorey species, a number of taxa have failed to establish using this method and many remain untested.

3.3.3.3 Litter islands

One opportunity for increasing the diversity of species able to colonise the waste rock final landform would be the establishment of fresh litter islands which would provide a number of valuable elements:

- act as a seed source for growth and further dispersal of a range of (particularly understorey) species (as long as the collection method ensured some of the surface ‘soil’, including much of the seed store, was obtained)
- introduce an array of microbes (especially mycorrhizae and rhizobia species) present in surface soils and litter of natural eucalypt-dominated woodlands that, by definition, will likely be suited to the native species being established in the waste rock.
- act as a mulch (by reducing surface temperatures and reflectance, and increasing surface soil moisture) and provide small ‘micro-niches’ where seeds or tubestock of plants that struggled to establish on bare waste rock are able to establish.
- include organic material that could kick start decomposition, support soil microbes and accelerate the soil development process.
- act as a source of future seed for further spread into the rehabilitation area.

This method might be an opportunity early in the initial establishment of revegetation, but it most likely has greatest potential to significantly assist with increasing diversity in the future, underneath the existing canopy of semi-developed overstorey framework trees.

A number of considerations must be made prior to this method being implemented at scale:

- timing (seasonality) of litter collection will highly influence the makeup of the seed store (particularly for annual species) and perhaps the makeup of the microbial population being transplanted with the litter.
- size of islands should be large enough to ameliorate the harsh impacts of the waste rock surface temperature, reflectance and so on, yet small enough to be able to be placed in and around established trees and shrubs.
- the thickness of the litter being applied must not be so thick that it will create a barrier for seedling emergence (e.g. as discussed by Parry 2018).
- suitable material may be limited (sources will be limited to natural sites on the RPA with no weeds) and so judicious use is advised. The number and size of islands must be carefully decided.
- the methods of litter collection and island 'construction' would need to be further developed to suit any large-scale rollout of the method.

Commencing in 2018, a small litter island trial at Jabiluka revegetation site has already shown potential in terms of introduction of target species but also non-target native species (deemed too problematic or non-dominant to warrant active introduction), with an early emergence of over 12 species observed including *Livistona*, *Grevillea*, *Phyllanthus* and *Spermacocce* species.

A series of investigations into this method will continue given that it is showing such potential to increase biodiversity, particularly of the understorey.

3.3.3.4 Passive or voluntary establishment

The Ranger Mine revegetation strategy includes deferring the introduction of competitive or 'sensitive' species (Section 1) until conditions improve. Thus, it is anticipated that understorey species richness will be low for a number of years after initial revegetation. ERA is committed to ensuring that target species composition and densities are achieved, and will develop and implement and, where required, innovative methods to actively ensure they establish on the final landform.

However, the potential role of 'passive' introductions of some of these species should not be overlooked, as this may enable resources to be focussed on the more 'recalcitrant' species requiring active introduction. A common experience in mining revegetation is the 'passive' establishment of what are termed 'volunteer' species, usually through dispersal by insects, animals and wind. These species often include grasses and fruiting species such as figs.

This was demonstrated at Pine Creek mine rehabilitation (on waste rock) where no understorey grasses or herbaceous species were actively introduced in the 1988-1996 seed mixes (Tony Scherer, *pers comm* May 2019) and yet the mature revegetation includes a 'some representative understorey' and 'limited evidence of invasive plants' (Dixon *et al.* 2019).

Observations from previous revegetation on waste rock at the Ranger Mine and more recently on the TLF have recorded a variety of native species establishing that were not actively introduced as part of the trial, these include *Ficus racemosa*, *Alstonia actonophylla*, *Eragrostis cumingii*, *Marsdenia* sp., and more that have yet to be identified.

The Species Establishment Research Program will continue to systematically review and improve the successful introduction of these species in revegetation at the Ranger Mine.

3.4 Early final landform trials (Stage 13.1)

As part of the SERP, a series of opportunistic, small-scale tubestock trials are currently being conducted at Stage 13.1 as a precursor to the large-scale Pit 1 revegetation trials (discussed in Section 6.1). For more information regarding the Stage 13.1 landform characteristics and trial layout see MCP Section 9.

The overall objective of the Stage 13.1 trial is to investigate different potting and planting techniques with the aim of improving tubestock survival during the 6 – 12 months after planting. However, this study will also provide an opportunity to:

- propagate and plant tubestock during different times of the year
- fine tune nursery propagation methods, such as germination rates, required growing times, irrigation requirements etc.
- improve planting methodology, trial new planting equipment, and collect information on ergonomics and HSE considerations
- obtain improved data on predicted species performance and adjust planting strategy (species, density, locations) accordingly
- obtain baseline performance data for species that have not been grown on FLF media previously
- inform future trials for Pit 1 and scaling up for operational planning for Final Landform (2023-2025)

The study consists of two distinct trials: wet season trials to investigate seven different potting and planting methods (treatment descriptions and rationale in Table 3-5); and unseasonal revegetation trials.

Thus far, propagating and planting of tubestock has only been performed for revegetation in the wet season. However, in 2024/2025 when revegetation is at its peak, tubestock will need to be grown and planted all year round. Revegetating between September – November (the 'build-up') may present some challenges; propagation will be needed during the cooler, dry months when seed germination and plant growth are typically very slow, and planting will occur during the hottest and most humid time of year when there is still minimal rainfall. Propagation for the unseasonal trials began in April 2020 and planting is scheduled for October 2020.

Table 3-5: Stage 13.1 Wet season 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	Microorganism inoculation has become standard practice in many commercial nurseries due to the vital role microbes perform in plant nutrient acquisition. The 2009 TLF planting tubestock potting mix included spores of locally collected fungi. 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 is regularly 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.
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 FLF.
7	Additional material in planting hole	Plant available water is a key concern for plant survival. Provision of additional growth medium may result in increased success. The additional material consists of approximately 2L of regular potting mix combined with the residual solid material used for local microbe application (collected mulch, puffballs, manure).

Approximately 1200 tubestock of 22 different species were planted at Stage 13.1 in April 2020 for the wet season trials (Table 3-6). All of the species had treatments 1 and 4, however the remaining treatments were only applied to select species so that the size of the study was manageable. Three of the treatments (2, 3 & 6) were trialled with three framework species: *Eucalyptus tetrodonta, Petalostigma quadriloculare* and *Terminalia ferdinandiana*. These species were also trialled with the remaining two treatments (5 & 7) along with three other species, *Brachychiton megaphyullus, Buchanania obovata* and *Grevillea decurrens*. These 'focus' species were chosen as they represent different community stratum (OS, MS, and US), they are from different Families (Myrtaceae, Picrodendraceae, Combretaceae, Malvacea, Anacardiaceae and Proteaceae), and are a combination of evergreen or deciduous.

Table 3-6: Stage 13.1 Trial Species

Species	Lifeform	Family	Treatments
Midstorey and Overstorey			
Acacia difficilis	Shrub	Fabaceae	1 & 4
Acacia dimidiata	Shrub	Fabaceae	1 & 4
Acacia mimula	Shrub	Fabaceae	1 & 4
Brachychiton megaphyllus	Shrub	Malvaceae	1, 4, 5 & 7
Buchanania obovata	Shrub	Anacardiaceae	1, 4, 5 & 7
Corymbia bleeseri	Tree	Myrtaceae	1 & 4
Corymbia chartacea	Tree	Myrtaceae	1 & 4
Corymbia dunlopiana	Tree	Myrtaceae	1 & 4
Corymbia foelscheana	Tree	Myrtaceae	1 & 4
Corymbia latifolia	Tree	Myrtaceae	1 & 4
Corymbia porrecta	Tree	Myrtaceae	1 & 4
Erythrophleum chlorostachys	Tree	Fabaceae	1 & 4
Eucalyptus miniata	Tree	Myrtaceae	1 & 4
Eucalyptus phoenicea	Tree	Myrtaceae	1 & 4
Eucalyptus tetrodonta	Tree	Myrtaceae	1 – 7
Grevillea decurrens	Shrub	Rubiaceae	1, 4, 5 & 7
Melaleuca viridiflora	Tree	Myrtaceae	1 & 4
Terminalia ferdinandiana	Shrub	Combretaceae	1 – 7
Understorey			
Cymbopogon bombycinus	Grass	Poaceae	1 & 4
Eriachne obtusa	Grass	Poaceae	1 & 4
Heteropogon triticeus	Grass	Poaceae	1 & 4
Petalostigma quadriloculare	Shrub	Picrodendraceae	1 – 7

3.5 Vegetation performance in waste rock

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), which was first formed over 15 years ago based on research conducted in the 80s, 90s and early 2000s. However, as ERA gather additional data and further revegetation experience, the Revegetation Strategy evolves. Some of the key learnings from recent revegetation trials (discussed in greater detail in the following sections) include:

- The FLF growth medium layer to be predominately grade 1 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 FLF; 2) vegetation generally performing better on waste rock only substrates in terms of germination and survival; 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, height, DBH (diameter at breast height), stem density, species diversity, production of flowers and fruit, and recruitment (Daws & Gellert 2010, 2011, Gellert 2012, 2013, 2014, Gellert & Lu 2015, Lu 2015, 2016 unpublished reports, Wright & Parry 2018, 2019, 2020 unpublished survey data).
- Initial revegetation will be irrigated during the first few months following introduction, regardless of season, as plant survival can be significantly impacted by water availability.

3.5.1 Overstorey and midstorey performance

3.5.1.1 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 3-7) (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). This clearly demonstrates 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.

After three months, the Stage 13.1 wet season revegetation seems to be tracking similarly to the 2010 tubestock on section 1A (Table 3-7). Mortality appeared to slow after 10 weeks with overall survival stabilising around 75% in the following four weeks; overall health of the tubestock also increased during that time as they slowly became less stressed (Figure 3-8). Some of the best performing MS and OS species thus far are *Brachychiton megaphyllus* (88%), *Buchanania obovata* (91%), *Grevillea decurrens* (90%), *Melaleuca viridiflora* (95%), and *Terminalia ferdinandiana* (88%).

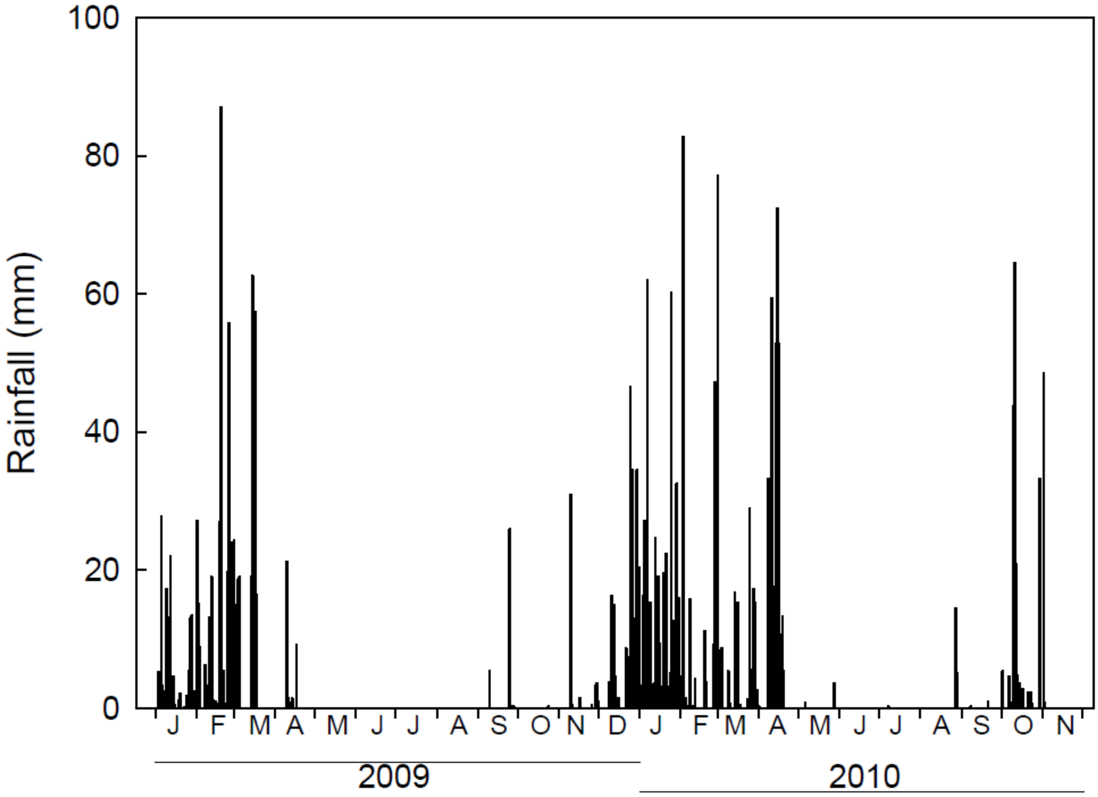


Figure 3-7: Daily rainfall for 2009 – 2010. Data up to 17 April 2009 from Jabiru Airport (Bureau of Meteorology): subsequent data from the TLF.

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 (September – December, depending on the year). However, it is likely that the consistent irrigation also contributed to the success of the July seeding.

Table 3-7: Initial overall survival (%) of tubestock planted on the TLF and Stage 13.1.

	Initial Overall Survival (%) of Irrigated Revegetation		
Areas	**2009 Tubestock (6 months post-planting)**	**2010 Tubestock (8 months post-planting)**	**2020 Tubestock (3 months post-planting)**
TLF waste rock (1A)	40	73.6	na
TLF laterite mix (3)	36.3	55.3	na
Stage 13.1	na	na	75

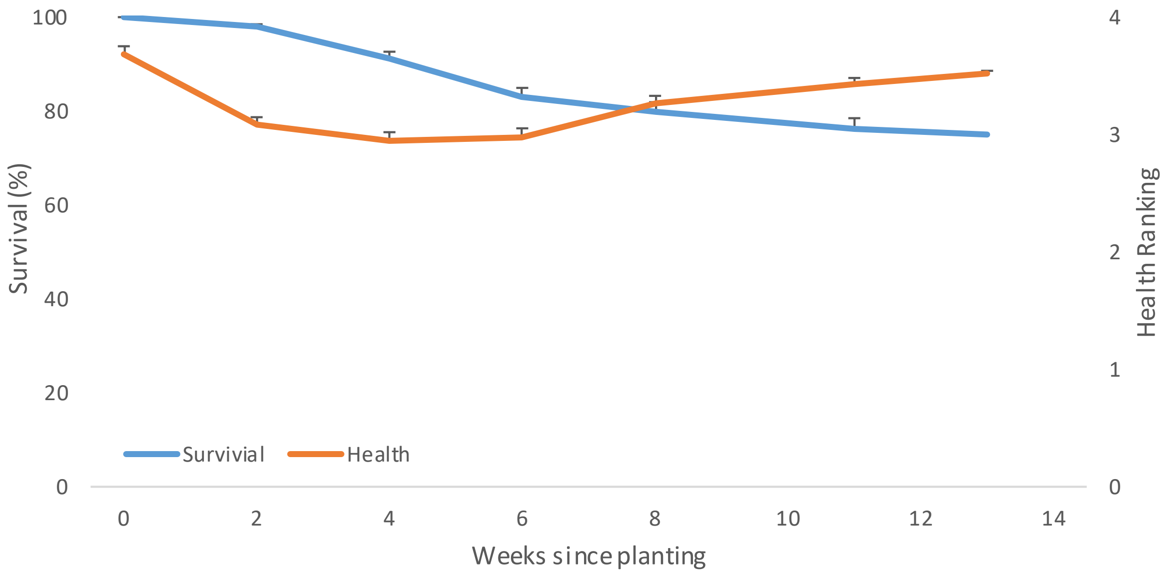


Figure 3-8: Stage 13.1 overall tubestock survival and health ranking (based on visual assessment) at 13 weeks after planting (includes OS, MS and US species data).

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.

Overall, 40 of the 42 tree and shrub species that were planted or direct seeded on the TLF are still present in 2020 (Table 3-8). The two 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 being ~94% viable (Daws & Gellert 2011). Some species established but over time disappeared from one section of the TLF (*Acacia dimidiata, Asteromyrtus symphyocarpa*, *Grevillea sp., Hakea arborescens* and *Planchonia careya*), and others have established but have very few individuals (*Jacksonia dilitata*, *Petalostigma pubescens* and *Owenia vernicosa*).

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 3-9). This is partly due to the high initial mortality rates of the 2009 tubestock and the shorter-lived species naturally 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 is better suited for introduction once the overstorey has had time to develop canopy and provide shade.

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. Although *E. tintinnans* does not occur in the ecosystems adjacent to the RPA, it is native to Kakadu National Park and has been included in the Ranger Revegetation Strategy at small densities as a climate change contingency species.

3.5.1.2 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 3-10). As of 2019, section 1A had the greatest stem density (of individuals >1/5m height) at approximately 727 stems/ha^{-1}, followed by 1B, 3 and 2 at 534, 354, and 200 stems/ha^{-1} respectively (Table 3-9). 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.

Table 3-8: The status of overstorey and midstorey species that were planted and/or direct seeded on the TLF between 2009 and 2011 (as of May 2020).

Species	Family	1A	1B	2	3
Acacia dimidiata	Fabaceae	Present	Not Present	Present	Present
Acacia hemignosta	Fabaceae	Present	Present	Present	Present
Acacia latescens	Fabaceae	Present	Present	Present	Present
Acacia mimula	Fabaceae	Present	Present	Present	Present
Asteromyrtus symphyocarpa	Myrtaceae	Present	na	na	Not Present
Brachychiton diversifolius	Malvaceae	na	Present	Present	na
Brachychiton megaphyllus	Malvaceae	Present	Present	Present	Present
Buchanania obovata	Acantahc	Present	Present	Present	Present

Species	Family	1A	1B	2	3
Cochlospermum fraseri	Bixaceae	Present	Present	Present	Present
Corymbia bleeseri	Myrtaceae	Present	Present	Present	Present
Corymbia disjuncta	Myrtaceae	Present	Present	Present	Present
Corymbia dunlopiana	Myrtaceae	Present	Present	Present	Present
Corymbia foelscheana	Myrtaceae	Present	Present	Present	Present
Corymbia latifolia	Myrtaceae	Present	Present	Present	Present
Corymbia polysciada	Myrtaceae	Present	Present	Present	Present
Corymbia porrecta	Myrtaceae	Present	Present	Present	Present
Erythrophleum chlorostachys	Fabaceae	na	Not Present	Not Present	na
Eucalyptus miniata	Myrtaceae	Present	Present	Present	Present
Eucalyptus phoenicea	Myrtaceae	Present	Present	Present	Present
Eucalyptus tectifica	Myrtaceae	Present	Present	Present	Present
Eucalyptus tetrodonta	Myrtaceae	Present	Present	Present	Present
Eucalyptus tintinnans	Myrtaceae	Present	Present	Present	Present
Gardenia megasperma	Rubiaceae	na	Present	Present	na
Grevillea decurrens	Proteaceae	Present	Present	Not Present	Present
Grevillea pteridifolia	Proteaceae	Present	Present	Present	Not Present
Hakea arborescens	Proteaceae	Present	Present	Present	Not Present
Jacksonia dilatata	Fabaceae	na	Present	Failed	na
Livistona humilis	Arecaceae	Present	Present	Present	Present
Livistona inermis	Arecaceae	Present	Present	Present	Present
Melaleuca viridiflora	Myrtaceae	Present	Present	Present	Present
Owenia vernicosa	Meliaceae	na	Failed	Present	na
Pandanus spiralis	Pandanaceae	Present	Present	Present	Present
Petalostigma pubescens	Picrodendraceae	na	Present	Present	na
Planchonia careya	Lecythidaceae	Present	Present	Not Present	Present
Stenocarpus acacioides	Proteaceae	na	Failed	Failed	na
Syzygium eucalyptoides sp. bleeseri	Myrtaceae	Present	Present	Present	Present
Syzygium eucalyptoides sp. eucalyptoides	Myrtaceae	na	Present	Present	na
Syzygium suborbiculare	Myrtaceae	Present	Present	Present	Present

Species	Family	1A	1B	2	3
Terminalia carpentariae	Combretaceae	na	Present	Present	na
Terminalia ferdinandiana	Combretaceae	Present	Present	Present	Present
Wrightia salingna	Apocynaceae	Present	Present	Not Present	Present
Xanthostemon paradoxus	Myrtaceae	Present	Present	Not Present	Not Present

Present = At least one individual present; *Not Present* = was once in that section, but no non-recruits currently present; *Failed* = species never observed despite being introduced; *na* = species never introduced

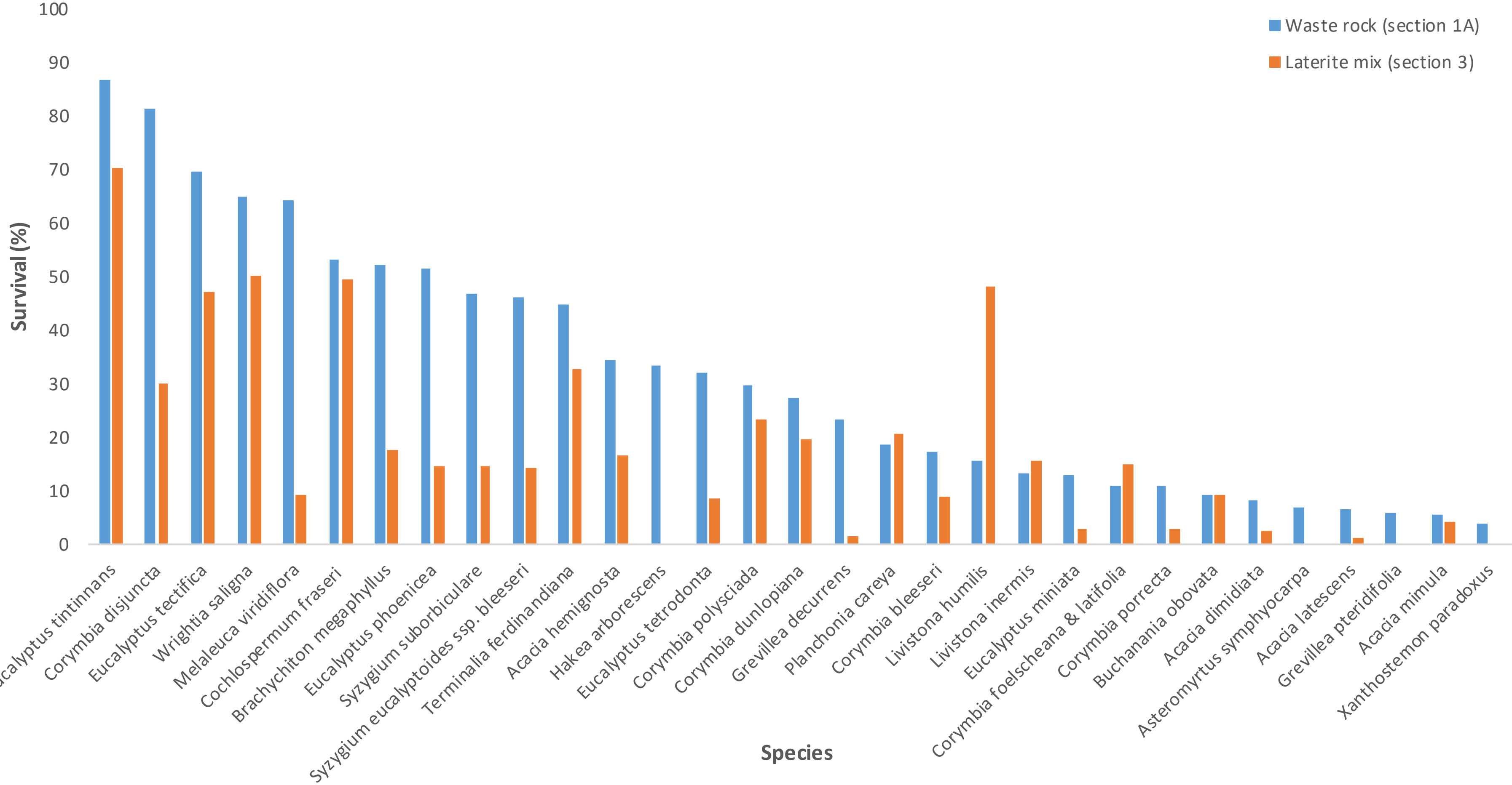


Figure 3-9: Tubestock Survival on 1A and 3 after ten years.

Calculated = (# of non-recruits present in 2019 / # planted in 2009 + 2010) * 100

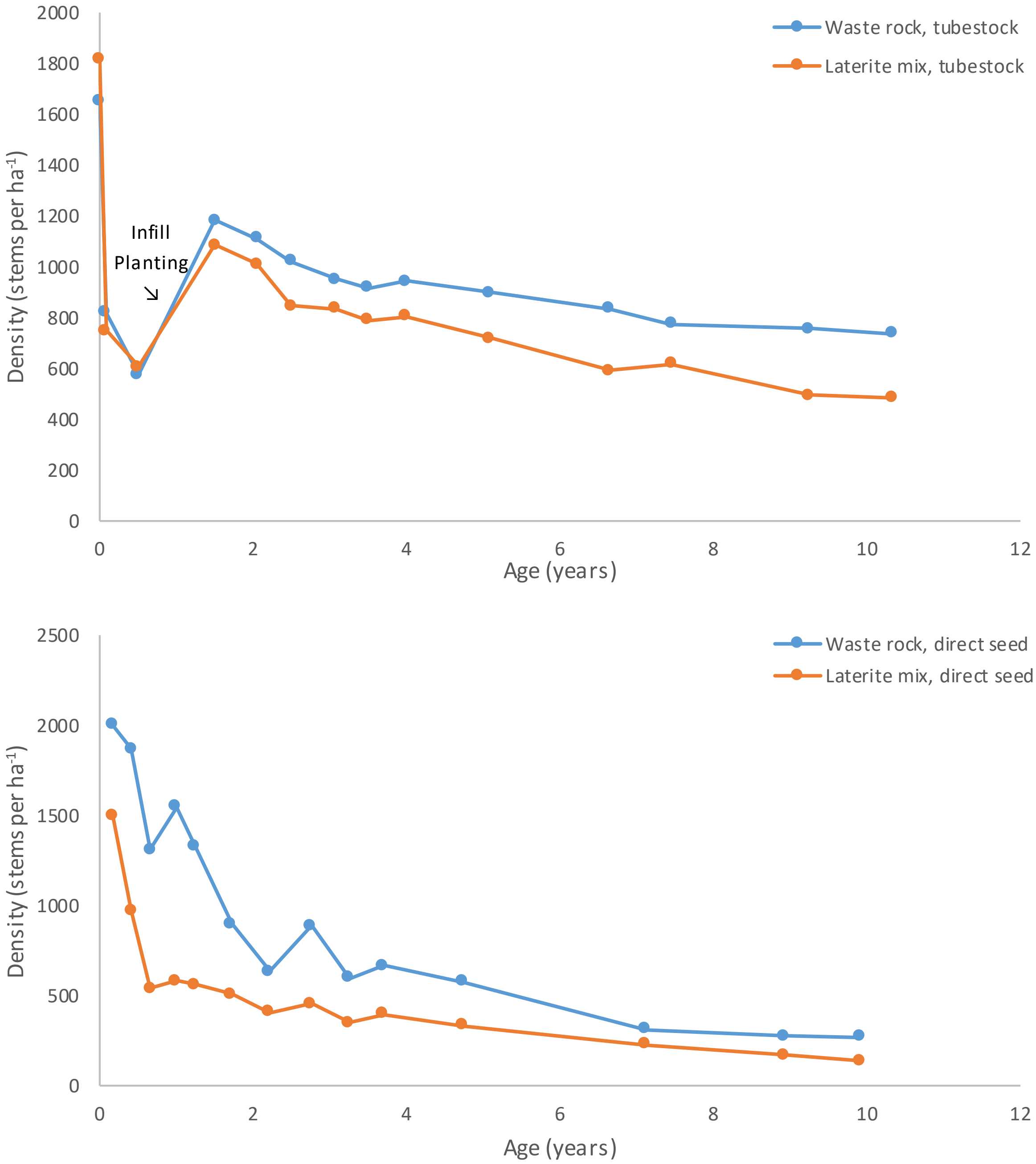


Figure 3-10: Longitudinal plant density (stems per ha^{-1}) based on the tubestock only (0 -14) and direct seeding only (15 – 29) Permanent Monitoring Plots on the TLF, not including recruits.

Note: Density is based on all introduced individuals inside the PMP 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 3-9: Approximate total overstorey and midstorey stems on the TLF, including recruits.

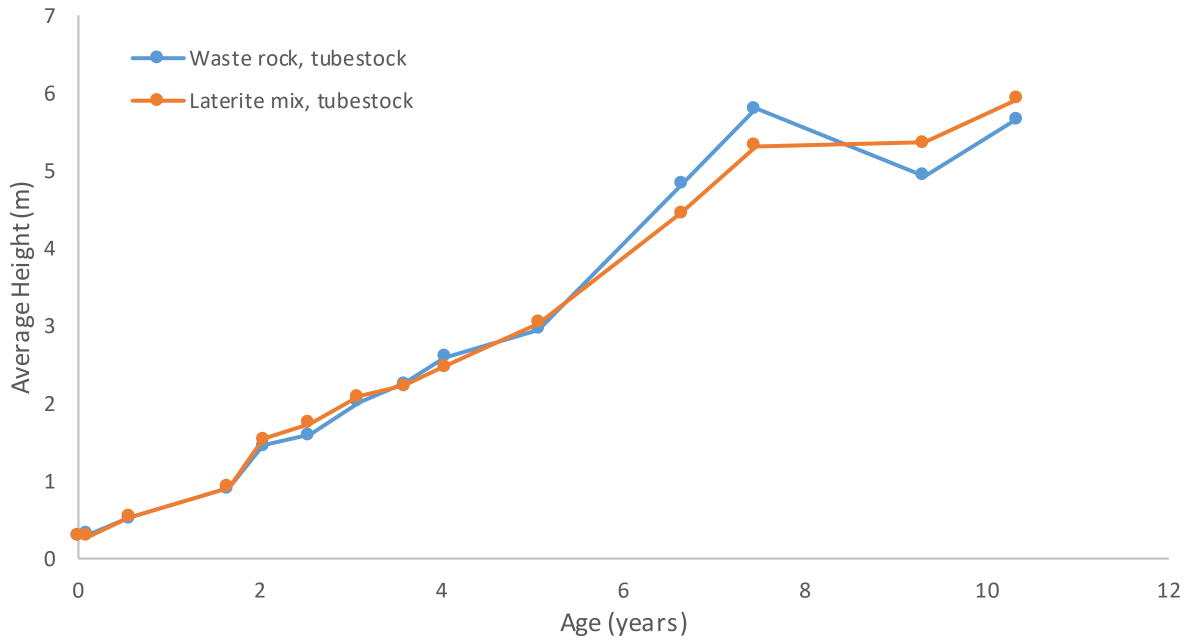
	Total # of individuals (approx.)	Total # of individuals >1.5 m	Stems per hectare (>1.5 m)
1A	967	727	727
1B	863	534	534
2	564	400	200
3	864	708	354
Total	3258	2369	296

3.5.1.3 Growth

Plant height on the TLF has not varied significantly by substrate in the tubestock areas (Gellert & Lu 2015, Parry 2019 unpublished data; Figure 3-11). 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 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 PMP 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 PMP 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 (Figure 3-12 and Figure 3-13).



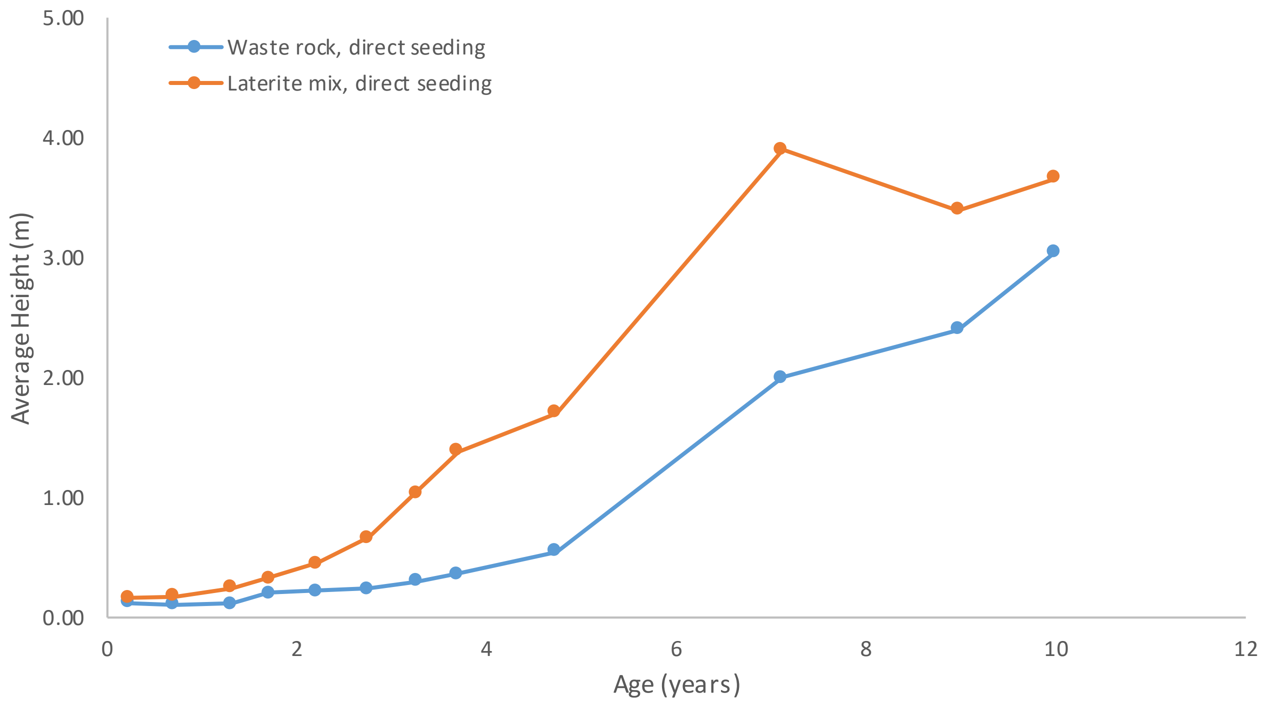


Figure 3-11: Longitudinal plant growth (height) based on the tubestock only (0 -14) and direct seeding only (15 – 29) Permanent Monitoring Plots on the TLF, not including recruits

Note: For the tubestock graph, the data points at 0.1 and 0.6 years are the average heights of the 2009 tubestock; from 1.5 years onwards, the graph is the combined average height of the 2009 and infill 2010 tubestock. Direct seeding height does not include the 2011 infill planting.

Figure 3-12: 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)

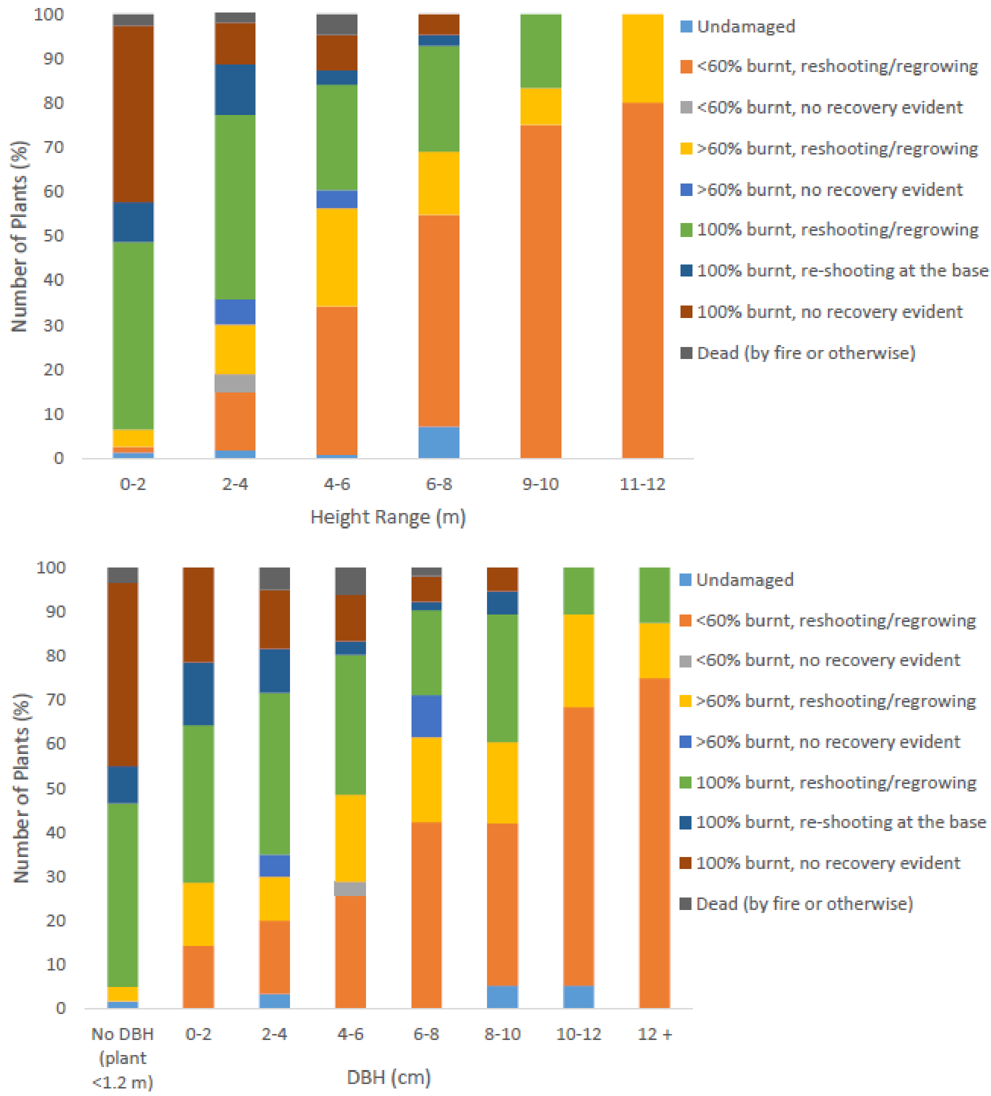


Figure 3-13: Height and DBH ranges and associated health classes after the 2016 burn on laterite mix areas of the TLF (Wright 2019a)

3.5.1.4 Flowering, fruiting and self-recruitment

Of the 40 OS/MS 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 monthly walk-throughs began) (Table 3-10). Over half of the species have flowered and fruited in every section that they are still present, including the majority of *Corymbias* and *Eucalyptus*. The three species that have not flowered and fruited at all include *Gardenia megasperma, Owenia vernicosa* and *Pandanus spiralis*, all of which were direct seeded. These species have grown very slowly (most <1 m) and are generally still too small to flower and fruit. Overall, species appear to flower and fruit most consistently in 1A, and least consistently in 1B.

Almost three-quarters of the OS/MS species on the TLF have self-recruited, either via seed and/or vegetative reproduction (suckering) (Table 3-10). Nine of the species have recruited in every section that they are present and another twelve have recruited in at least half of the sections they are present. Twelve species have had no observed recruitment. This includes the three species that have not fruited, and another five that have very few individuals on the TLF (*Acacia dimidiata*, *Asteromyrtus symphyocarpa, Jacksonia dilatata, Petalostigma pubescens* and *Xanthostemon paradoxus*). It is less clear why *Brachychiton diversifolius, Planchonia careya, Syzygium eucalyptoides* subsp. *eucalyptoides* and *Terminalia carpentariae* have had no self-recruitment; however, it is possible that these species actually have recruited, but the seedlings were either missed or died before the next walk-through was conducted.

Although the majority of the MS/OS 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 (Table 3-10).

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 contributed to 1A's high stem density, it also skews the section's species composition, which Gellert (2014) predicted may occur. It should be noted that *C. fraseri* recruitment is considerably lower in the other three sections of the TLF. 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 in the 1A. This information is important for planning future planting densities.

Fire also appears to be an important factor influencing self-recruitment. *Eucalyptus tetrodonta* and *Wrightia 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, versus seed in sections 1A and 1B.

Overall, section 1A has had the greatest number of species recruit (79% of the species present), followed by section 3, 1B and 2 (48%, 44% and 39% respectively). There may be several reasons why the level of recruitment is considerably higher in 1A than the other areas of the TLF. Section 1A has 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 2018). Lastly, section 1A has never had a dense weedy groundcover, unlike sections 2 and 3, which can outcompete young emerging recruits.

Table 3-10: Flowering, fruiting and self-recruitment of the MS/OS species on the TLF

Species	Flowering and Fruiting	Self-recruiting
Acacia dimidiata	At least 1 section	Not observed
Acacia hemignosta	All sections species is	All sections species is
Acacia latescens	All sections species is	All sections species is
Acacia mimula	At least 1 section	At least 1 section
Asteromyrtus symphyocarpa	All sections species is	Not observed
Brachychiton diversifolius	At least 1 section	Not observed
Brachychiton megaphyllus	All sections species is	At least 1 section
Buchanania obovata	All sections species is	All sections species is
Cochlospermum fraseri	All sections species is	All sections species is
Corymbia bleeseri	At least 1 section	At least 1 section
Corymbia disjuncta	All sections species is	At least 1 section
Corymbia dunlopiana	All sections species is	At least 1 section
Corymbia foelscheana	All sections species is	At least 1 section
Corymbia latifolia	All sections species is	At least 1 section
Corymbia polysciada	All sections species is	At least 1 section
Corymbia porrecta	All sections species is	At least 1 section
Eucalyptus miniata	At least 1 section	All sections species is
Eucalyptus phoenicea	All sections species is	At least 1 section
Eucalyptus tectifica	All sections species is	At least 1 section
Eucalyptus tetrodonta	All sections species is	All sections species is
Eucalyptus tintinnans	All sections species is	At least 1 section
Gardenia megasperma	Not observed	Not observed
Grevillea decurrens	At least 1 section	At least 1 section *
Grevillea pteridifolia	All sections species is	At least 1 section
Hakea arborescens	All sections species is	At least 1 section
Jacksonia dilatata	All sections species is	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	All sections species is
Owenia vernicosa	Not observed	Not observed
Pandanus spiralis	Not observed	Not observed
Petalostigma pubescens	At least 1 section	Not observed
Planchonia careya	At least 1 section	Not observed
Syzygium eucalyptoides sp. bleeseri	At least 1 section	At least 1 section
Syzygium eucalyptoides sp. eucalyptoides	At least 1 section	Not observed
Syzygium suborbiculare	At least 1 section	At least 1 section
Terminalia carpentariae	All sections species is	Not observed
Terminalia ferdinandiana	All sections species is	All sections species is
Wrightia salingna	All sections species is	All sections species is
Xanthostemon paradoxus	At least 1 section	Not observed

* Species with recruits >12-months-old

Figure 3-14: Flowering and fruiting on the Trial Landform. Top right to bottom left: *Brachychiton megaphyllus, Jacksonia dilatata, Eucalyptus tectifica, Cochlospermum fraseri*

3.5.2 Understorey performance

Experience at Ranger suggests that understorey species are more likely to establish successfully when tubestock planted rather than direct seeded, particularly during the initial revegetation of waste rock when there is no shade or organic matter.

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 cloth was 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 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 2018). 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. There has been significant mortality over the two years following seeding, with the best performing plots having fertiliser, surface litter, or a combination treatment (Figure 3-15) (Parry 2019 unpublished data).

Although some amelioration treatments have been found to improve directly seeded understorey establishment (Parry 2018), tubestock planting has consistently better survival and significantly higher rates of self-recruitment (Parry 2018, 2019 & 2020 unpublished data). The tubestock planted in 2018 still had up to 92 % survival after one year for all the species; after two years, the legumes had begun flowering and fruiting and the grasses had produced 2 – 3 generations of recruits (Parry 2020 unpublished data).

Initial survival of the US species tubestock planted at Stage 13.1 is generally high. Two of them are amongst the best performing species, *Heteropogon triticeus* and *Cymbopogon bombycinus,* with 100 ± 0 % and 90 ± 4 % survival respectively. The other two US species, *Eriachne obtusa* and *Petalostigma quadriloculare* have lower initial survival rates, but in the case of *E. obtusa,* it is likely that more seedlings are actually alive and have simply browned off due to the dry season.

It appears that some understorey species are more suited for 'secondary' establishment, even when tubestock planted. On the TLF, some species performed much better when planted in section 1A compared to those planted in the more open areas of 1B. It is likely the greater density of trees in 1A provided shade, reduced evaporation and surface temperature, protected the plants from drying, damaging winds, and made the area less accessible to herbivorous animals (Parry 2018). *Alloteropsis semialata* and the legumes had considerably lower mortality (particularly *I. saxicola*) and greater growth (particularly *G. tenuiflora*) in section 1A. The *Eriachne* grasses were the most successful in terms of recruitment, and had similar levels of survival, growth and recruitment in 1A and 1B. These results indicate that *A. semialata* and the two legumes likely require a more developed overstorey/soil for optimal establishment, whereas *Eriachne* could be introduced on less developed, more open landscapes if needed.

Overall, of the 24 understorey species that have been actively introduced to the TLF via seed and/or tubestock, eight have persisted, flowered and fruited, and a further four have recruited (Table 3-11). This number will likely increase in the next 12 months as the species introduced in February 2020 have the chance to establish.

Figure 3-15: Directly seeded *Galactica tenuiflora* in mixed treatment plot with fallen tree

Table 3-11: Timeline and method of understorey species introductions on the TLF.

Species	Jan-11	Nov-12	Apr-18	Jan-19	Feb-20
Acacia gonocarpa				Tubestock	Seed & Tubestock
Alloteropsis semialata			Seed & Tubestock	Tubestock	Seed
Aristida holathera		Seed		Tubestock	
Aristida inaequiglumis					Seed & Tubestock
Chrysopogon fallax		Seed			
Cymbopogon bombycinus					Seed & Tubestock
Dichanthium sericeum	Seed	Seed			
Ectrosia leporina					Seed & Tubestock
Eriachne armittii	Seed		Seed & Tubestock	Tubestock	Seed
Eriachne avenacea	Seed				
Eriachne ciliata	Seed				
Eriachne obtusa		Seed	Seed & Tubestock	Tubestock	Seed & Tubestock
Eriachne schultziana					Seed
Eriachne triseta	Seed	Seed			Seed & Tubestock
Galactia tenuiflora			Seed & Tubestock	Tubestock	
Haemodorum coccineum					Seed & Tubestock
Heteropogon triticeus					Seed & Tubestock
Indigofera saxicola			Seed & Tubestock	Tubestock	Seed & Tubestock
Petalostigma quariloculare				Seed	Seed & Tubestock
Pseudopogonatherum contortum		Seed			
Rhynchospora sp.					Seed
Templetonia hookeri					Seed
Tephrosia oblongata				Tubestock	
Triodia bitextura		Seed			

Species	Jan-11	Nov-12	Apr-18	Jan-19	Feb-20
Outcome	Failed to persist	Failed to germinate/ persist	Establishment successful via tubestock, some seeding also successful	Successful establishment	TBD, but preliminary results appear promising with tubestock and seeding

3.5.3 Ecosystem development

3.5.3.1 Exotic and weedy species

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 is 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 LFA 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. Five of these species have not been observed since March 2020, including *Crotalaria goreensis, Cyanthillium cinereum, Echinochloa colona, Euphorbia hirta* and *Sida acuta;* however, it will take multiple months of no observations to consider them eradicated. 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 and *Urochloa sp.* are generally considered native/naturalised species in the Northern Territory. However, due to their aggressive colonisation and dominance of disturbed areas they are considered weeds on the TLF. 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*. Approximately 90% of the *A. holosericea* did not recover from the burn, drastically reducing its number to only a few pockets that were protected from fire (eg. very rocky patches that did not burn, Figure 3-16). The prescribed burn also considerably changed the composition of the groundcover weed layer. Pre-burn the ground layer was dominated by buffalo clover whereas now it's predominately *Urochloa* grass, a more manageable species.

Figure 3-16: *Acacia holosericea* exposed to fire (top) and protected from fire (bottom), four months after 2019 June burn.

3.5.3.2 Species self-colonisation

At least thirty-eight native species have naturally colonised the TLF. The majority of these are understorey (Figure 3-17), however eight MS/OS species have also been observed.

Five of the OS/MS species, *Acacia difficilis, A. oncinocarpa, Alstonia actinophylla, Ficus racemosa* and *Lophostemon lactifluus* colonised the TLF well before the walk-throughs began in 2018, and are now several metres tall.

Understorey species with the greatest presence have been *Boerhavia coccinea, Brachyachne convergens, Phyllanthus sp.* and *Sporobolus australasicus* followed by *Blumea tenellula*, *Ectrosia leporina, Eragrostis cumingii* and *Marsdenia sp.* 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, most recently *Indigofera linifolia* (Figure 3-18), *Tacca leontopetaloides* and *Triodia bitextura.*

Figure 3-17: Various grasses, herbs, sedges and vines that have naturally colonised the TLF.

Figure 3-18: Leguminous understorey self-colonisers on the TLF, *Indigofera linifolia* (left) and *Tephrosia sp.* (right).

As of March 2020, section 1A has a significantly greater diversity of native species colonising from external sources than the other sections of the TLF (Figure 3-19). This is likely due to 1A having a more favourable microclimate for seedlings (increased shade and litter) and having minimal weedy groundcover. Another possibility is that the 2018 Honours trial may have inadvertently increased recruitment from external sources due to increased foot traffic and low-intensity dry season irrigation. However, if this was the primary cause of increased recruitment it would reason that 1B would show similar increases, as it was watered and monitored at the same frequency as 1A.

The rate of recruitment on 1A has increased exponentially over the 18-month monitoring period. It may be that the ecosystem has reached a certain level of development were it can now sustain a native understorey. 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). The other waste-rock only section, 1B, has also shown an increase in the number of species recruiting over the 18-month period, however only slightly. This is another indication that section 1A is further along in its ecosystem development than 1B, undoubtedly stemming from being initially tubestock planted rather than direct-seeded.

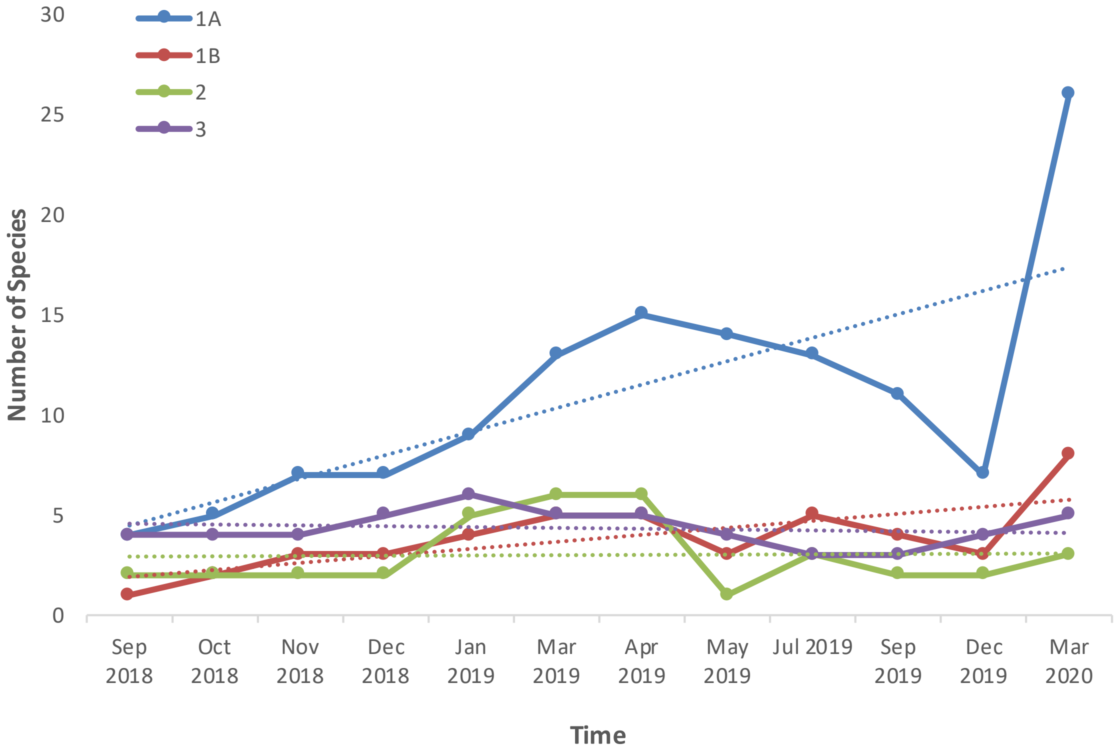


Figure 3-19: Rate and diversity of species colonising from external sources on the TLF

3.5.3.3 Fauna sightings

A variety of different faunal guilds have been observed utilising the TLF. Anecdotal observations include insects, arachnids, reptiles, birds, amphibians and mammals (Figure 28), with some occurring within the first year after construction – i.e. rock rats (Collier & Hooke 2011).

Figure 3-20: Fauna visitations on the TLF.

4 WASTE ROCK AS A GROWTH MEDIUM

At the Ranger Mine, the final landform of the disturbed area will be constructed of stockpiled run-of-mine waste rock with limited laterite and topsoil. The revegetation strategy of the final landform is therefore based on the assumption that most of the growth media will be waste rock only.

The physical characteristics of waste rock as a growth medium affects seed germination, initial survival of the young seedling (tubestock and direct seeded) and subsequent plant growth. This can make establishing diverse vegetation, especially shallow rooted understorey species, difficult. Waste rock, which has high proportions of coarse fragments, has low water-holding capacity which can cause severe surface drought and stressful growth conditions (eg. heat) for plants (Bradshaw & Chadwick 1980; Sheoran *et al*. 2010; Tordoff *et al*. 2000). Media with large sized particles can also have poor nutrient retention, and may not provide adequate root-soil contact needed for seedling establishment and survival (Chambers & MacMahon 1994).

The chemical and biological properties of waste rock can also inhibit seedling emergence, plant establishment and growth. Limiting chemical characteristics can include low organic matter content, low concentrations of plant-essential macronutrients such as nitrogen, phosphorus and potassium, acidity, salinity, and elevated bioavailability of metals (Ashwath *et al*. 1993, Bolan *et al*. 2017; Singh *et al*. 2002; Sheoran *et al*. 2010). Waste rock is also virtually devoid of soil microorganisms, such as mycorrhizal fungi, which limits mine waste revegetation by impacting nutrient cycling and microbial processes (Huang *et al*. 2012; Reddell & Milnes 1992).

The Ranger Mine is located in the seasonally wet-dry tropics, where approximately 95% of rainfall occurs between November and April, followed by an essentially rainless dry season, lasting from May to September. In this region, the most important factor shaping the landscape and determining the type of savanna ecosystems is the soil water availability and whether vegetation can survive the half-year dry season. Soil water availability is a key challenge for Ranger Mine site ecosystem re-establishment because the majority of the final landform will be constructed of waste rock growth media which often lack structure and contain large amounts of rock fragments and macro-pores that reduce their water holding capacity (compared to natural soils, Figure 4-1).

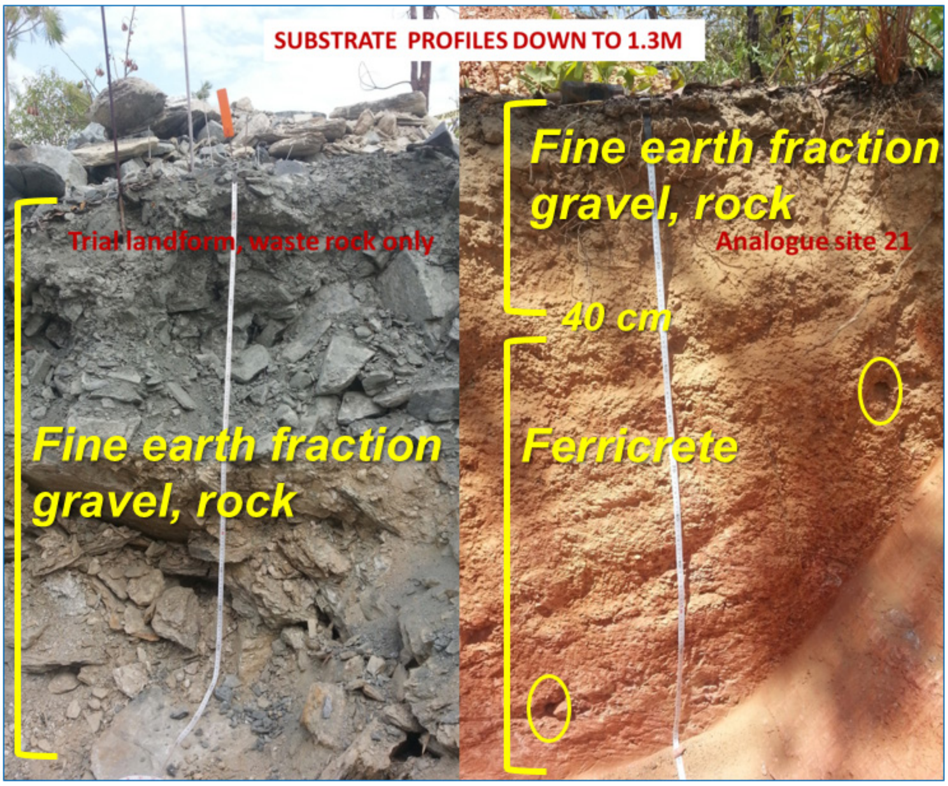


Figure 4-1: The waste rock substrate at the Ranger TLF Section 1A in 2014 (left) is fundamentally different to local substrates at Ranger's Georgetown Reference area (site 21) (right)

To address the question of whether the waste rock growth media of the Ranger final landform cover can supply sufficient plant available water (PAW) and nutrients to sustain a local native woodland, ERA has undertaken extensive research in the past three decades (Johnston & Milnes 2007, ELA 2017) on growth media particle size distribution, soil water dynamics, root depth, soil chemistry and nutrient cycling, and vegetation performance on the Ranger trial landform (TLF) (ELA 2017, Huang and You 2018, Huang *et al.* 2020, Lu 2017, Lu *et al*. 2019). This section will summarise the key knowledge on waste rock as a growth medium.

4.1 Waste rock particle size distribution

For the purpose of assessing water holding capacity of the growth media (waste rock), a key parameter is the % of the fines that are smaller or equal to 2mm in size. In soil science, only this portion of the material is considered to be able to store water for plant use.

During the construction of the Ranger TLF in 2009, waste rock samples were taken in triplicate from the surface of the TLF and at depths of one, two, three and four metres from the TLF pits (there was one pit in each of the 1A and 1B subsections that were constructed of waste rock only). These samples were sieved to determine the weights of the fraction 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 sent to the University of Melbourne for particle size analysis using the Bekham Coulter LP

13320 laser sizer. Particle sizes were grouped into the sand, silt and clay fractions according to the USDA size classes.

Particle size distribution (PSD) results from the TLF section 1A profile are presented in Table 4-1. Note that sand, silt and clay make up 100 % of the fine earth material particles (i.e. particles <2 mm), commonly referred to as '*fines*'. The rock content (i.e. particles >2 mm) ranges from 61 to 73 % with an average of about 67 %. This is consistent with SSB observed 70 % rock content (Mike Saynor, *pers. comm.*). A breakdown of the fines content is shown in the three right-hand columns in Table 4-1, and is similar to values published by Saynor & Houghton (2011) (Figure 4-2). Saynor & Houghton (2011) described the determination of the particle size statistics of the surface material from different parts of the TLF. In 2009 two surface material samples were collected from each of two different sample sites within each of the six treatment areas, with 24 samples collected in total (Saynor *et al*. 2012a).

Table 4-1: 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

(Source: Segura 2017)

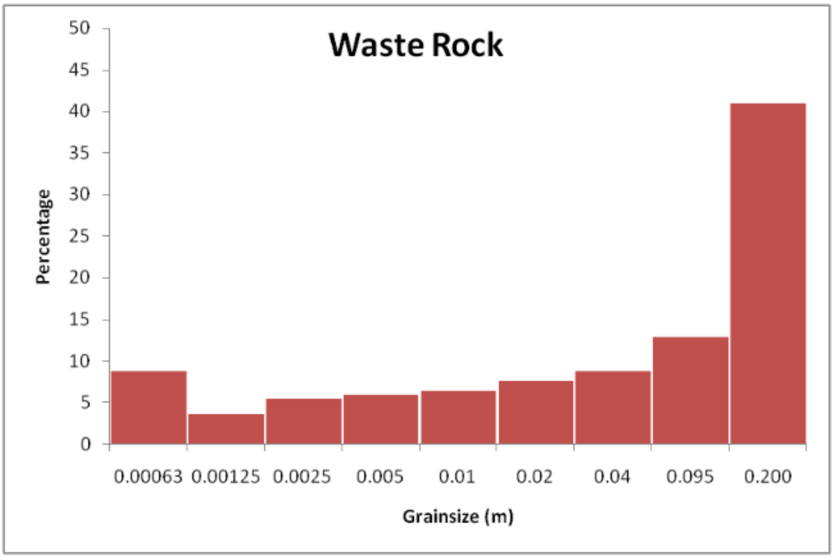


Figure 4-2: Surface grain size distribution for waste rock samples from sections 1 and 2 of the trial landform

Hollingsworth (2010) measured PSD, water content and water potential of the substrates in an experimental waste rock cover established on the northern Ranger Mine waste rock dump of the Pit 3 materials. It was reported that the substrate contains 36% of fines (<2 mm) and 64% of gravels/rocks from 24 core samples.

In an early CSIRO study on revegetated waste rock dumps at Ranger, Emerson and Hignett (1986) found that the rock fractions (> 2 mm) of the samples taken from trenches in three rock piles of Pit 1 materials were 'surprisingly' uniform and the mean was 61%, 54% and 57%, respectively (Table 1 in Emerson & Hignett 1986). These rock contents are comparable to, though consistently lower than, the TLF finding of 67% for the Pit 3 materials. These findings suggest that waste rock materials are similar in terms of fractions <2 mm particles (fines) between Pit 3 materials used for the TLF and Hollingsworth (2010), and even between Pit 1 materials (Emerson & Hignett 1986) and Pit 3 materials.

With the assistance of the Douglas Partners Geotechnical & Environmental Consultants, ERA has undertaken a PSD sampling campaign of stockpiled waste rock (2019) and also progressive sampling of the waste rock material being placed in the Pit 1 upper 6 m growth layer during the 2019/2020 construction activity (note: not all of the Pit 1 samples have been analysed yet). Figure 4-3 provides a comparison of the results available to date, and indicates that the Pit 1 backfill material is significantly finer (averaging about 40% <2mm fraction) than the estimated stockpile average (about 21% fines). The stockpile sampling data suggests that the stockpiles used for backfilling Pit 1 ('Stage 10 and some Stage 6 stockpiles) have unusually high fines compared to the other stockpiles, and so it is expected that the remainder of the material used in construction of the final landform will be more like the overall average of 20-25% fines.

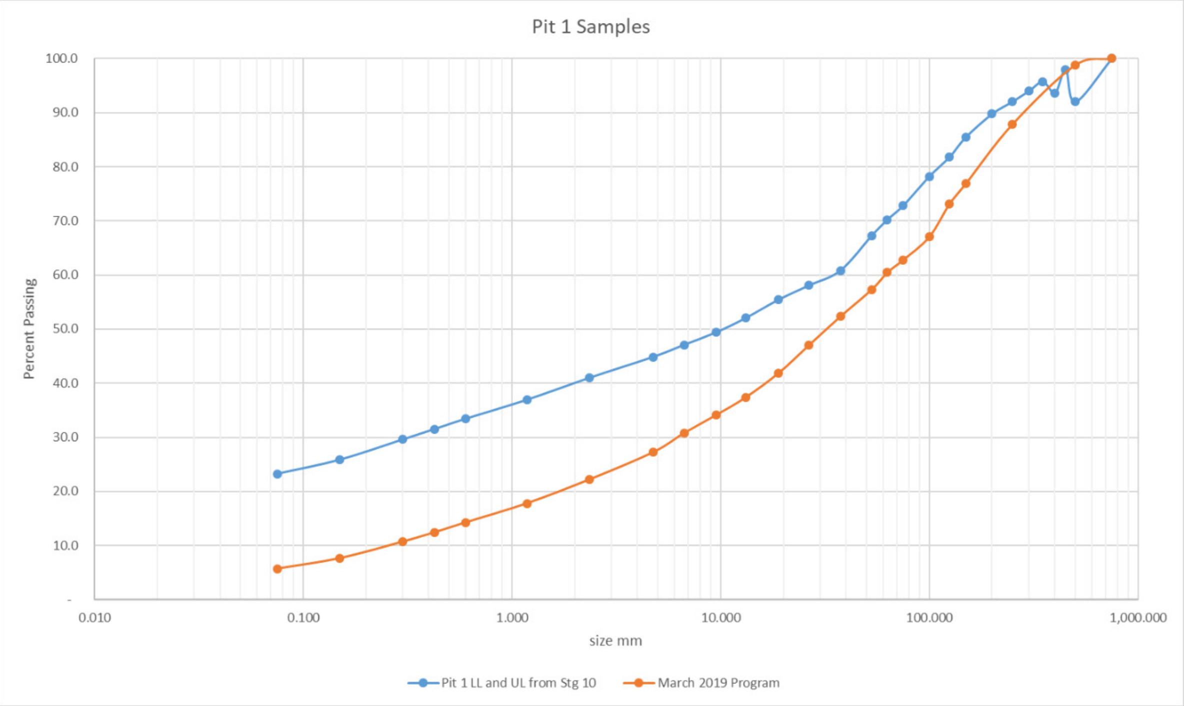


Figure 4-3: Particle size distribution for Pit 1 growth layer materials compared to 2019 stockpile samples.

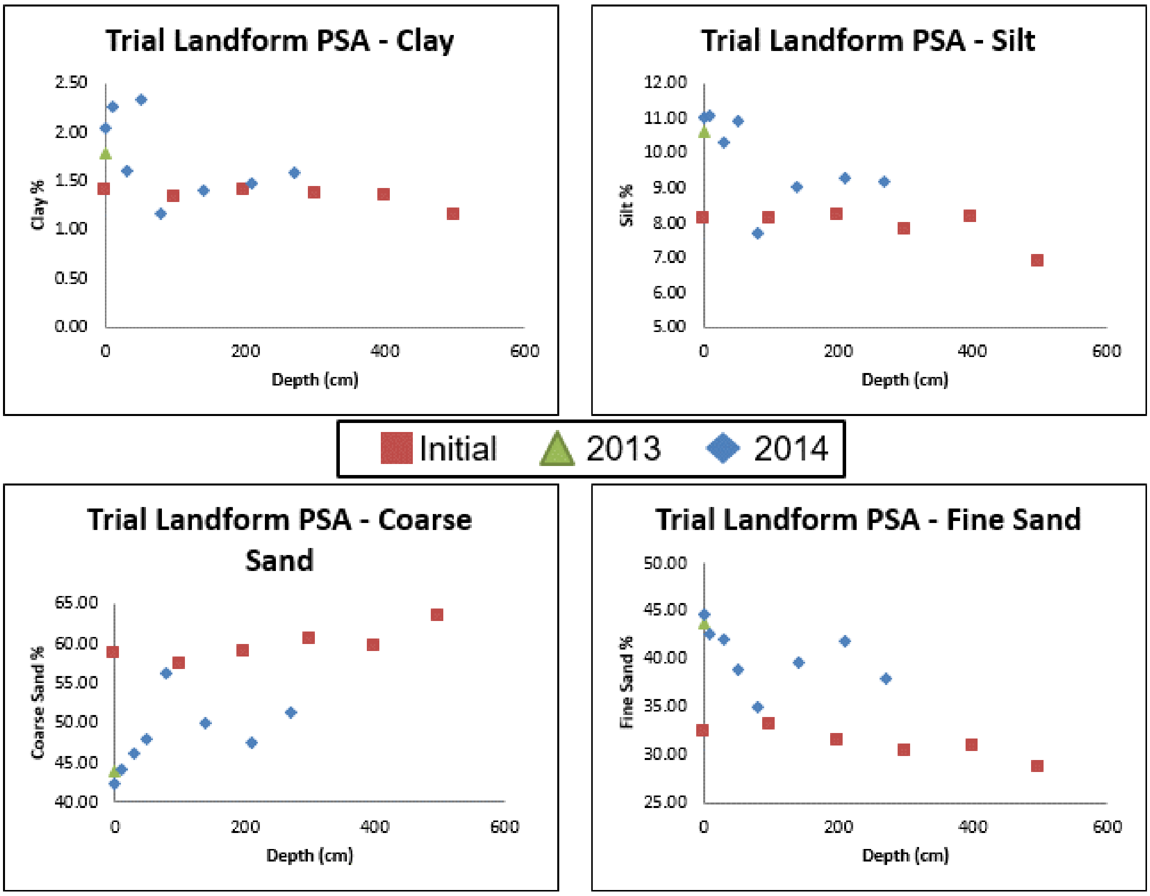
4.2 Weathering and soil development

Development of a waste rock 'soil' able to sustain native vegetation is a result of the 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 is one component of this, however generation and infiltration (illuviation) of organic matter is another important process (Tony Milnes, *pers. comm*. 2019).

Weathering of the waste rock over time will increase the proportion of fines in the profile, which increases the water holding capacity of the material. General observations indicate ROM waste rock on the TLF has been breaking down since initial placement as a consequence of physical, chemical and biological weathering processes, and also due to vegetation establishment and litter accumulation, and decomposition by microbial activity in the substrate. The increased proportion of fines will create a suitable substrate for understorey development. Some natural establishment of understorey species in the waste-rock-only section has been observed since 4-5 years after revegetation, which supports this theory.

Johnston and Milnes (2007) reviewed a number of early CSIRO investigations into the formation of waste rock 'soils' to inform the revegetation strategy and summated that weathering of much of the rock materials exposed on the surface of the stockpiles was rapid. Within two years of construction of waste rock stockpiles, properties such as colour mottling due to increased hydromorphy, variations in soil texture as a result of water erosion of fine material, structure development, decrease in pH due to pyrite oxidation and sulfate weathering were recognised by Fitzpatrick *et al* (1989).

In 2013 the University of Queensland and Charles Darwin University conducted a small-scale excavation of the TLF section 1A and particle size analysis (PSA) was undertaken to determine particle size distribution. A slight increase in fines was observed compared to proportions measured during initial construction of the TLF in 2009 (Figure 4-4and Figure 4-5).

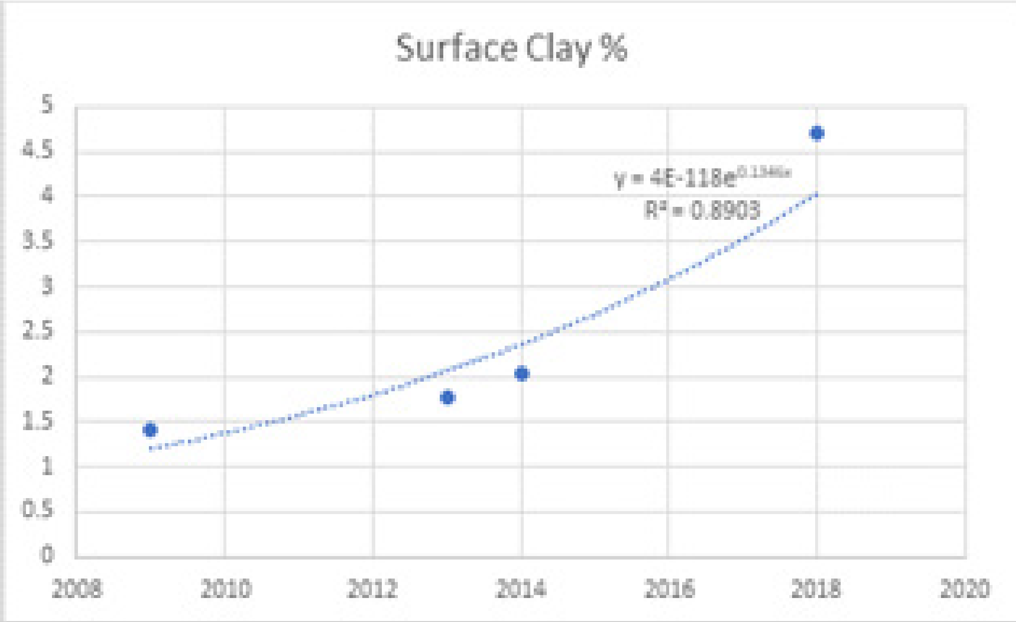


(Source: Lu *et al*. (2018)

Figure 4-4: Changes in PSD on TLF from 2009 to 2014 inclusive

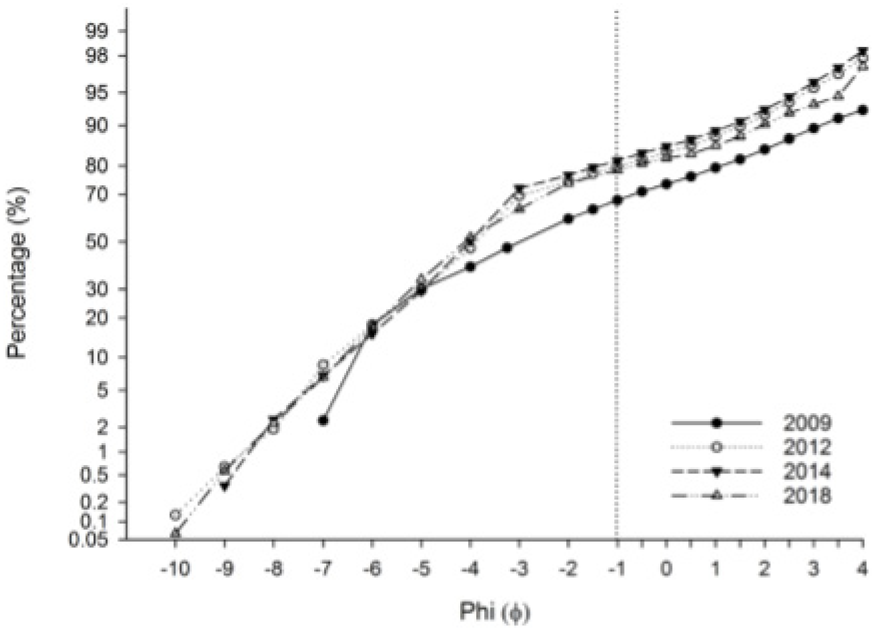
The SSB has measured, *in situ*, particle size of waste rock on the surface of the TLF since 2009 (Saynor 2019). Results indicate that the samples are exhibiting a trend of very little weathering over the five-year period (2012-2018). Measuring only surface samples risks missing the important fines that move vertically into the substrate profile, however Saynor (2019) suggests that this is only a minor 'loss', despite not having been measured. It is explained that "the near-uniformity of the cumulative particle size class distributions over time indicates such potential loss is minor over the sampling period" (Figure 4-6).

Nevertheless, the weathering measured as above did not account for the fines that were removed from the surface so the rate of material weathering is potentially underestimated.



(Source: Lu *et al.* 2018)

Figure 4-5: Changes in PSD on TLF1 (including 2018 surface soil samples) at 5 cm depth



(phi)	(mm)
-10	1024
-9	512
-8	256
-7	128
-6	64
-5	32
-4	16
-3	8
-2	4
-1	2
0	1
1	0.5
2	0.25
3	0.125
4	0.063

Figure 4-6: Cumulative percentage of particle size for waste rock on TLF (from Saynor 2019)

4.3 Chemical characteristics and nutritional processes

4.3.1 Chemical characteristics

Chemicals in substrates can play a critical 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).

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 nitrogen and extremely low organic carbon at the beginning of the landform establishment because the materials were just run-of-mine without topsoil (Ashwath *et al*. 1993, Gellert 2014, Table 4-2**)**.

Table 4-2: 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)	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)

Worth noting is that compared to waste rock from other mines in the Alligator Rivers Region, 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 the natural soil (19:1). The presence of high ratio of C:N in mine waste rock than in natural soils may restrict the net release of N to plants and soils.

As part of the 2018 *Cumulative ecological risk assessment for the rehabilitation and closure of Ranger uranium mine* (Bayliss 2018) assessments of potential chemical effects on seedling plant growth and survival were made. The assessments related to toxicity thresholds reported in the literature for species (or at least genera) that will be used in revegetation at the Ranger Mine, and their potential roles as either limiting nutrients, toxicants or chemical facilitators. Bayliss (2018) arrived at the following conclusion:

> *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 their conclusion to ARRTC (May 2018) on 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.

Despite these positive conclusions, it is always preferred to have site specific and species-specific information on the nutrient requirements, and toxicity risks, of target species for rehabilitation of the Ranger Mine final landform. General findings and observations may obscure specific effects that could cause sub-optimal vegetation establishment and development. For example, 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 of most species 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 was 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.

4.3.2 Nutrient cycling

The diversity and sustainable growth of revegetated plants is closely related to nutrient cycling in soil-plant systems, which is 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 contain after the same period of time following burning (Ward 2000). Surface roughness (for example 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/year) 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 forest) 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.

4.3.2.1 Nutrient cycling studies at the Trial Landform

ERA recently commissioned a study (Huang & You 2018, Huang *et al.* 2020a) into nutrient cycling of the revegetation at the Ranger TLF compared to the Ranger Georgetown Creek reference sites. The 2018 study compared TLF-1A and Georgetown Site 21 while the 2019 study looked at TLF-1A and Georgetown Site 30, where soil is more gravelly and shallower than at Site 21. The key findings of the 2018 study are summarised in Table 4-3.

Huang and You (2018) suggest that the low mineralisation rates in the 9 year-old revegetated TLF soils may be attributed to the consequence of combined abiotic stress selection (e.g. 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 could be one of the key factors limiting microbial growth and functions in soil.

In 2019 the study aimed to assess key microbial and nutrient cycling attributes of litters and surface soils from 10 year-old revegetated waste rock (TLF-1A and 1B) in comparison with a natural vegetation reference Site 30 (Huang *et al.* 2020a). The investigation characterised litter properties (e.g. elemental and organic compound composition) and a range of key soil molecular microbial, chemical and biogeochemical indicators for assessing the potential capacity of organic carbon decomposition and nutrient (particularly nitrogen (N)) cycling processes in surface soil of trial landform (TLF 1A and 1B).

The litter collected from the sites mostly 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 site and the TLF sites (Table 4-4).

Table 4-3: 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 the 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.

Surface soil at the reference site was more fertile compared to the rehabilitated waste rock sites (Figure 4-7). It was 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 at the reference site. This is consistent with the findings that 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).

Table 4-4. 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

The surface soil from the TLF sites is slightly alkaline and less fertile than those from the reference site, as the surface soil layer is formed from the freshly formed/weathered rock fines and decomposed organic matter. The levels of organic matter of TLF soil samples were only about one third of the reference site, with even much lower levels of total nitrogen (<5mg/kg). Microbial communities in the surface soils were highly diverse and dominated by organoheterotrophs, regardless of sampling sites. Bacterial and fungal communities in the soils from the reference site had the highest diversity. The microbial communities from the reference site appeared structurally different from those of the other sites, while a few Actinobacteria associated with N enrichment and fungi associated with later stage of decomposition were abundant in the soil from the reference sites, which are capable of decomposing woody organic matter. The soils from the site of TLF-1A and TLF-1B 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. Both 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 carbohydrate (eg. sugar), but the selected enzymes involved in cellulose, hemicellulose and protein decomposition were at a similar level as those from the reference site. As sugar metabolisms is usually associated with opportunistic bacteria that require 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 to establish productive understorey species (including N_2-fixing leguminous species) to increase labile organic matter (ie. biomass residues and root debris) and N inputs. This is critical to restoring the nutrient pools and maintaining the biological functions in surface soil. Importantly, the increased understorey vegetation would provide shading effects, to help alleviate radiation heat stress and drought stress in the surface soil of the TLF sites in future, which are favourable for soil microbial activities and nutrient cycling in the surface soil.

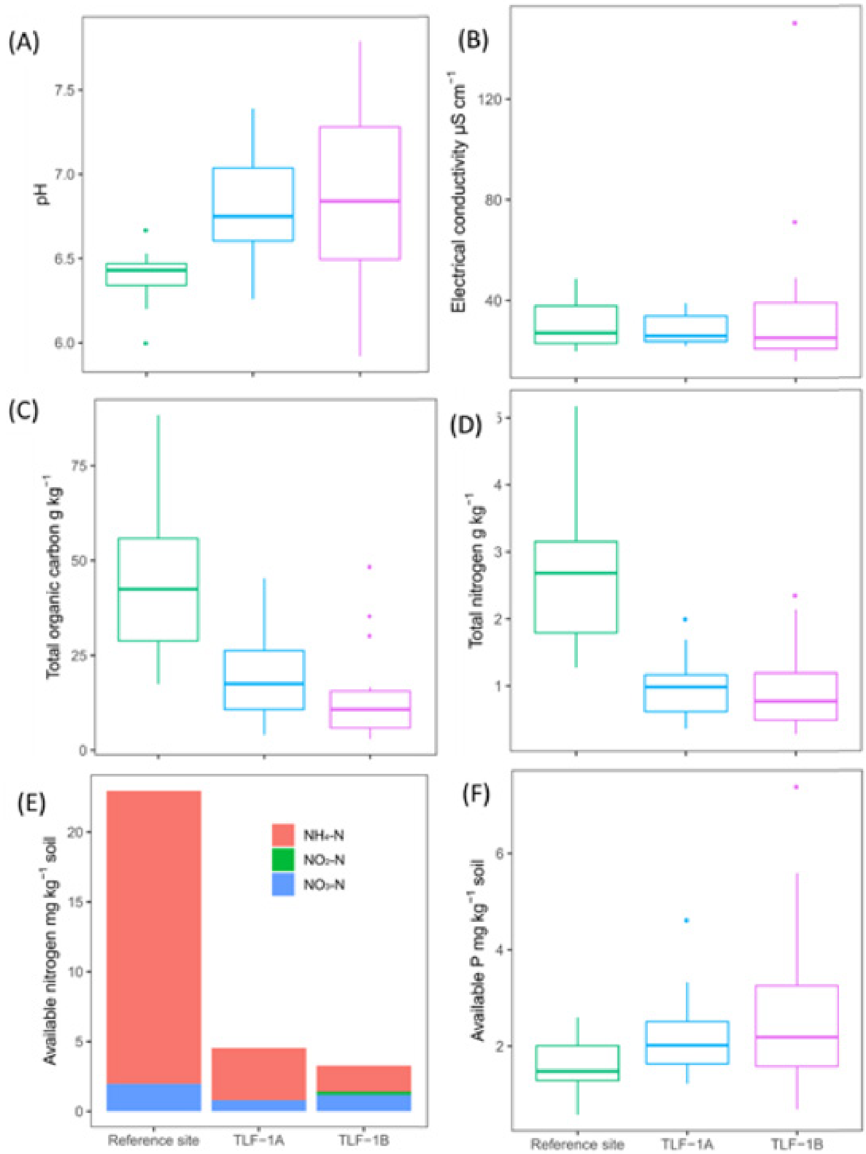


Figure 4-7: Selected soil chemical properties pH (A), EC (B), and nutrient availability, including total organic carbon (C), total nitrogen (D), Available N in the form of NH4+-N, NO2--N and NO3--N (E) and Available P (F) among reference Site 30, TLF-1A and TLF-1B.

In summary, 10 years after the revegetation, the TLF growth media have significantly improved their nutrient level compared to the initial stage of the revegetation and the microbial communities in the surface soils were highly diverse which is similar to the reference site. However, 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 that the most important strategies were to:

(1) Minimize surface drought and heat;

(2) Enrich high quality organic matter by understorey growth; and

(3) Improve N-supplying capacity by introducing diverse deep-rooting understorey legumes.

4.4 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 4-8). The TLF surface was ripped on the contour before the erosion plots were constructed, and plots were located to represent two types of potential final cover layers (waste rock, or waste rock – laterite mix) and planting methods (direct seeding and tube stock).The plots were physically isolated from runoff from the rest of the landform by raised borders.

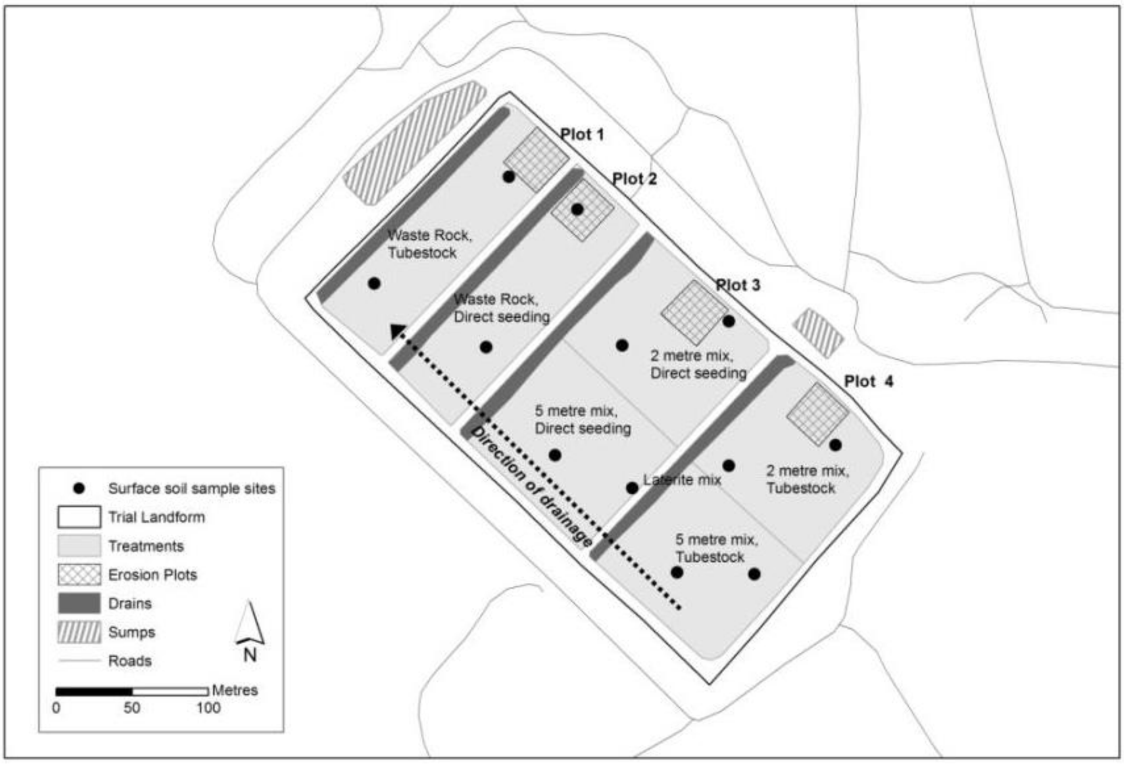


Figure 4-8: Layout of the erosion plots on the trial landform (Boyden *et al.*, 2016, Saynor *et al.*, 2016)

Sensors installed in each plot included: a tipping bucket rain gauge, a 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 at 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 4-9).

Figure 4-9: Runoff through the flume on the trial landform erosion plot 3 during a storm event (Saynor *et al.*, 2014)

Monitoring results including generation and transport of solutes, hydrology and bedload yields, have been reported regularly (Saynor *et al.* 2009, Saynor *et al.* 2011, Saynor *et al.* 2012, Saynor *et al.* 2014, Saynor *et al.* 2015).

4.4.1 Infiltration

Studies have been undertaken involving some field measurements of infiltration and runoff rates of the TLF. In his PhD study into surface hydrological modelling for rehabilitated landforms, Shao (2015) developed a modified runoff model (RunCA) and then applied it to the Ranger Mine 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) and carried out 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 if 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 θFC 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 $\theta 0$, TP and θFC were then determined by weighing the core samples before and after oven-drying at 105°C for 24 hours in the laboratory.*

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 4-5 and Table 4-6) Shao's direct measurements from the TLF were used to calibrate the WAVES model (Section 4.5).

Table 4-5: 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 4-6: 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.

4.4.2 Runoff

Annual runoff from the TLF was determined to be the 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 4-10), 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, hence generates runoff from the whole plot surface.

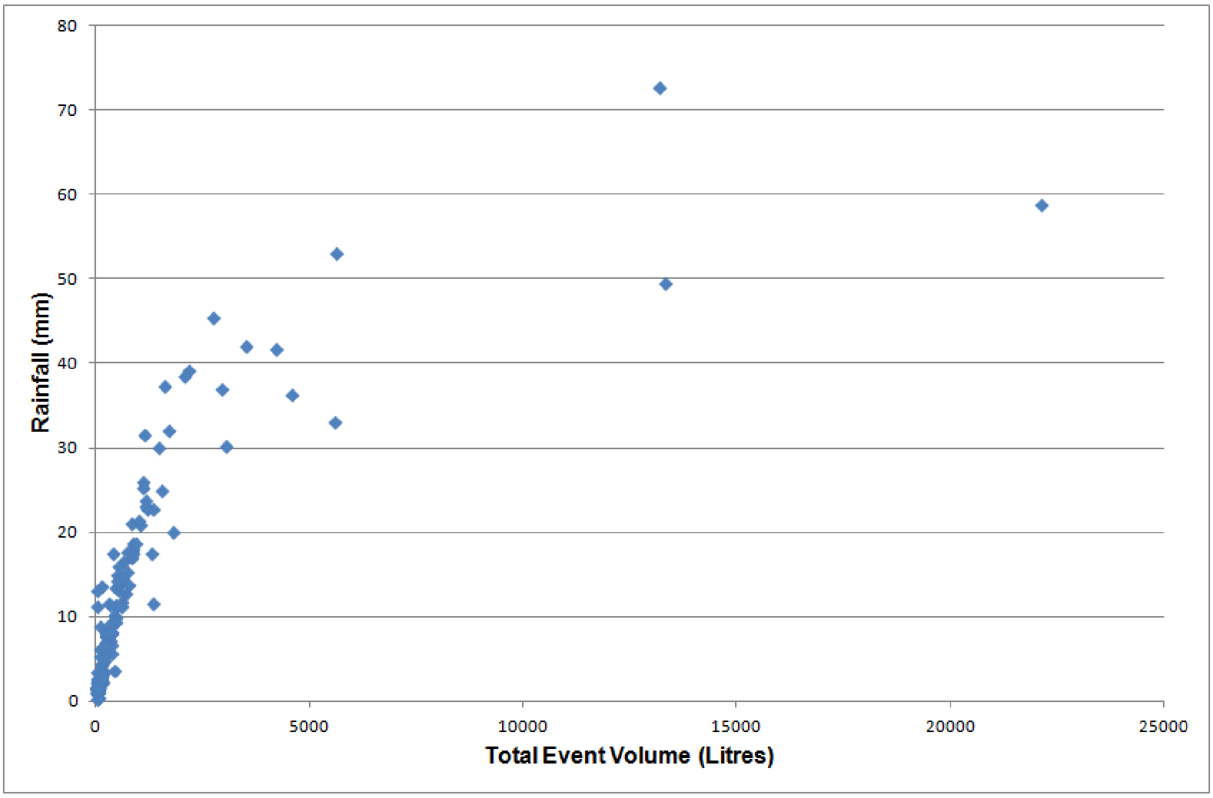


Figure 4-10: Relationship between total event rainfall and runoff for erosion plot 1 for 156 runoff events in the 2013–14 wet season (Saynor *et al.* 2015)

4.4.3 Erosion

Run-off and erosion rates measured on the trial landform have been used to assess the long-term geomorphic stability of the trial landform 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 trial landform annual bedload yield, which is characterised by an exponential decline since construction (Figure 4-11). 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.

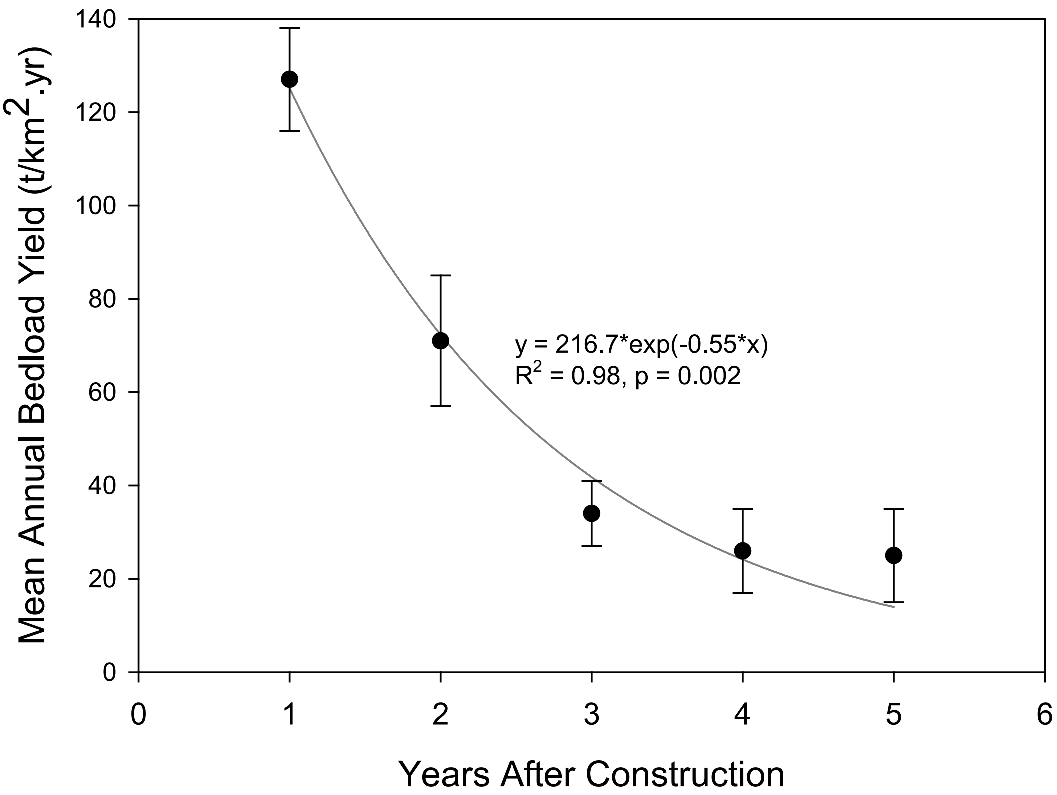


Figure 4-11: Exponential decrease in mean annual bedload yield with time since construction for the four plots on the trial landform. Data represent annual mean and standard error of estimate for all plots (Lowry & Saynor, 2015)

4.5 Plant available water (PAW) studies

Ranger Mine is located in the seasonally wet-dry tropics of northern Australia, where ~95 % of rainfall occurs between November and April (Section 4). In this tropical region, the most important factor shaping the landscape and determining the type of savanna ecosystems is the soil water availability and whether vegetation can survive the half yearly dry season. This presents the most critical challenge for Ranger Mine site revegetation as post-mining soils often lack structure or contain large amounts of rock fragments that reduce their water holding capacity.

To address this critical question of whether the waste rock substrate of the Ranger Mine final landform can supply sufficient plant available water (PAW) to sustain a local native woodland, ERA has undertaken extensive research over the past three decades, especially in the last two decades (Hollingsworth 2010, Lu 2017, Lu *et al*. 2019). ERA has undertaken long-term ecohydrological studies in the Georgetown Creek Reference Ecosystem area since 2008 (MCP Section 5.3.3.5) and studied soil water dynamics and vegetation performance on the Ranger Mine TLF since 2009.

Since 2011, ERA has engaged Charles Darwin University to undertake a modelling approach to study the water balance of the TLF. The study used hydrologic characteristics of the waste rock substrate and the outcomes of the above ecohydrological studies to model the water balance using the Commonwealth Scientific and Industrial Research Organisation (CSIRO) WAVES model (Zhang & Dawes 1998). This modelling focussed on estimating the required PAW in the waste rock surface layer to meet the anticipated demand for sustaining the rehabilitated ecosystem.

PAW 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 is going to be a challenge for the Ranger Mine ecosystem re-establishment as waste rock growth media often lack structure or contain large amounts of rock fragments and macropores that reduce their water holding capacity (compared to natural soils).

A range of ecohydrological research and modelling has been undertaken at the Ranger Mine to support the intention to use waste rock to construct the final landform and establish a range of sustainable vegetation communities similar to those in Kakadu National Park.

4.5.1 Volumetric soil moisture content

After construction of the TLF in 2009, a pit was dug to the natural ground level by an excavator to allow vertical installation of soil moisture probes to integrate a measure over the 0.3 m length of the probe at 0 to 0.3 m, 0.3 m to 0.6 m, 0.6 m to 0.9 m, 0.9 m to 1.2 m, 1.2 m to 1.5 m, 2.7 m to 3.0 m, and 3.7 m to 4 m below ground surface in the TLF 1A section. For other sections, additional 1 probe per metre was added in depth until reaching the nature ground surface. Another four probes were installed horizontally at 0.1 m below ground surface to monitor shallow soil moisture.

Soil volumetric water content at different depths in the waste rock only substrate in the TLF 1A section over a two year period are shown in Figure 4-12 and Figure 4-13. Soil volumetric water content at the TLF 1A section show significant seasonal variations. The entire soil profile is recharged with rainfall water during the wet season and gradually dries out during the dry season. The landform substrate acts as a ‘store and release’ reservoir for the establishment and development of vegetation.

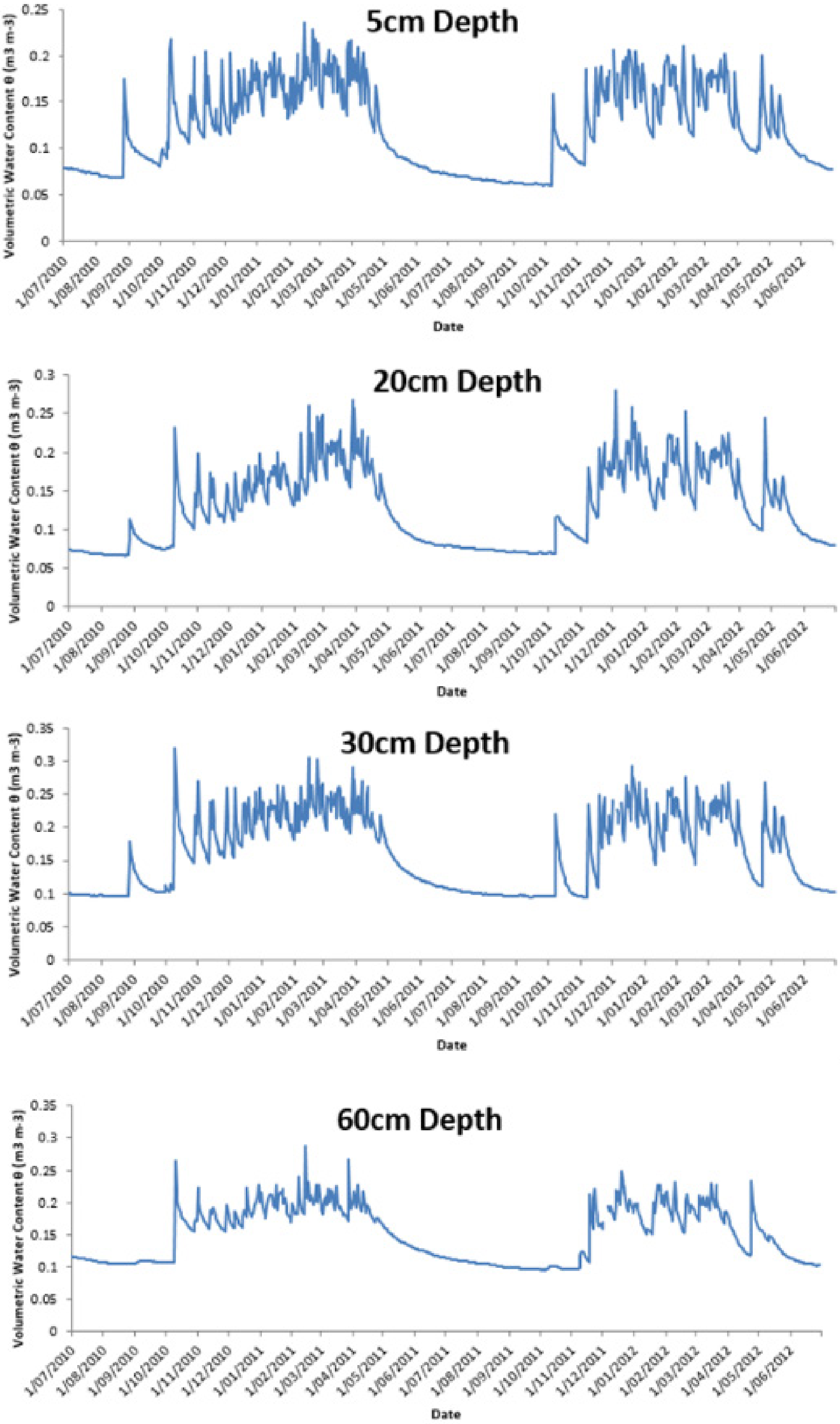


Figure 4-12: Seasonal dynamics in soil volumetric water content at depths 5 to 60 cm in the waste rock only substrate in the TLF 1A section

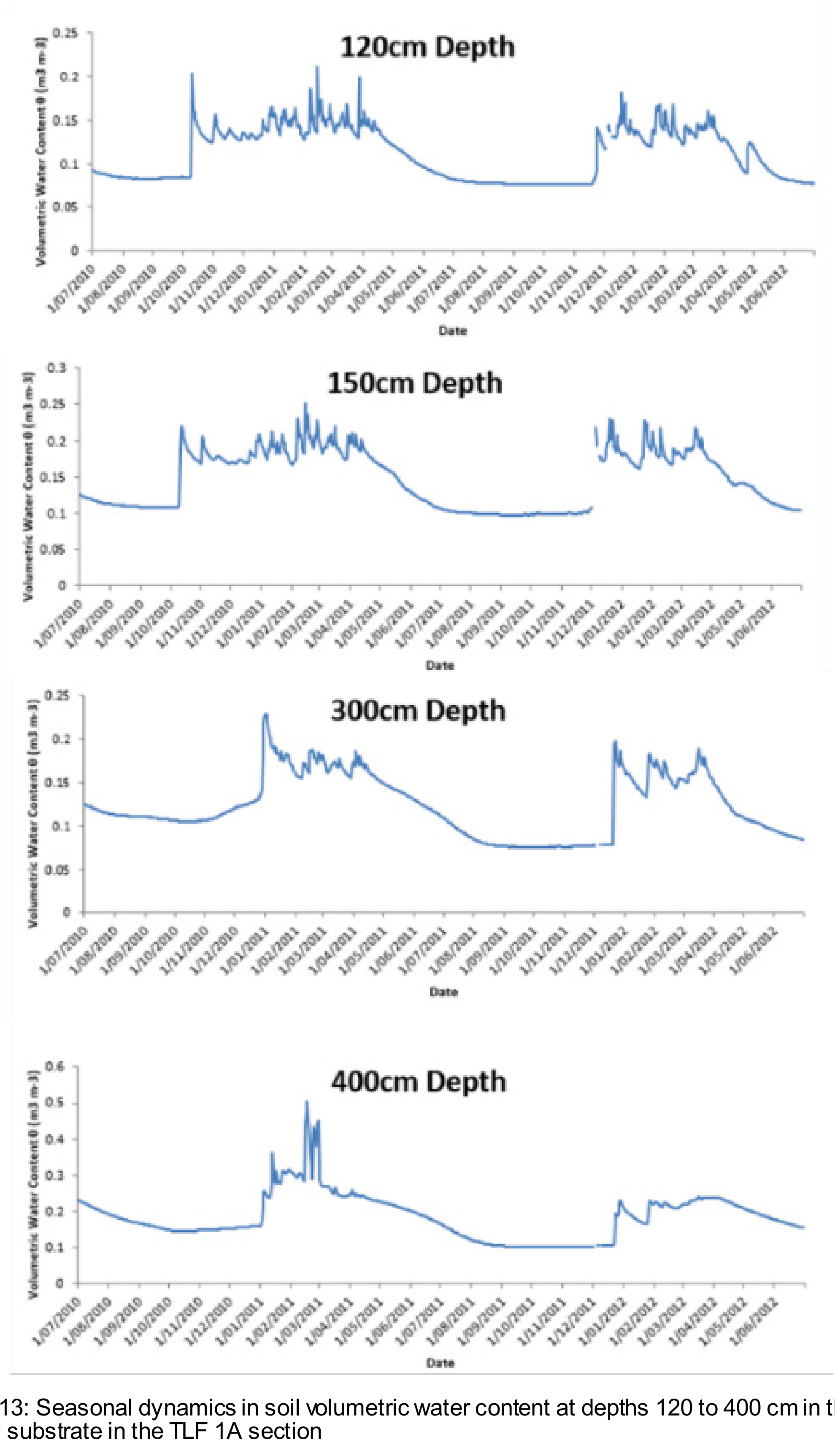


Figure 4-13: Seasonal dynamics in soil volumetric water content at depths 120 to 400 cm in the waste rock only substrate in the TLF 1A section

Figure 4-14 shows long-term dynamics of the soil water contents in the above soil profile from immediately after landform construction until 5 years after. Presumably as a result of the consolidation and improved sensor/substrate contact over time the peaks during the wet season became substantially reduced.

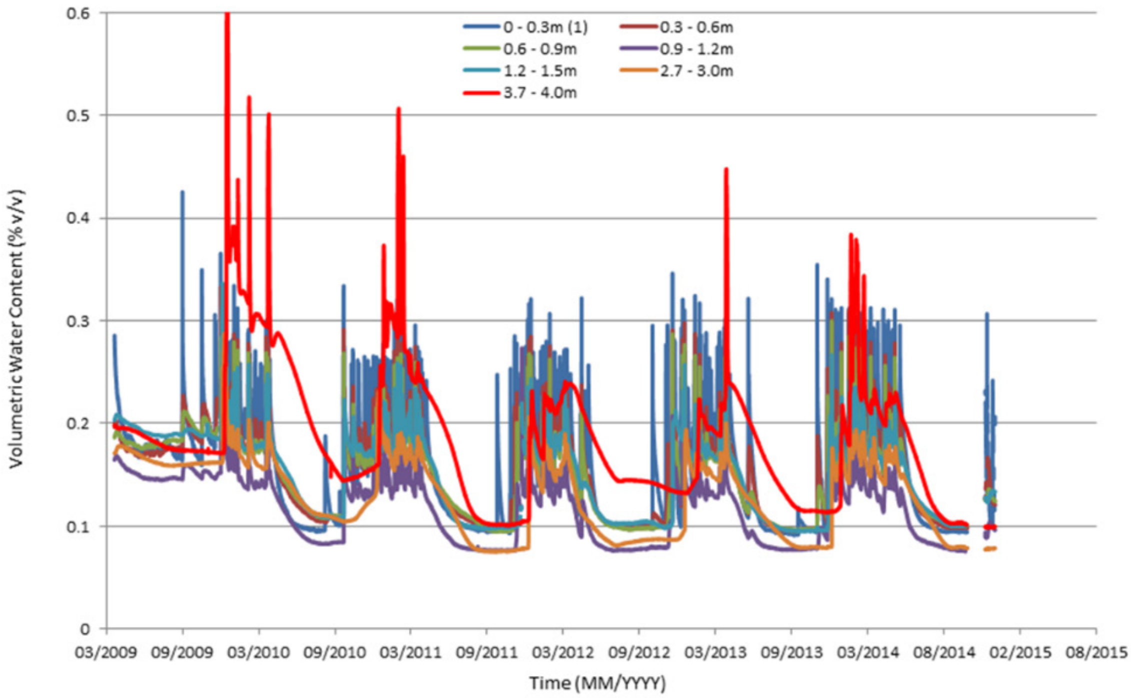


Figure 4-14: Long-term dynamics of the soil water contents in the TLF 1A soil profile from immediately after landform construction until 5 years later

Average volumetric water content for depths 0.3 m to 1.5 m and 2.7 m to 4.0 m are shown in Figure 4-15. Maximum water contents are about 0.25 (25 %) indicating that the saturated void-space is about 25%. Estimated field capacity (green-coloured line) and wilting point (mauve-coloured line) by Croton (2017) are also plotted on the graph in Figure 4-15. The average estimated field capacity is in good agreement with the troughs of the wet-season curve, and the dry-season minima are aligned well with the wilting point.

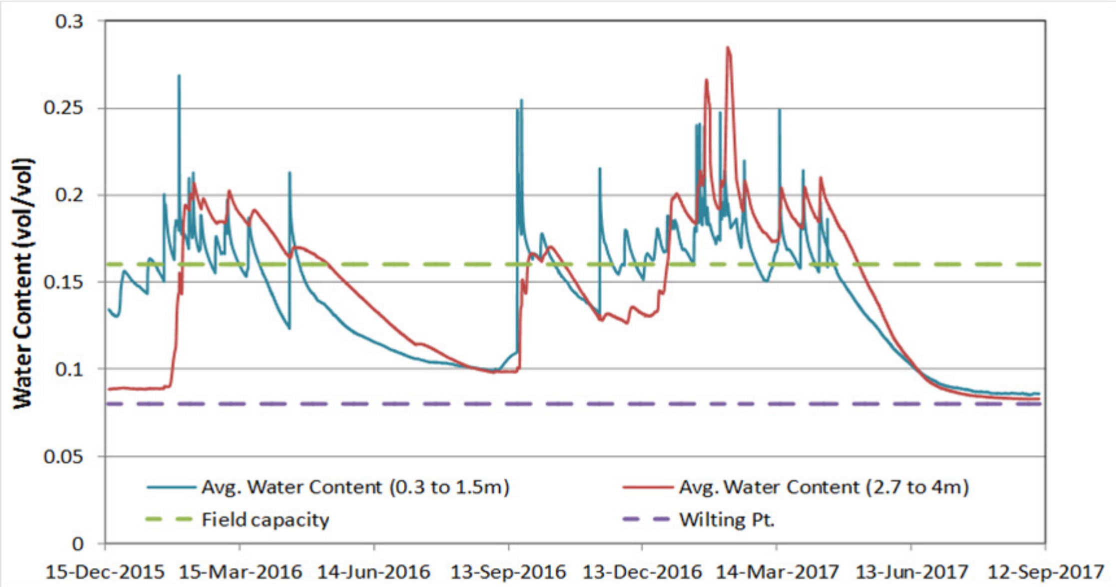


Figure 4-15: Measured volumetric water content and estimated average field capacity and permanent wilting point for TLF growth substrate

The wetting front progression (as shown by soil volumetric water content dynamics) in the in the TLF 1A section is shown in Figure 4-16. The behaviour of wetting front progress after a significant rainfall (47.8 mm) on 24 January 2016 demonstrates a steady downward progression of the wetting front without abrupt peak at lower positions. This suggests that preferential pathways are not a major issue in the TLF 1A section.

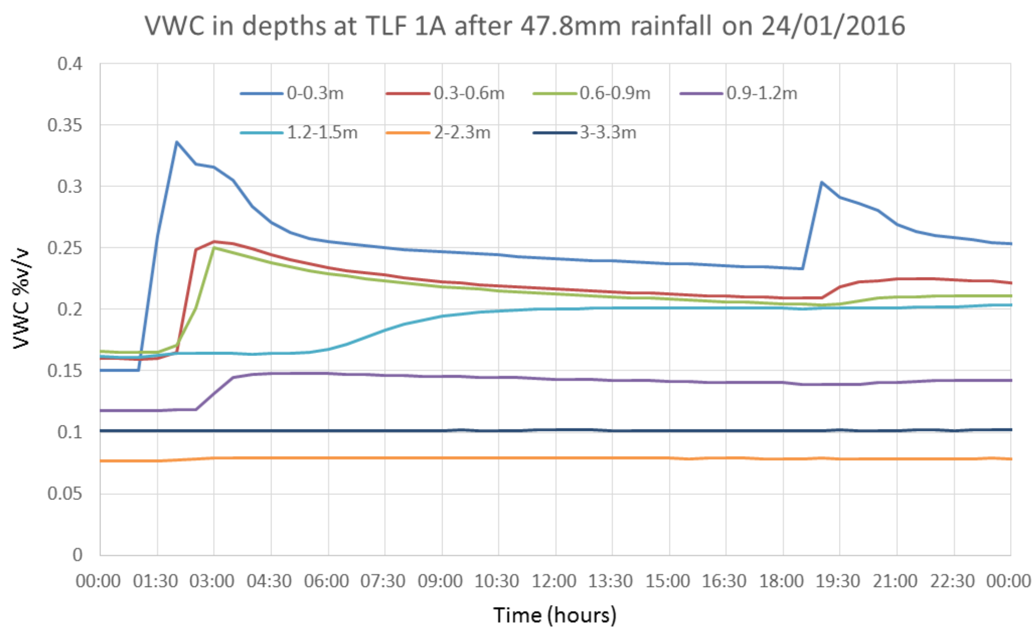
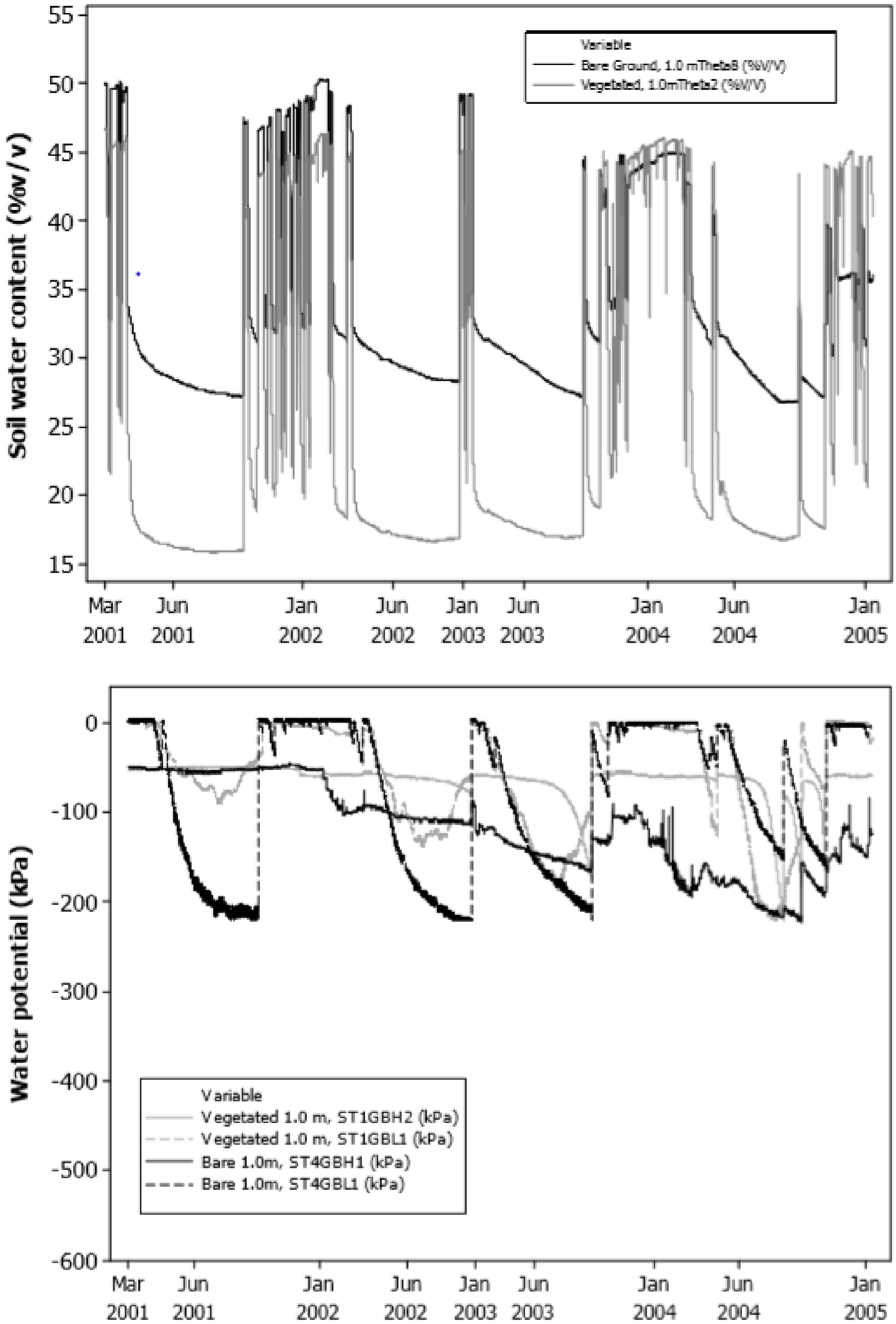


Figure 4-16: Wetting front progression as shown by soil volumetric water content dynamics in the waste rock only substrate in the TLF 1A section

In the study on an experimental waste rock cover established on the Ranger Mine waste rock pile, Hollingsworth (2010) monitored the soil water content and water potential in the cover (0.5 m – 1.0 m) (Figure 4-17). The measured soil water content and water potential in the waste rock cover were higher or similar to that observed on the TLF (Figure 4-13). Hollingsworth (2010) reported the saturated water contents range from 29.5 to 46.0 % v/v and from the above curves, the field capacity is at least 18 %, and the residual water content was 3.2 to 3.5 %. This suggests that the PAW is at least 15 % which is comparable with, albeit higher than the PAW of about 10 % found at the TLF.



(Source: Hollingsworth 2010)

Figure 4-17: Soil water content and water potential monitoring for Horizon 2 (0.5 to 1.0 m) in an experimental waste rock cover established on the Ranger Mine waste rock pile

4.5.2 Rooting depth in the waste rock landform

To estimate the total PAW in the landform's growth media, it is necessary to know the rooting depth of the revegetation in the waste rock substrate.

In March 2019, ten years after the initial revegetation of the TLF, one observation pit in each of the section 1A and 1B of the TLF (Figure 3-3, the two 2019 pits located furthest from the erosion plots) were excavated to assess root distribution throughout the waste rock soil profile. Pit 1A was excavated less than 0.5 m away from a large *Eucalyptus tetrodonta* tree (9 m high) to approximately 3.5 m deep (which was 0.5 m from the bottom of the landform); Pit 1B was less than 0.5 m away from a large *Eucalyptus phoenicea* tree (8 m high) and excavated to approximately 4 m deep (about 0.5m from the bottom of the landform). Bulk samples (each of ca. 4kg) were collected both at surface and different depths (Table 4-7).

Roots were separated from the waste rock by dry picking and wet sieving. The waste rock was also separated during the process into large, medium and fine fragments (>5 mm, 2 – 5mm, and <2mm, respectively). The separated materials were then oven-dried at 105°C. Surface roots were mostly observed in the top 1 m of the soil for both pits, whilst the tap roots were still visible at approximately 2.5 m depth in pit 1A and 2.0 m depth in pit 1B (Figure 4-18).

Table 4-7: Dry weight percentage of waste rock and roots in pit 1A and pit 1B of the TLF

		Dry Weight Percentage (%)			
Area	**Depth (m)**	*Large WR*	*Medium WR*	*Fine WR*	*Roots*
1A	Surface	37.180	19.312	43.465	0.043
1A	0.5	52.751	20.581	26.633	0.034
1A	1	66.359	18.555	14.586	0.500
1A	2	55.910	18.845	25.222	0.023
1A	3.5	64.316	17.632	18.051	0.001
1B	Surface	26.779	24.935	48.190	0.095
1B	0.5	67.342	13.134	19.400	0.124
1B	1.5	48.826	21.016	30.035	0.123
1B	2.5	60.838	17.899	21.259	0.004
1B	4	66.087	15.345	18.563	0.005

WR = w aste rock

Pit observation and root mass measurements demonstrated that root matter was present in all samples at all depths (Figure 4-18), which indicates that large trees can root down to at least 3.5 m depth in pit 1A and down to 4.0 m in pit 1B of the TLF. This is consistent with the visual observation of the pit walls (Figure 4-19). This was the first time that roots were excavated to the 4 m depth in the waste rock landform at the Ranger Mine and provides direct evidence that local native woodland tree species roots can reach depth beyond 1 to 2 m. Although the root biomass significantly decreased with depth, those small amounts of fines roots are critical for the survival of the trees through the late dry season.

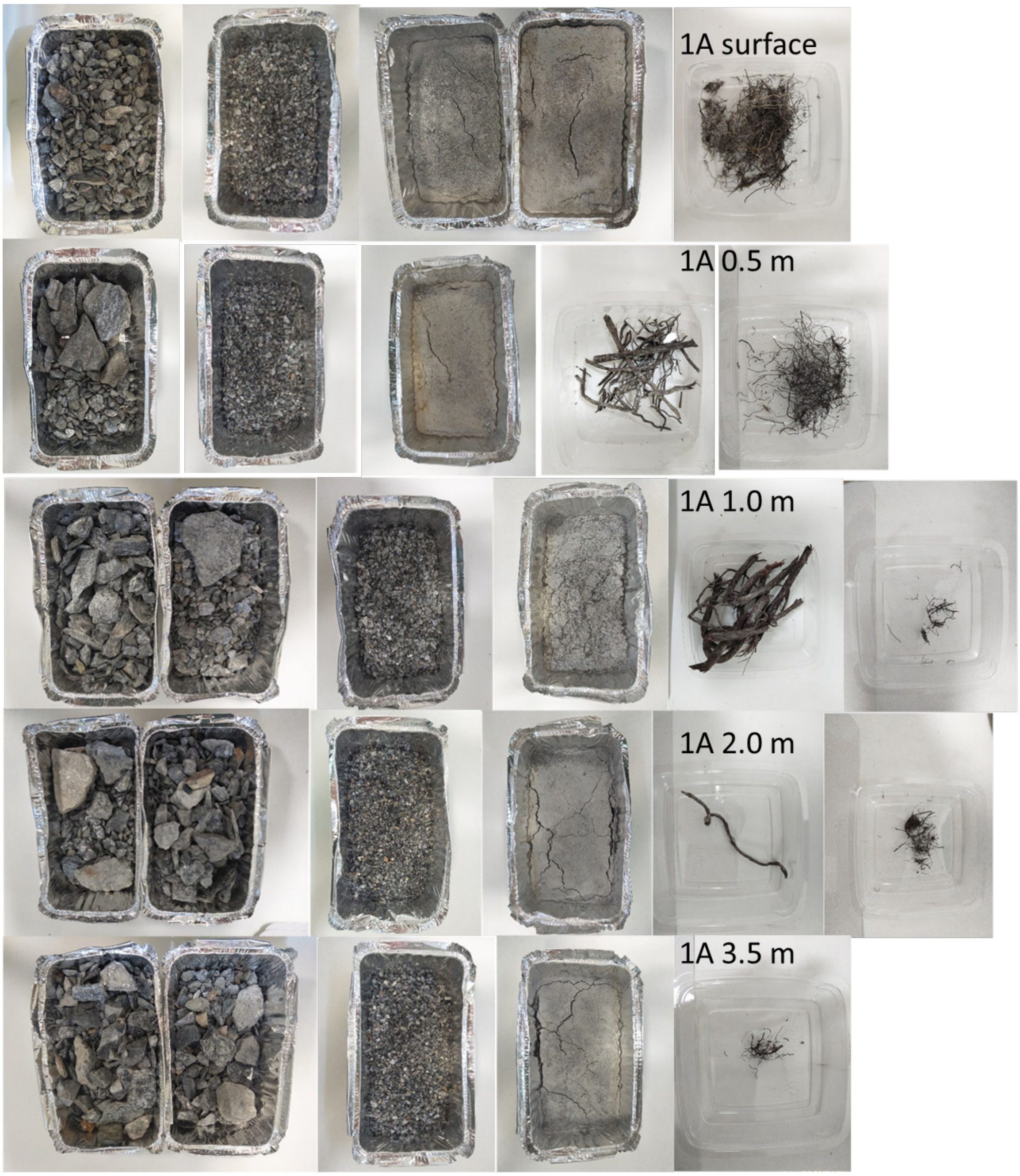


Figure 4-18: A visual comparison of the root mass and waste rock materials from a bulk sample taken at different depths in the pit 1A of the TLF

Figure 4-19: Presence of roots of 1-2 mm in diameter visible at 3.0 m deep in the Pit 1A and at 3.7 m deep in the pit 1B of the TLF

In addition, Humphrey *et al*. (2009) reported that ERA and ERISS have opportunistically examined the depth of penetration of roots of excavated trees, growing in media that includes waste rock, waste rock and fines, or various laterite/waste rock mixes, and in the natural bush soil. They stated that while some roots were observed at depths of 2.1 and 2.5 m in mine-derived and natural soils, respectively, the main root ball of trees, comprising an estimated >95% of the root biomass, is invariably contained in the top 0.7 m of the soil profile. Figure 4-20 is a photograph showing the root ball of 7.7 m high, 12 year old *Eucalyptus glomericassis* excavated from a trial rehabilitation site on the eastern edge of the Ranger tailings dam (from the so-called 'Heritage' site). While shallow lateral roots have been broken off, the main primary (tap) root is relatively intact.

A trench cut in a revegetated Ranger waste rock pile with 4 year-old trees grown from seed showed obvious roots to 0.8m with some evidence of roots at the bottom of the trench (1.6 m) (Emerson & Hignett 1986).

(Source: Humphrey *et al*. 2009)

Figure 4-20: Root ball of a *Eucalyptus glomericassis* excavated from a trial rehabilitation site

4.5.3 Estimated and actual potential plant available water

The SPAW Hydraulic Properties Calculator (a pedotransfer calculator) (Saxton & Rawls 2006) was used to develop the estimated soil water retention curve (volumetric water content vs. matric potential) and the volumetric water content at permanent wilting point and field capacity for the waste rock substrate of the TLF (Segura 2017). The potential PAW for the <2 mm fraction of the profile (PAWp) was calculated by subtracting volumetric water content at permanent wilting point from the field capacity (θ_{fc}- θ_{pwp}) and then multiplying this by the matric fraction of the soil that has the ability to store water. The >2mm fraction of the media is considered to be rock and deemed to be unable to store PAW. The proportion of the rock in the TLF 1A profile is about 67 %v/v, so the fraction of soil is 33 % v/v. (Table 4-8).

Approximately 400 mm of PAW can be potentially held in the substrate of the TLF of a thickness of four metres, corresponding to a 10 % v/v water content. This is the same as the 400 mm identified by Hollingsworth (2016) for 'plant available soil water content between 0 to

8 m depth' (Table 4-8). Whilst the 90 mm of PAW in the top one metre of the waste rock plant growth substrate is more than the required 60 mm identified by Hollingsworth (2016).

The estimated 400 mm PAW is the potential PAW, i.e. assuming the soil profile is filled with that amount of water at the end of the wet season. However, the actual PAW might be less than that amount, depending on the rainfall distribution, especially the last rainfalls in the wet season.

Table 4-8: Potential PAW in the layers of the growth substrate of the TLF section 1A 4 m profile

Nominal Depth (actual depth) (mm) of the layer	Layer Thickness (mm)	Gravel Content %	Potential PAW (mm)
0 (0-500)	500	66	51.90 ± 0.10
1000 (500-1500)	1000	68	97.92 ± 0.32
2000 (1500-2500)	1000	64	109.91 ± 0.21
3000 (2500-3500)	1000	73	82.35 ± 0.00
4000 (3500-4000)	500	62	57.95 ± 00
Total	4000		400 ± 0.13

(Source: Segura 2017)

Observed plant available water (PAW_{obs}) at the TLF section 1A during seven consecutive dry seasons, over the period 2010 to 2016, is presented in Table 4-9. Additional PAW from dry season rainfall has been added to the end of wet season maximum PAW_{obs}. Wet season rain is the total rainfall prior to the studied dry season (based on Segura (2017)). The average actual total PAW stored in the four-metre thick TLF section 1A is 261 mm which is significantly less than the 400 mm which is potentially storable in the four-metre thick waste rock landform (Table 4-8).

Table 4-9: Observed plant available water at the TLF for seven consecutive dry seasons

Dry Season Start	Dry Season End	Duration (d)	Wet Season Rainfall (mm)	Maximum PAWobs (mm)	Additional PAW (mm)	Total PAW (mm)
23/04/10	9/10/10	169	1490	247	13	260
19/04/11	8/11/11	203	2275	231	20	251
27/03/12	10/11/12	228	1318	236	88	324
13/04/13	02/11/13	203	1087	224	30	254
10/05/14	05/11/14*	179	1857	228	17	245
14/04/15	28/11/15**	228	988	217	24	241
21/04/16	19/09/16	151	856	225	30	255
					Average	261
				Average PAW per metre		65.4

*Date based on rainfall, no θ data available for PAW calculation on that day, data missing

**Last PAW value before a data gap, supported by rainfall

(Source: Segura 2017)

Six years of PAW_{obs} is a very limited period for assessing whether the actual PAW will be sufficient to meet the evapotranspiration requirements of the reference vegetation, given the natural variability in weather conditions that the natural vegetation experiences historically. Therefore, a risk assessment was undertaken to simulate the historical actual PAW and evapotranspiration using the past 117 years weather data (1900 to 2016). A modelling approach (WAVES model) was employed to achieve this objective as detailed below.

4.5.4 Modelled actual plant available water

4.5.4.1 WAVES Model

In collaboration with Charles Darwin University, ERA engaged a PhD candidate to undertake PAW studies utilising the 'WAVES Model' on the Ranger Mine TLF. WAVES (Water Atmosphere Vegetation Energy and Solutes) is a coupled water and carbon ecohydrological model that predicts dynamic interactions within the soil-vegetation-atmosphere system at a daily time step (Dawes & Hatton 1993, Zhang & Dawes 1998). In WAVES, soil water movement in both the unsaturated and saturated zones is simulated using a fully finite difference numerical solution of the Richards equation (Berry *et al.* 2005). Modelling of the unsaturated zone using the Richards equation allows water movement in the soil profile to be modelled under dry conditions. For each soil type, an analytical soil model proposed by Broadbridge and White (1988) was employed to describe the relationships between water potential, volumetric water content and hydraulic conductivity. Evapotranspiration was estimated by the Penman-Monteith approach (Monteith & Unsworth 2008). Leaf stomatal conductance was calculated by the equation developed by Ball and Leuning (Ball *et al.* 1987, Leuning 1995), which was scaled to canopy scales using the method proposed by Sellers *et al*. (1992). The micrometeorological feedback of the sensitivity of transpiration to a marginal change in stomatal conductance at the stand level is regulated by a dimensionless decoupling coefficient proposed by McNaughton and Jarvis (1991). The rate of plant growth in the presence of different availabilities of light, water and nutrients was estimated by the integrated rated methodology (IRM) of Wu *et al*. (1994), which is an empirical model without resolving the details of chemical and mechanical controls on photosynthesis. Water is extracted for transpiration by roots, which is distributed along the root profile according to root density distribution and water availability in each soil node (Ritchie *et al*. 1986). The WAVES model is able to simulate plant physiology, which allows changes in environmental factors (temperature, solar radiation, rainfall) to impact water use by vegetation and recharge (Chen *et al*. 2014).

WAVES predicts the dynamic interactions and feedbacks between these processes. Thus, the model is well suited to investigations of hydrological and ecological responses to changes in land management and climatic variation. WAVES emphasises the physical aspects of soil water fluxes and physiological control of water loss through transpiration. It can be used to simulate the hydrological and ecological effects of scenario vegetation management options (e.g. for recharge control), or the water balance implications of changed climatic conditions. A more detailed modelling strategy and description of WAVES is provided in Dawes *et al*. (1998), and Zhang and Dawes (1998).

4.5.4.2 Modelled scenarios and modelling approach

The WAVES model was used to assess the water balance of the TLF and the proposed Ranger Mine final landform under the supervision of Professor Lindsay Hutley of CDU. The focus of this investigation was to determine whether the waste rock substrate of the TLF would be suitable for supporting tropical savanna similar to that of the Georgetown Creek Reference Area, specifically Site 21 (conservative, high ET scenario) and Site 30 (low ET scenario).

Site 21 is typical of one of the vegetation types found in the region and represents high evapotranspiration (ET) and high leaf area index (LAI) and thus is a useful **conservative case** for estimating vegetation water demand (Baumgartl *et al*. 2018).

Site 30 is a less dense woodland with a lower ET and lower LAI, representing the variation in vegetation types that occur in landscapes similar to that predicted for the final landform. At Site 30 the estimated average dry season overstorey transpiration is 0.25 mm/day compared to 0.50 mm/day at Site 21.

Soil water balance inputs include rainfall and run-on, and the outputs are evapotranspiration (soil evaporation and vegetation transpiration), runoff and drainage. Evapotranspiration and drainage are linked to the water holding capacity of the soil (which is a product of its texture/composition) whilst runoff is linked to landform slope, soil saturation and surface conditions.

This study used a variety of methods to measure, calculate or predict the different components of the soil water balance on the TLF (with the exception of run-on which was not applicable in the situation studied).

This study first calibrated the soil component of the WAVES model using the measured soil water contents in the four-metre soil profile at the TLF (Figure 4-21). Potential plant available water (PAW_p) in each layer of the substrate was calculated. Then annual dry-season PAW in the landform was simulated ($PAW_{Predicted}$) using the actual weather-rainfall data of the historical weather records over 117 years. Observed PAW (PAW_{Obs}) scaled from observations of TLF water content dynamics (running monthly mean) and predicted PAW ($PAW_{Predicted}$) dynamics on the TLF over multiple wet-dry cycles using century-scale rainfall are presented in Figure 4-21 and show good agreement.

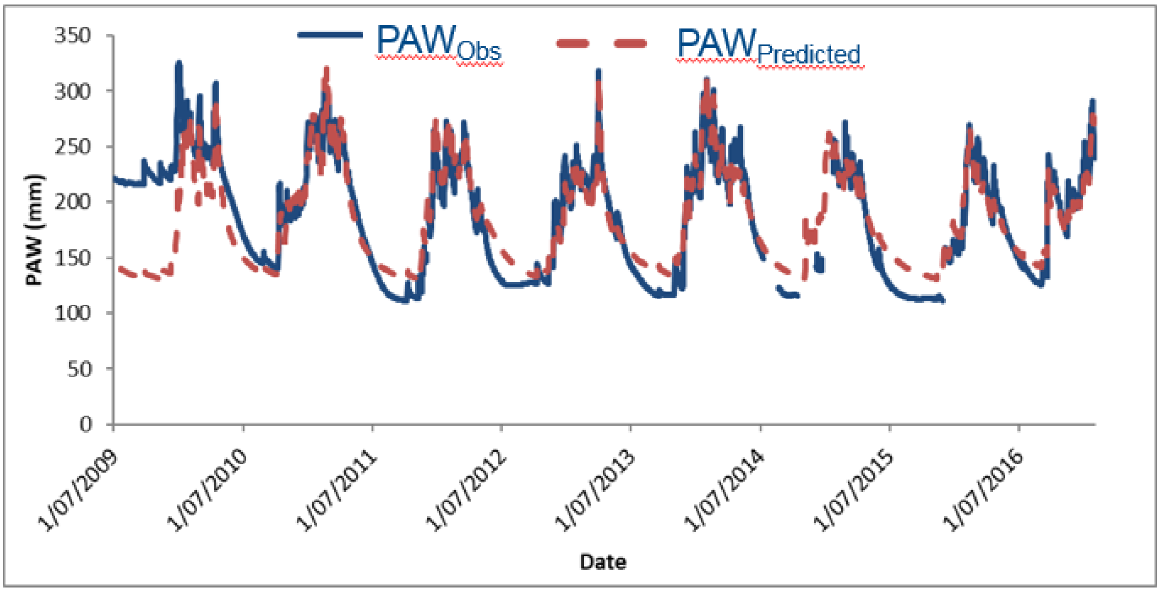
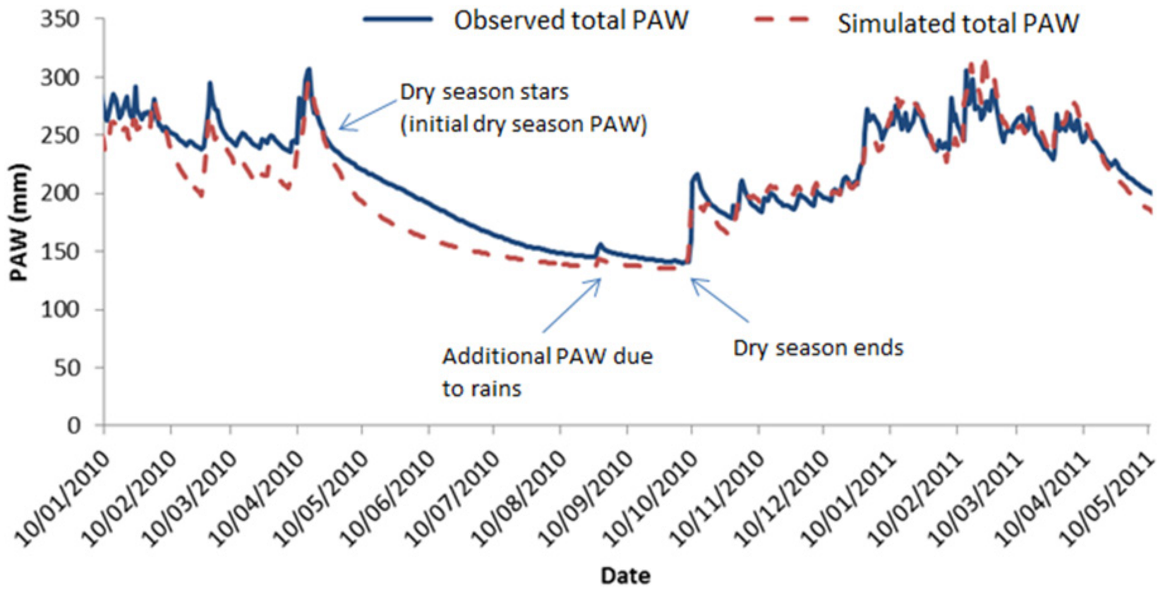


Figure 4-21: PAW_{obs} scaled from observations of TLF water content dynamics and predicted PAW dynamics on the TLF

The soil water balance is assessed by comparing the simulated annual dry-season landform PAWs to the simulated dry season evapotranspiration of the reference sites. Dry season PAW and dry season length were determined from the simulated landform PAW (Figure 4-22). Dry season length was determined based on the assumption that the start of dry season is when consistent decline in soil water starts, and the end of dry season is when PAW is consistently increasing. The simulated and observed PAW values (Figure 4-22) were noted to be well aligned.



(Source: Modified from Segura 2016)

Figure 4-22: Simulated landform PAW versus observed PAW in the trial landform

4.5.4.3 Annual water deficit risk assessment over historic 117 years

Annual dry season PAW over 117 years was simulated using the calibrated WAVES model and compared to the estimated dry season evapotranspiration of Site 21 and Site 30 to derive a PAW balance (deficit or surplus). The PAW balance (within the four-metre waste TLF growth substrate layer) at the end of each dry season was calculated as follows:

> PAW balance = PAW - (measured dry season overstorey transpiration + simulated understorey transpiration and soil evaporation).

The net PAW balance within the four-metre waste TLF growth substrate layer at the end of each dry season, over 117 years, is shown in Figure 4-23. Site 30 (represented by blue bars in Figure 4-23) has a low canopy density and Site 21 (represented by red bars in Figure 4-23) represents the "conservative scenario" with a higher canopy density.

The data in Figure 4-23 (red bars, Site 21) show that the four-metre thick TLF growth substrate layer would have held sufficient PAW for each of the 117 years, except for the year 1915 with a deficit of 8 mm. There is a simulated mean net positive PAW balance of 54.4mm for the 117 years (Lu *et al.* 2019) which suggests that a four-metre thick waste rock cover similar to that of the TLF would be able to supply sufficient water to sustain mature native woodland that is similar to that at Site 21.

It might seem to be concerning that the simulation has shown the TLF PAW status to be close to a deficit in a number of years, and in one year recorded an 8mm deficit, and also considering the level of uncertainty for these predictions. However, one shall remember that this deficit situation has only been predicted for when the simulation used a 'conservative' scenario, i.e. by using Site 21 with a high ET. When the model uses a vegetation water use or ET of a site dominated by deciduous species (Site 30) the net PAW balance is much more favourable (Figure 4-23, blue bars; Table 4-10). Meanwhile, it must be considered that a slight deficit over a couple of years may not necessarily result in a vegetation collapse, rather vegetation would most likely increase deciduousness and under more severe and long-term drought, decrease stem density via, for example, self-thinning. The data in Figure 4-23 also shows a general trend of increased surplus over the last century, which is mainly due to increased rainfall in the region.

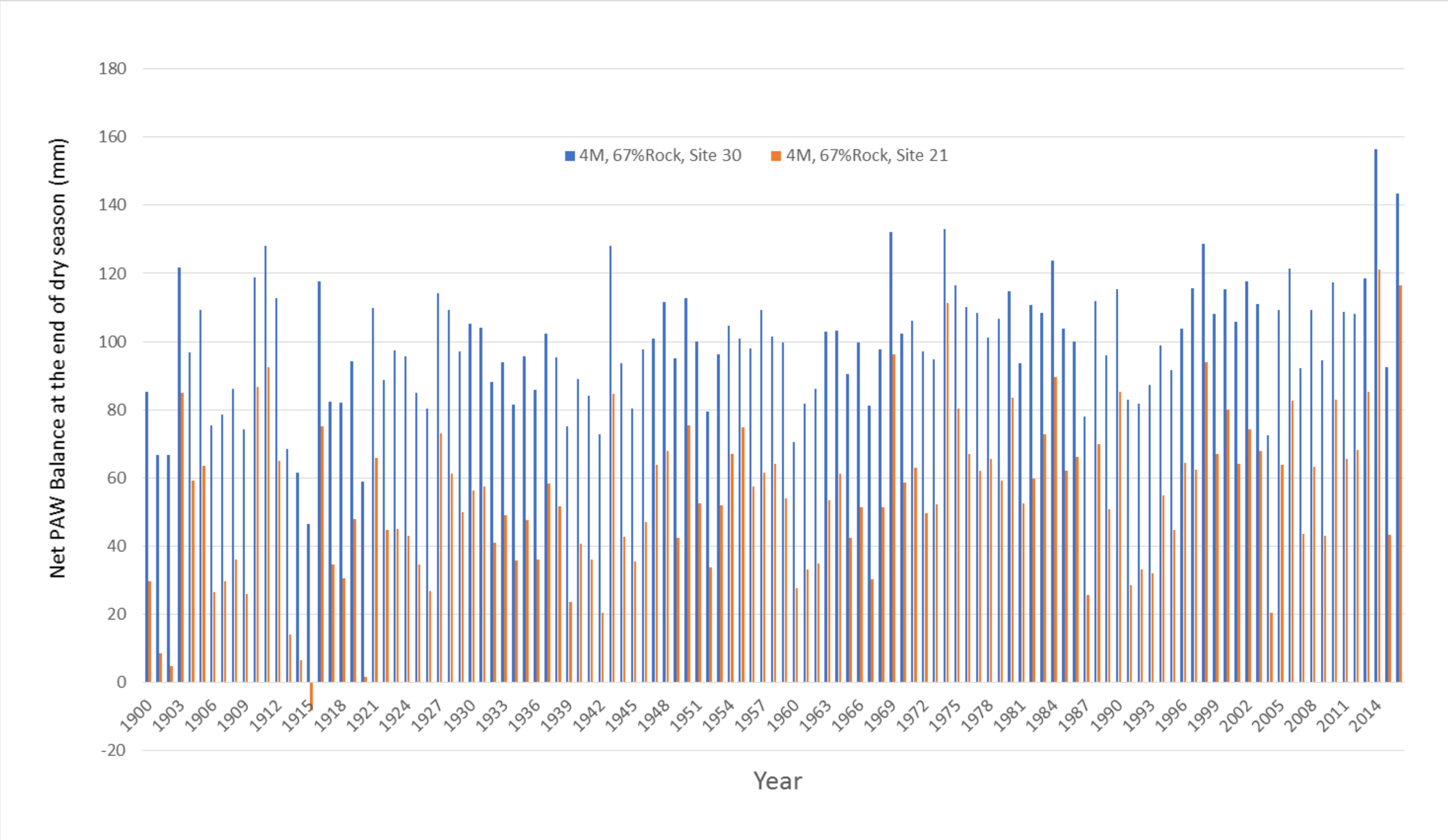


Figure 4-23: Net PAW balance within four metre waste TLF growth substrate at the end of each dry season over 117 years

4.5.4.4 Model uncertainty analysis

Uncertainty of the modelled outcome with regard to occurrence of water deficit depends on mainly three factors:

- Fines % of the growth medium (ie. Potential water holding capacity);
- Growth media thickness (assuming it is also accessible by root system);
- Type of vegetation supported by the growth media; and
- Weather conditions.

The above 117 years PAW balance simulation was based on the worst case scenario where a given area of land of four-meter waste rock growth substrate layer sits on top of a crest where it does not receive run-on (Figure 4-24), and it was assumed that beneath the 4 m depth the root could not access due to either an impermeable layer exist or that roots biologically could not extend below 4 m. In the final landform design, at the crest and over the pits there is actually more than 15 m thick waste rock material (Figure 2-2). Therefore, if necessary roots shall be able to access a depth of 6 m as demonstrated in the natural woodland (Section 4.5.2). It also evident that if below 4 M layer there is natural soil (much better water holding capacity), then the PAW status will be improved. Similarly, if part of the 4 m growth media is natural soil, the PAW status shall be more favourable than discussed in the Figure 4-24.

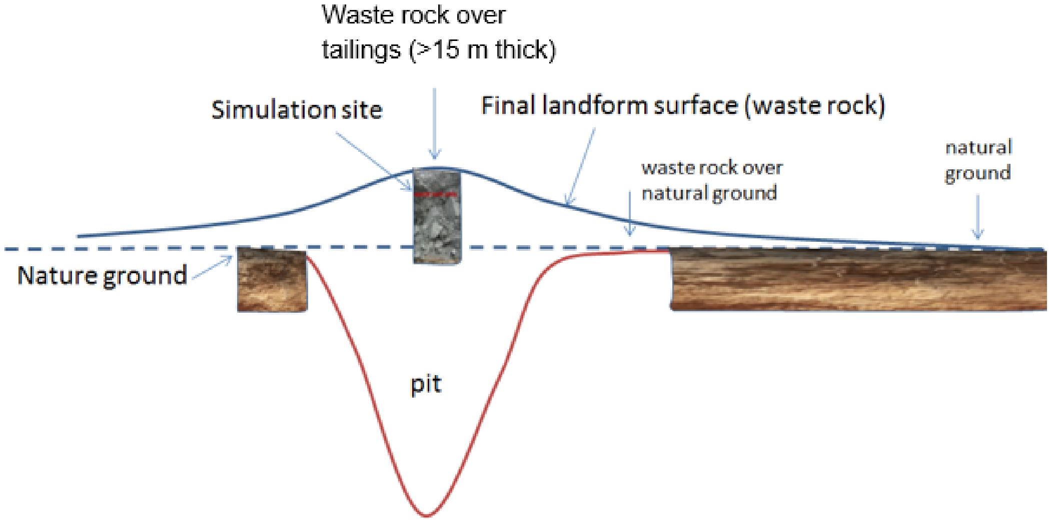


Figure 4-24: Illustration of the waste rock cover in relation to natural ground and backfilled pit

From the TLF monitoring, it is understood the four-metre waste rock growth substrate layer contains an average actual PAW of 261.4 mm, giving an average 65.4 mm of PAW for each metre. If the TLF growth substrate layer thickness was increased from four to five metres, PAW would increase from 261.4mm to 326.76mm, even further reducing the chance of a PAW deficit in any given year (Table 4-10).

Revegetation community type on the final landform shall be matched to the best to the site condition, for the crest site, it may well be a vegetation type that is similar to that at Site 30. Therefore it will use less water than that of the vegetation type that is similar to Site 21.

Fines % of the growth medium can be expected to be quite variable (Section 4.1), and it can range from 40% to 15% of fines. To assess the risk of an annual PAW deficit when using the scenario of the historic 117 years climate conditions, percentage of 117 years with a net negative PAW balance were commutated by varying the above three factors (Table 4-10).

The WAVES model outputs have been used to assess the probability of a constructed landform being able to sustain a mature reference vegetation (Site 21, a ‘conservative’ scenario).

For construction of the Ranger Mine final landform, there will be some areas where plant roots are entirely in the waste rock landform cover and also some areas where materials of a higher rock proportion may have to be used. Following on from the TLF WAVES modelling, WAVES simulations were run to derive the predicted PAW balance for materials higher than that in the TLF section 1A, which contains 33 % v/v of fines. Simulations were run with proportion of rock ranging from 30 to 15 % v/v fines, and for increased waste rock substrate layer thicknesses (i.e. five or six metres). Full simulation results are presented in Lu *et al.* 2019. A summary of percentage of years experiencing a net PAW deficit over 117 years for Site 21 and Site 30, for different modelled rock proportions and substrate thicknesses are presented in Table 4-10.

Table 4-10: Percentage of 117 years with a net negative PAW balance

Substrate thickness (m)	**ET from site**	**% Fines <=,2mm)**							
		33	**30**	**27.5**	**25**	**22.5**	**20**	**17.5**	**15**
4	Site 30	0%	0%	0%	1%	2%	9%	30%	53%
	Site 21	1%	5%	17%	38%	58%	83%	91%	98%
5	Site 30	0%	0%	0%	0%	0%	1%	3%	19%
	Site 21	0%	0%	1%	3%	13%	36%	64%	88%
6	Site 30	0%	0%	0%	0%	0%	0%	1%	2%
	Site 21	0%	0%	0%	0%	2%	6%	30%	57%

The WAVES model outputs have been used to assess the probability of a constructed landform being able to sustain a mature reference vegetation (Site 21, a ‘conservative’ scenario).

For construction of the Ranger Mine final landform, there will be some areas where plant roots are entirely in the waste rock landform cover and also some areas where materials of a higher rock proportion may have to be used. Following on from the TLF WAVES modelling, WAVES simulations were run to derive the predicted PAW balance for materials higher than that in the TLF section 1A, which contains 33 % v/v of fines. Simulations were run with proportion of rock ranging from 30 to 15 % v/v fines, and for increased waste rock substrate layer thicknesses

(i.e. five or six metres). Full simulation results are presented in Lu *et al.* 2019. A summary of percentage of years experiencing a net PAW deficit over 117 years for Site 21 and Site 30, for different modelled rock proportions and substrate thicknesses are presented in Table 4-10.

For the scenario of a four-metre waste rock cover and the plant water demand of Site 30, the waste rock cover would not experience any PAW deficit with fines percentage as low as 27.5%. With access to additional substrate (total thickness of 5 and 6 m), the waste rock cover would continue to have no net PAW deficit even when the percentage of fines dropped to 22.5 % and 20 % respectively. This is consistent with the general observation that some vegetation can still survive and even thrive on rocky ridges on the Jabiluka lease and close to Ranger Project Area (RPA) in the Kakadu NP.

For the scenario of a four-metre waste rock cover and the plant water demand of Site 21, decreasing the proportion of fines to 30 or 27.5 % results in a PAW deficit for 5 % and 17 % (respectively) for the 117 years modelled (Table 4-10). However, these deficits can be offset by an increase in substrate thickness (presumably up to the 6 m). This analysis has demonstrated that a five-metre thick growth substrate containing 30% fines (particles <=2 mm) would never experience a net PAW deficit (based on the 117-year rainfall record), although a substrate containing 27.5% fines would experience a net PAW deficit for about 1 % of the years of the modelled scenario and would require an increased substrate (total thickness six metres) to avoid any PAW deficit. A six-metre-thick cover would continue to have no net PAW deficit even when the proportion of fines decreases to 25 %.

This adjustment of the fines proportion by 2.5 % reductions also demonstrates how the PAW status of the landform should improve over time as the proportion of fines improves (and thus rock proportion decreases) due to weathering and soil formation processes.

Previous studies have reported that modifying waste rock cover thicknesses can provide greater (potential) PAW and thus aid in the establishment of self-sustaining plant communities. Mature trees were considered to be able to access water down to four to six metres below ground surface (Lamoureux *et al.* 2016). Further details are available in Lu *et al.* (2018 & 2019) and Lu (2017).

4.5.5 Soil water retention as affected by landform construction method (including ripping)

In addition to designing planting to optimise vegetation sustainability (i.e. the right species and density for the right locations), the final landform cover will also be designed and constructed to optimise the ability of the final landform to sustain the target vegetation. Choice of construction design and method can have a positive (and negative) impact on the ability of the final landform cover to store/release water and sustain the target vegetation. Final landform cover construction methods and their impact on plant growth substrate properties are discussed in the following sub-sections with full details provided in Section 9.

4.5.5.1 Sub-surface consolidated horizon

The final landform cover over mined out pits will be constructed in lifts (MCP Section 9.4.5). The material at the surface of waste rock dump lifts (or layers) is often consolidated due to heavy machinery activities, such as dump trucks positioning and dumping material in accordance with the spacing plan, or dozers pushing material off tip heads or flattening paddock dumps as shown in Figure 4-25 (e.g. Martin *et al*. 2004 and Diodato & Parizek 1994). This mechanical disturbance can also cause larger particles to break-down, increasing the proportion of fines in the compacted zone. This sub-surface consolidated horizon can be up to one-metre thick and shows a sharp transition back to uncompacted material (Martin *et al*. 2004).

This sub-surface consolidated horizon can be important in reducing macropores and increasing water retention capacity of the plant growth substrate and is discussed in the following sections.

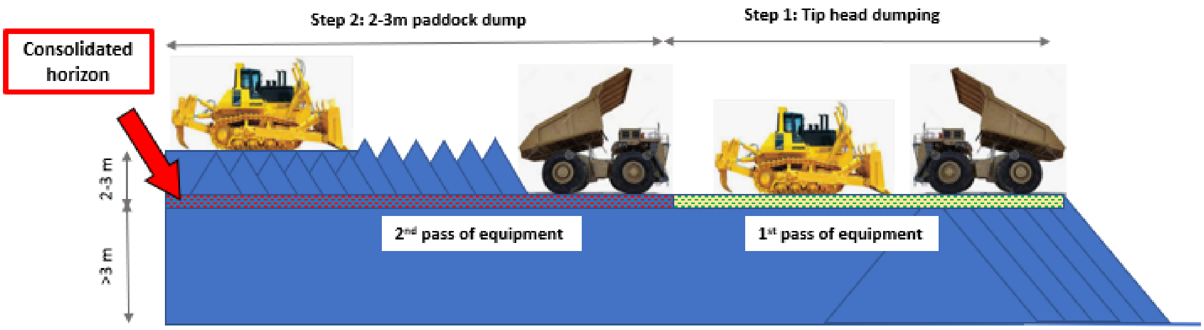


Figure 4-25: Example of a combination of construction methods improving density of sub-surface horizon

4.5.5.2 Macropores and preferential flow

A number of authors have observed that water flow in waste rock dumps occurs preferentially through channels and voids/macropores (e.g. Harries & Ritchie 1983). Water may flow in the channels and macropores somewhat independently. The hydraulic conductivities of the macropore region can be up to several orders of magnitude higher than the micropore hydraulic conductivity. In a waste rock dump composed of coarse fragments, with limited fines content, flow is expected to occur predominantly through partially-saturated channels (Smith *et al*. 1995). These preferential flow paths effectively bypass the desired even percolation of rainfall throughout the profile and prevent the wetting up of the material and thus development of positive PAW.

Good agreement between WAVES modelling results and the measured PAW dynamics in the TLF (Figure 4-22 and Figure 4-23) suggests that the substrate in the TLF 1A is behaving like a soil. The wetting front progression (assessed by soil volumetric water content dynamics) in the TLF 1A section is shown in Figure 4-16. The behaviour of wetting front progress after a significant rainfall (47.8mm) on 24 January 2016 demonstrates a steady downward progression of the wetting front without abrupt peak at lower positions. This suggest that preferential pathways are not a major issue in the TLF as it was constructed.

The sub-surface consolidated horizons within waste rock dumps act to intercept preferential flow paths provided by large or consecutive macropores, or air voids, formed during material placement. Cutting any preferential flow paths off at the higher density horizon ensures that the percolating water is redistributed laterally before continuing through the profile. Additional preferential flow paths may occur below the higher density horizon however these should reduce over time with gravitational compaction and the generation and movement of fines into the voids.

In a more typical 'soil', even incidental mechanical compaction can result in negative impacts to vegetation establishment, including reduced infiltration and root penetration. In fact, in their literature review of over 200 references, the Supervising Scientist were unable to locate any studies that directly investigated a positive outcome of compaction on post-mining rehabilitation (Supervising Scientist 2019). The review concluded, however, that there was also no evidence that the creation of higher density horizons will be "unequivocally detrimental to ecosystem restoration".

The TLF was constructed with two lifts of two to three metres each, thus including a central consolidated horizon. The MCP states that the final landform will be constructed using a similar method; therefore, the degree of consolidation shall not significantly differ from that of the TLF. The proposed paddock dump method for the final landform surface layer is unlikely to create a sub-surface consolidated horizon that is impermeable. Observations at the TLF where the same dumping method was used, does not suggest there were such an impermeable layer (Figure 3-5 and Figure 4-18). The sub-surface consolidated horizons proposed for the Ranger final landform, being only incidental due to heavy equipment traffic, will not create an impermeable layer but will break the preferential pathway and slow down the rate of water movement through the profile, and should not impact the ability of roots or water to penetrate to deeper levels.

4.5.5.3 Water retention characteristics

Compaction changes the pore size distribution of a soil. Specifically, it reduces the volume and continuity of the larger pores (voids) in the soil, which slows the movement of water through the soil (Hillel 1980). Dawson and Morgenstern (1995) found that hydraulic conductivity of waste rock material decreases with decreasing void ratio. Archer and Smith (1972) investigated the relation between bulk density, available water capacity and air capacity of soils. They found that for four soils of different textures studied, the volumetric water content increased linearly with bulk density until, depending on texture, a maximum bulk density was reached above which continued compaction decreased the water content. It was concluded that available water (and air) capacity could be optimised using cultivation techniques to adjust the bulk density. The available water capacity of coarse-textured *droughty* soils may be increased by increasing the bulk density, provided the air capacity remains above acceptable lower limits (Archer & Smith 1972).

Knoche (2006) investigated the structural dynamics of a vegetative soil cover for waste rock dumps and found that, six years after placement, self-compaction increased the soil dry bulk density and, as a consequence, decreased the air filled macropores and increased the water storing medium pores. This resulted in a “significant increase in plant available water-holding capacity”.

Due to their higher bulk density and proportion of fines, sub-surface consolidated horizons could have a greater ability to retain water than uncompacted waste rock.

4.5.5.4 Particle size segregation due to dumping method

Final landform backfill methods used at Ranger mine are consistent with those found elsewhere (e.g. McLemore *et al.* 2009; Wilson 2011; Nichols 1986), and include the following:

- Tip head or end dumping (dumping rock over dump face resulting in some particle size segregation down slope towards the toe of the rock pile, with particle size generally increasing).
- Short or push dumping (dumping from trucks then levelling by pushing by dozers resulting in particle size segregation; finer at the top, coarser at the toe of the rock pile).
- Paddock dumping (dumping in small piles on the surface of the rock dump, grading the material, and compacting in layers or lifts resulting in dense layers with no real particle size segregation).

End dumping and push dumping are known to result in some particle size segregation down slope, with coarse material occurring further down the profile. There is likely a height threshold below which segregation is insignificant, which would need to be determined at a site-specific level (Wilson 2011).

Particle size segregation was observed during the TLF construction process in 2008. The photograph in Figure 4-26 shows dump trucks end dumping waste rock to form the lower layers of the landform and larger rocks and boulders accumulating at the toe of the dump face.

Figure 4-26: Tip head dumping of the lower layer(s) during TLF construction

The observed particle size segregation means that in the upper levels of the TLF layer there is a higher proportion of fines, which increases the potential PAW in these locations. Positive PAW is more valuable to a vegetation community at the upper-levels of the substrate profile, where more species have access, than further down the profile. Thus, use of a construction method that results in increased fines in the upper level of the (sub-surface) layer is likely to have a beneficial ecological impact.

5 THE ERA REVEGETATION STRATEGY

The Ranger Revegetation Strategy was first endorsed by stakeholders and an independent scientific advisory panel (the Alligator Rivers Region Technical Committee) in 2004 (Reddell & Meek 2004) and more recently updated, refined and published in the Ranger Mine Closure Plan (this document). The strategy is developed based on the learnings from extensive revegetation trials at Ranger and the revegetation of ERA's Jabiluka mineral lease, over the last three decades undertaken by ERA, as well as other research agencies (e.g. CSIRO, ERISS and CDU). Most significantly, recent learnings and experience from a large-scale landform trial of revegetation and monitoring methods, has enabled ERA to further refine its revegetation strategy as reviewed in this report.

A key aspect of the strategy is that the final landform growth medium will be predominately waste rock, setting a not insignificant challenge for the establishment of self-sustaining native eucalypt-dominated woodland. Experience and research outcomes have shown that this objective is achievable, and ongoing efforts are focussed on optimising establishment practices to maximise success, including harnessing and manipulating natural ecological processes such as reproductive phenology and the structural and functional importance of framework species.

5.1 Fourteen key elements

The strategy is comprised of fourteen elements that address: setting objectives and targets; understanding site physical and chemical constraints; species selection and target densities; site preparation and soil amendments including microbial inoculants; plant establishment methods including fertiliser use and irrigation; seed management; weed and fire management; and ongoing monitoring.

It is believed that the strategy will continue to be improved based on long term monitoring of the past revegetation, feedback from stakeholders and forthcoming learnings from the progressive revegetation on site – especially the revegetation of the Pit 1 landform. The fourteen elements of the revegetation strategy are outlined below:

1. Develop different revegetation strategies for different land surface: waste rock covered landform vs disturbed natural land with a 'soil' layer (e.g. land application areas).
2. Identify the likely physical and chemical constraints of the final landform that will influence both the initial establishment and the long-term growth, development and functioning of revegetated plant communities.
3. Maximise surface roughness and "patchiness" during site preparation.
4. Identify and describe vegetation types that are ecologically and technically realistic target endpoints (or 'habitats'), for different facets of the final landform, based on the likely physical and chemical environments that will be created.
5. Use of seed collected within KNP for all species.
6. Introduce a range of local mycorrhizal fungi to aid in the establishment of the framework species.

7. Include non-aggressive local native acacias but avoid the use of high densities of aggressive Acacia species.
8. Avoid actively introducing overly competitive grasses and herbaceous species, or sensitive species, until framework species are established and conditions are suitable.
9. Use nursery-grown planting stock to establish the framework species.
10. Apply fertilisers in a strategic manner using formulations and delivery methods that maximise their effectiveness.
11. Provide irrigation to new planted or sown plants.
12. Rigorously control potentially threatening weed species, both on and in proximity to the final landform.
13. Exclude fire from the revegetation areas during the first 5 – 8 years after establishment.
14. Design and implement a rigorous and scientifically-based strategy for on-going evaluation of the performance of the revegetation.

Element 1: Develop different revegetation strategies for different land surface types

The physical, chemical and biological characteristics of the waste rock landform and disturbed natural areas with a 'soil' layer are fundamentally different to each other and also from the natural ecosystems of the region. Despite this, they share a broad objective of re-establishing vegetation that is similar to the natural eucalypt-dominated woodlands, or other suitable vegetation communities of the surrounding area. To achieve this from such different starting points requires specially tailored revegetation strategies and the revegetation will develop along different pathways, or trajectories, to become the mature target ecosystem/s.

The waste rock landform presents unique ground conditions which are not present in the natural environment and subsequent elements of this revegetation strategy are largely focused on addressing unique challenges such as limited plant available water (PAW; in unit volume but similar in total root extractable volume), high levels of sunlight, thermal stress and open space, threat of weeds and fire, and an absence of any plants, propagules, organic matter, nutrient cycling, or natural fauna or microbial communities.

While areas of disturbed natural land with soil, such as the Land Application Areas (LAAs), have more suitable physical and chemical characteristics for vegetation establishment compared to bare waste rock, it still requires a revegetation strategy that will overcome its own unique challenges. These include the threats of 'weeds' (including local native aggressive acacias and spear grasses), fire, herbivores and competition for resources from surrounding vegetation, which necessities adjusted strategies such as spray of pre-emergence herbicides, more frequent weed and fire management and revegetation maintenance interventions (e.g. thinning of aggressive acacias).

ERA will use revegetation domains to identify and describe the different post-mining conditions of the final landform and surrounding disturbed areas requiring rehabilitation (Section 7.2.1.1).

Element 2: Identify the likely physical and chemical constraints of the final landform that will influence both the initial establishment and the long-term growth, development and functioning of revegetated plant communities

This element concentrates on characterising geomorphic and hydrological features, in different facets of the rehabilitation, that will determine (a) seasonal water availability for vegetation (e.g. infiltration and PAW), (b) chemical fertility and nutrition in the varying substrates, and (c) any other features that will impact revegetation (Section 7.2.1.1).

ERA's water balance study of the Ranger trial landform indicates that a waste rock cover layer of 4 – 6 metres thick would provide sufficient plant available water for most overstorey revegetation (Section 1 and Lu *et al*. 2019). Although framework tree and some shrub roots are capable of accessing deeper rock substrates (up to 6 metres), low net PAW in the near surface section (e.g. 0 – 1 metres) may affect the establishment and success of some shallower rooting species. Evidence from the trial landform indicates that surface and subsurface preparation methods such as rip lines and consolidation of sections of the subsurface as a result of material placement methods will improve the water holding capacity of the waste rock substrate.

Many soils typical of the tropical north of Australia are very old and highly leached, and have inherently low fertility, including a particularly low phosphorus and nitrogen content (Langkamp & Dalling 1979). Ranger Mine waste rock has, compared to the natural undisturbed soils of the area, higher pH, higher content of labile minerals, but lower organic carbon content, and nitrogen (Fitzpatrick 1989). Huang and You (2018) found that nutritional and microbial components of the TLF waste rock 'soil' was developing, however they observed relatively low rates of mineralisation that may be due to heat stress, rapid evaporation and water deficit at the surface. As vegetation establishes, and overstorey canopy and shade from other plants increase, these conditions should improve. The chemical characteristics and nutritional processes of the rehabilitated waste rock landform is presented in Section 4.3.

There is no concern of phytotoxity limiting revegetation outcomes. As part of a 2018 cumulative ecological risk assessment, Bayliss (2018) determined that risks to revegetation from mine-derived chemicals is assumed to be zero. This is supported by observations and studies of natural vegetation irrigated with water (mostly waste rock solutes) for over a decade, which indicate there are no observed negative effects on vegetation from waste rock contaminants (e.g. Addison 2011).

Element 3: Maximise surface roughness and 'patchiness' during site preparation

The aim is to establish a heterogeneous land surface that has (a) localised run-on/ runoff zones for control and capture of sediment, water and nutrients, and (b) microhabitats for seedling establishment and litter accumulation/decomposition and nutrient cycling, to support plant development, and to encourage natural flora recruitment and ground dwelling fauna. Experience and modelling have shown that rip lines installed at across the entire surface of the waste rock landform will mitigate soil loss and sediment transport (Saynor *et al*. 2019), particularly where slopes are less than 4% (i.e. the majority of the final landform).

Site preparation, including surface treatments, are presented in MCP Section 9.4.5.

Element 4: 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

The identification of suitable reference vegetation types has mainly been based on surveys in the surrounding natural landscapes that are potential geomorphic analogues of those formed on the final landform (based on the reasonable assumption that many of the environmental determinants of vegetation distribution will be similar in these settings). The majority of the landform will be revegetated to open eucalypt-dominated woodland vegetation typical of the surrounding area. Reference sites are discussed in Section 2.1.

The revegetation strategy is to initially establish framework overstorey species along with a subset of important and predictable midstorey and understorey species (MCP Section 5.3.3). Framework species control much of a site's nutrient and water resources, providing many of the core habitat values for other plants and animals, and contributing substantially to both the overall functioning and long-term stability of the plant communities (Reddell & Hopkins 1994). They typically include eucalypts, corymbia, xanthostemons, ironwoods, kakadu plum, quinine bush and other long-lived shrubs. Ecologically, these species are characterised by:

- High resistance to (tolerance of) fire.
- Reliance primarily on vegetative regeneration strategies (through root suckers, lignotubers and rhizomes) in response to stresses and disturbance.
- Seeds which are relatively short-lived and do not accumulate as a canopy (serotinous) or soil seed bank.
- A population structure dominated by even-age cohorts from one or a small number of discrete regeneration/recruitment events (usually from vegetative sprouts), resulting in highly discontinuous size class distribution.
- High predictability of growth performance and development.

Element 5: Use of seed collected within KNP for all species

The use of seed collected only from within KNP 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 2013b). 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 revegetation in order to possibly extend the 30 km seed collection zone (Zimmermann 2013b, 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.

In identifying the environmental factors, the provenance assessment took into account the unique growing conditions on the constructed final landform, which are unlike those found in the natural surrounding ecosystems. Earlier studies identified an analogue site the nearby Georgetown area on rocky substrates.

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 5-1) 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.

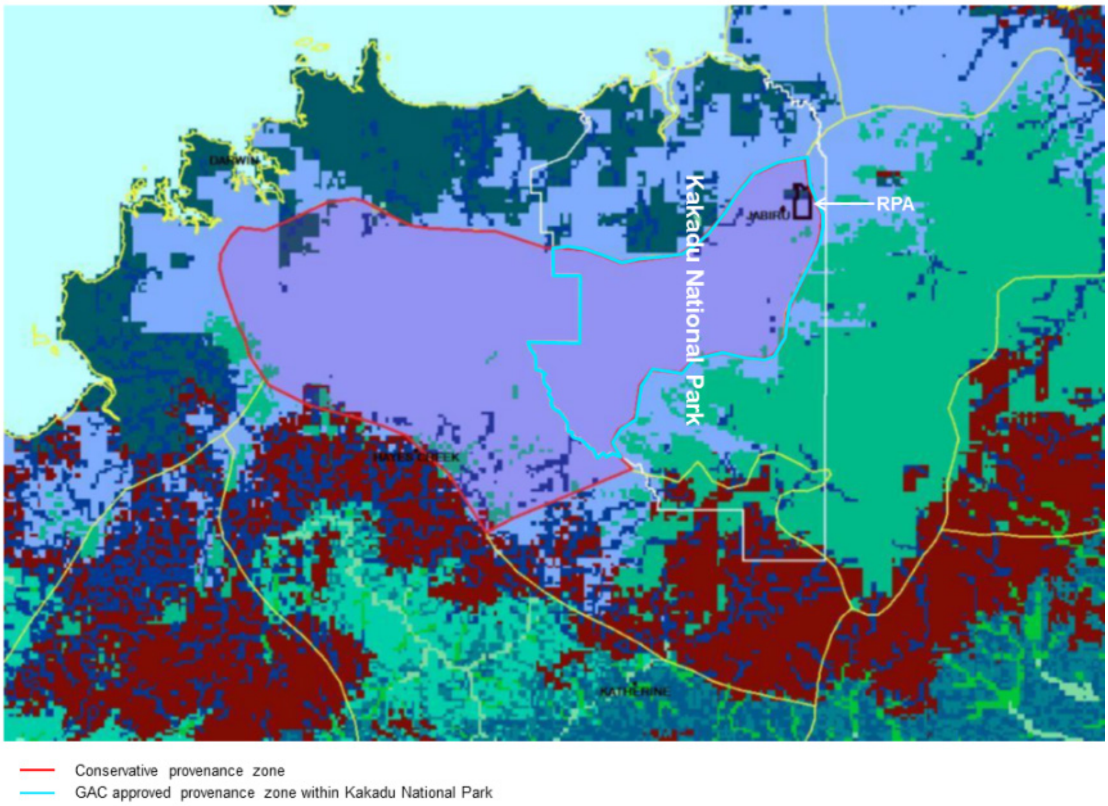


Figure 5-1: Proposed conservative provenance zone (bordered by the red line) and the GAC approved provenance zone within Kakadu NP (bordered by the blue line)

Element 6: Introduce a range of local mycorrhizal fungi to aid in the establishment of the framework species

As discussed in Section 1 above, initial establishment of vegetation into waste rock is a challenge; the substrate lacks nutrients, organic matter and fine particles, and, is also virtually devoid of nutrient-acquisitioning microorganisms (Reddell & Milnes 1992; Milnes 1989). Symbiotic microorganisms, such as mycorrhiza fungi and *Rhizobium* bacteria, play a critical role in nutrient uptake (esp. nitrogen and phosphorus) from soil by native Australian plants (Attiwill & Wilson 2006), and are highly prevalent in the natural soils of the Kakadu region (Brundrett *et al*. 1995; Reddell & Milnes 1992; Reddell & Joyce 1989). The vast majority of flora species in the undisturbed woodlands surrounding Ranger Mine have been found to have positive associations with symbiotic microorganisms (Reddell & Milnes 1992).

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 also 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*".

An effective microbial population, including mycorrhizae, is considered essential to establishing a self-sustaining woodland ecosystem on waste rock. A practical method has been refined at Ranger Mine by incorporating mycorrhizal fungal spores in the tubestock potting mix during propagation in the nursery.

Element 7: Include non-aggressive local native acacias but avoid the use of high densities of aggressive acacia species

A number of acacia species are common in the local woodlands, and are generally a positive component of the revegetation because of their ability to fix atmospheric nitrogen and rapidly produce organic matter. However, some acacias can be overly 'aggressive' in young revegetation and outcompete the slower-growing framework species, which are much less competitive until they have established dominant canopy and underground regenerative structures (e.g. Meek 2008; Zimmerman & Reddell 2011). Only natural proportions of short-statured, non-aggressive acacias will be included at initial establishment. Other acacia species are expected to self-colonise over time or can be introduced at the secondary establishment stage, once the framework species are dominating the site (see Element 8 below).

Element 8: Avoid actively introducing overly competitive grasses and herbaceous species, or sensitive species, until framework species are established and conditions are suitable

In young revegetation, vigorous grasses and herbaceous species can outcompete the preferred framework species (as for acacias) and if present in high densities can also increase the risk of fire (e.g. Meek 2008). Only low-risk native grasses and herbs will be introduced at initial establishment.

As the initial plantings of (mostly) framework overstorey and midstorey species establish and develop, a process expected to take five or more years based on trial landform experience (Section 3.2), the soil and litter layer will develop, canopy should increase providing shade and plants will develop attributes resilient to fires (e.g. stem diameter, lignotubers). It is at this stage that introductions of the remaining target understorey (and any midstorey or overstorey) species are planned to complete the diversity of the ecosystem. These species are generally those that are either too high risk or, alternatively, too sensitive to introduce at the earlier (initial) stage.

High risk species, also known as r-strategists (*sensu* MacArthur & Wilson 1967), are those that have, for example, high fecundity and rapid growth and should thrive in the temporary initial conditions of open space and high sunlight. These species might threaten to take advantage of the situation and out-compete the preferred eucalypt and other framework species as they gradually mature. This group includes aggressive acacias (e.g. *Acacia holosericea*), grasses (e.g. Sorghum spp.) and some herbs and will only be introduced during the secondary establishment stage. This will ensure that the preferred species are dominating the ecosystem and the r-strategists can establish in natural densities that will be supportive of a stable, self-sustaining ecosystem.

Sensitive species are those that are not suited to initial conditions however, they should be suited to passive or active introduction as environmental conditions improve. For example, *Xanthostemon paradoxus* is an important midstorey tree species and has shown extremely low survival rates in past revegetation at ERA. Research conducted in 2011–12 investigated the potential reasons for this and tested planting methods that could be used to improve the survival rate of this species in future revegetation (Gellert 2012). This study demonstrated that the use of shade-cloth tree shelters when planting can significantly increase survival, likely because the shade cloth reduced the light stress and heat stress experienced by the plants during planting shock and initial establishment.

More recently, Parry (2018) found that understorey species established from seed at almost twice the rate in the presence of surface litter as compared to other ameliorants (fine sand, fertiliser, ground incorporated organic matter, or combinations) or controls. Relationships between seedling emergence and distance to nearest tree, canopy cover and seed mass were also found. The study concluded that when establishing native understorey on mine waste rock in hot and intermittently dry periods in the wet season, the application of locally-collected surface litter to waste rock with broadcast seed may improve seedling establishment. With understorey species that have poor establishment from seed, tubestock planting has been proved to be a viable method for more efficiently introducing native understorey species into the ecosystem (Parry 2018).

These species will be established through either application of seed or tubestock planting, potentially concentrated in islands or strips across the final landform (particularly for the more infrequent or recalcitrant species). These concentrated areas will act as sources of future propagules which will spread out and self-colonise the rest of the landform over time. The work will be scheduled to utilise wet season rains and will be complemented by application of suitable fertiliser to assist early establishment and also contribute to the overall nutrient status of the developing rehabilitation.

Refining the appropriate introduction strategy for each species is the focus of the ERA species establishment research program (SERP) and is discussed further in Section 3.3.

Element 9: Use nursery-grown planting stock to establish the framework species

Based on current technology this will (a) significantly reduce the risk of planting failure associated with erratic rainfall and extreme temperatures; (b) accelerate the speed of vegetation development; and (c) overcome the poor predictability of establishing a final revegetated landform from direct seeding techniques. This strategy is proven to be the most cost-effective method for the initial establishment of framework species at Ranger and is reasonable given the constraint imposed by greatly limited seed availability within KNP. However, where reliable and predictable direct seeding success can be achieved for some species, such as Pandanus and Kapok *(Cochlospermum spp.)*, this method will be used.

Vegetation establishment techniques are discussed in Section 3.3.3 and MCP Section 9.4.6.

Element 10: Apply fertilisers in a strategic manner using formulations and delivery methods that maximise their effectiveness and environmental outcomes

Slow release fertiliser will be incorporated into the potting media for all planting stock, at rates that provide a significant 'residual' effect on growth after planting out. Some fertiliser will also be applied during the first wet season to facilitate more rapid seedling growth, especially if direct seeding is used; however, this fertiliser will not be of a highly soluble formulation. Additional fertiliser will be applied as required to ensure vegetation structural development is not inhibited and that sufficient site nutrient recapitalisation occurs, and also to support any subsequent infill or understorey planting. Fertilisation particularly favours invasive grassy species colonisation in the Top End and will be carefully managed to minimise this risk.

Use of fertilisers in the Ranger revegetation program is included in MCP Section 9.4.6.

Element 11: Provide irrigation to new planted or sown plants

For the initial planting activities, irrigation shall ensure good plant survival rates across all framework species during dry season and potentially erratic wet season conditions. However, irrigation will only be applied for 6 months or so, to avoid dependence and encourage deep rooting. Where possible, wet season rains will be used as the primary water source, particularly for the replacement ('infill') and secondary planting activities.

Some detail on proposed irrigation is provided in MCP Section 9.4.6.

Element 12: Rigorously control potentially threatening weed species

Weeds are the most critical risk to the reconstruction of the ecosystem. Final landform substrates shall be carefully managed during construction to prevent site contamination with weeds or their seeds. Furthermore, a weed-free buffer zone (approximately 200 metres wide) around the revegetation sites will be established to assist in preventing weed incursion into revegetation zones and areas will be treated with a pre-emergence, residual herbicide prior to planting. Weed monitoring and control will continue during the revegetation and post-closure management phases until closure criteria and relinquishment are achieved.

Weed management is further discussed in MCP Section 9.4.6.

Element 13: Exclude fire from the revegetation areas during early establishment until all plants have developed adequate resilience

Fire will be actively excluded from the developing revegetation through a program of controlled fuel reduction burns in surrounding vegetation and delayed introduction of highly flammable or high-biomass species, such as vigorous grasses. However, fire-resilience is a desirable feature of the mature ecosystem and it is important to introduce it as soon as possible, to ensure that fire-sensitive species do not come to dominate the revegetation. Introduction of low intensity fire to the developing revegetation will be dependent on the stage of development in the revegetation, for example framework species achieving a minimum stem diameter of six centimetres (Gellert 2013) and optimal fuel loads being present. Fire would then be used to maintain 'natural' fuel loads and to prime the framework species composition and structure to future fire regimes.

Surveys of the vegetation response to a controlled burn undertaken on the TLF (Wright 2019a), have shown that, especially when combined with appropriate and thorough herbicide application, may also be a useful method for controlling the spread of weeds and undesirable aggressive species such as *Acacia holosericea*. Fire may also promote germination and recruitment of several species such as *Owenia vernicosa* and *Eucalyptus tetrodonta*, and contribute to the establishment of a functioning and robust ecosystem.

Element 14: Design and implement a rigorous and scientifically based strategy for on-going evaluation of the performance of the revegetation

ERA is committed to a period of monitoring and maintenance, including activities required to manage the rehabilitated site, until all closure criteria can be satisfied (MCP Section 8).

A flora and fauna monitoring program will be developed for rehabilitation and closure, taking into consideration the information provided by the monitoring of natural reference sites. The monitoring program will comprise vegetation plots and fauna observation methods to assess terrestrial flora and fauna development.

The monitoring program will capture relevant information as the revegetation progresses. For example, in the initial stages of revegetation (e.g. years 1–5), the flora monitoring will focus on species survival rates, which will inform remediation works. As plants develop, a more comprehensive suite of parameters addressing ecosystem development and closure criteria will be introduced. The early fauna monitoring (e.g. years 1–3) is likely to focus on incidental observations of vertebrates and invertebrates. As habitat features develop, there will be an increase in monitoring to include trapping and systematic observation-based surveys to determine the presence of major functional groups. The proposed survey frequency of flora and fauna across the final landform is: three, six and 12 months (year 1); annually (years 1–5); and one-off surveys every five years (e.g. at years 10, 15, etc).

6 PLANNED REVEGETATION TRIALS

6.1 Pit 1 revegetation trials

Pit 1 will be available for revegetation in 2021, two years before other sections of the FLF, and provides an opportunity to test and evaluate a range of aspects relating to early revegetation activities. Overall, Pit 1 will allow ERA to:

- Fine tune nursery propagation and planting methods;
- Obtain improved data on predicted species performance and adjust planting strategy (species, density, locations) accordingly;
- Develop efficient monitoring for establishment and long term species-specific performance;
- Inform the FLF Revegetation Application (July 2022 submission); and
- Inform future trials and scaling up for operational planning for FLF (2023 – 2025);

The revegetation activities at Pit 1 will include 'conceptual reference ecosystem' (CRE) trial plantings based on reference ecosystem surveys, and targeted revegetation trials.

The information presented in the following sections is subject to change as the Pit 1 trials are yet to be finalised and stakeholder consultation is ongoing. The completed design, details on execution and preliminary results will be provided in the 2021 MCP.

6.1.1 Conceptual reference ecosystem trial planting

ERA has been collaborating with key stakeholders to develop a series of 'conceptual reference ecosystems' that represent the locally-occurring natural vegetation communities most likely to be suited to the challenges posed by the rehabilitated Ranger Mine site (Section 2.1.3). Recent focus has been eucalypt-dominated woodland ecosystems, based on vegetation surveys conducted by Supervising Scientist Branch (SSB) and ERA on ecosystems in areas adjacent to the Ranger Mine. Four potential woodland CREs have been identified: the Initial Conceptual Reference Ecosystem (ICRE) based on SSB survey sites, and three versions of draft Agreed Conceptual Reference Ecosystems (ACREs) based on different combinations of SSB and/or ERA survey sites.

Multiple areas of Pit 1 will be planted trialling different CREs. The objective is to revegetate using different CREs so that their suitability for revegetating waste rock landforms can be assessed/determined. The CRE trial planting will also provide an opportunity to visually demonstrate the different ecosystem types to Traditional Owners and external stakeholders.

6.1.2 Targeted revegetation trials

Tubestock and direct seeding trials will be conducted on Pit 1.

6.1.2.1 Tubestock trials

Similarly to Stage 13.1, the overall objective of the tubestock trials is to investigate different potting and propagation techniques with the aim of improving tubestock survival and health during the first two years after planting. The study will provide an opportunity to:

- Gather species-specific data to fine tune nursery propagation methods, such as germination rates, required growing times, irrigation requirements etc.;
- Obtain baseline performance data for species that have not been grown on FLF media previously; and
- Propagate and plant tubestock during different times of the year.

ERA has explored a range of methodologies and techniques for optimising tubestock planting success (most recently at Stage 13.1). Three factors have been identified which warrant further investigation/experience, including:

- *Pot type* - Although plastic 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.
- *Plant Size/Age* - Planting smaller tubestock may result in a higher root-shoot ratio, decreasing the initial water demand of the seedling. Planting smaller sized tubestock appeared to improve *Xanthostemon paradoxus* survival on the TLF (*per comms*. Dr Ping Lu).
- *Planting Season* - When revegetation is at its peak in 2024/2025, tubestock will need to be grown and planted all year round. There will be three lots of tubestock planting: during the wet, dry and build-up.

Species will be selected for tubestock trials based on the following four considerations (Table 6-1):

- Which species are most important to optimise establishment? eg. Culturally significant species, species which occur at high densities etc.
- Which species have historically been difficult to establish on waste rock?
- Which species do ERA have limited or no experience establishing on waste rock?
- Which species are not suitable for initial planting, either because the conditions are too harsh or because they may be too aggressive?

All of the trial species will be planted in March; however, due to space and planting restraints approximately half of the species will be included in the dry and build-up trials. The species chosen for the unseasonal planting trials will: generally occur at high densities; will be a range of Families and lifeforms; and a combination of deciduous, evergreen and/or fresh-seeded species.

Table 6-1: Species being considered for trials at Pit 1 (currently being reviewed)

Species	Lifeform	Family
Overstorey and Midstorey		
Acacia lamprocarpa	Tree	Fabaceae
Acacia mimula	Shrub	Fabaceae
Brachychiton megaphyllus	Shrub	Malvaceae
Buchanania obovata	Shrub	Anacardiaceae
Calytrix exstipulata	Shrub	Myrtaceae
Corymbia bleeseri	Tree	Myrtaceae
Corymbia chartacea	Tree	Myrtaceae
Corymbia disjuncta	Tree	Myrtaceae
Corymbia dunlopiana	Tree	Myrtaceae
Corymbia foelscheana	Tree	Myrtaceae
Corymbia polysciada	Tree	Myrtaceae
Corymbia porrecta	Tree	Myrtaceae
Erythrophleum chlorostachys	Tree	Fabaceae
Eucalyptus miniata	Tree	Myrtaceae
Eucalyptus tectifica	Tree	Myrtaceae
Eucalyptus tetrodonta	Tree	Myrtaceae
Gardenia megasperma	Shrub	Rubiaceae
Grevillea mimosoides	Shrub	Rubiaceae
Jacksonia dilatata	Shrub	Fabaceae
Livistona humilis	Palm	Arecaceae
Melaleuca viridiflora	Tree	Myrtaceae
Planchonella arnhemica	Shrub	Sapotaceae
Planchonia careya	Shrub	Lecythidaceae
Stenocarpus acacioides	Tree	Proteaceae
Syzygium eucalyptoides ssp. bleeseri	Shrub	Myrtaceae
Terminalia ferdinandiana	Shrub	Combretaceae
Terminalia pterocarya	Shrub	Combretaceae
Understorey		
Acacia gonocarpa	Shrub	Fabaceae
Alloteropsis semialata	Grass	Poaceae
Ampelocissus acetosa	Vine	Vitaceae
Aristida holathera	Grass	Poaceae
Cartonema spicatum	Herb	Commelinaceae

Species	Lifeform	Family
Eriachne obtusa	Grass	Poaceae
Galactia tenuiflora	Vine	Fabaceae
Larsenaikia suffruticosa	Subshrub	Rubiaceae
Grevillea goodii	Shrub	Proteaceae
Haemodorum coccineum	Herb	Haemodoraceae
Heteropogon triticeus	Grass	Poaceae
Petalostigma quadriloculare	Shrub	Picrodendraceae
Tacca leontopetaloides	Herb	Taccaceae
Uraria lagopodioides	Vine	Fabaceae

6.1.2.2 Direct seeding trials

The overall objective is to determine which species can successfully establish from seed on the FLF during the initial stages of revegetation. In addition, for some species:

- Does time of sowing impact plant establishment from seed?
- Does surface treatment impact establishment from seed?

Species will be selected for direct seeding trials based on the following considerations:

- Which species have seed available in high quantities, and are easy to collect and process?
- Which species occur at high densities in the surrounding bushland, therefore would provide significant savings if able to direct seed?
- Which species have failed to establish in previous direct seeding trials on Ranger waste rock?
- Which species do ERA have limited or no experience direct seeding on waste rock?
- Which species have naturally colonised Ranger waste rock dumps or typically grow in harsh conditions somewhat similar to those found on the initial FLF?
- Which species are not suitable for initial planting, either because the conditions are too harsh or because they may be too aggressive?

The majority of the species selected for direct seeding trials will be understorey species, however a few midstorey species that are deemed to be potentially suitable for direct seeding will also be included.

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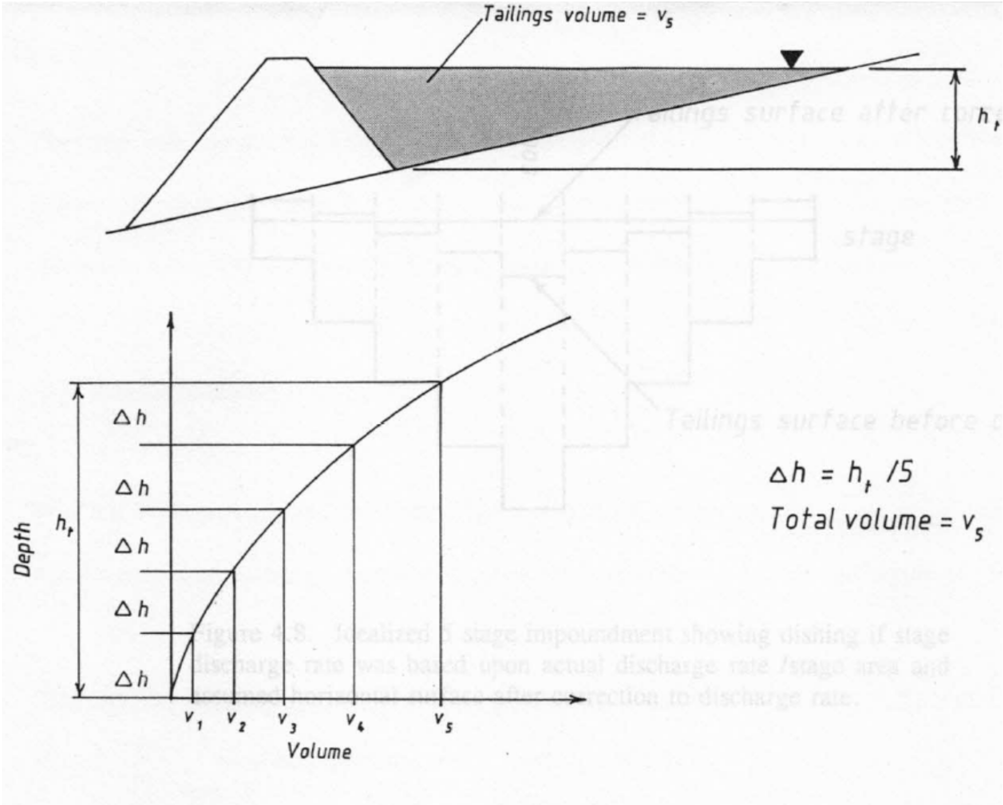
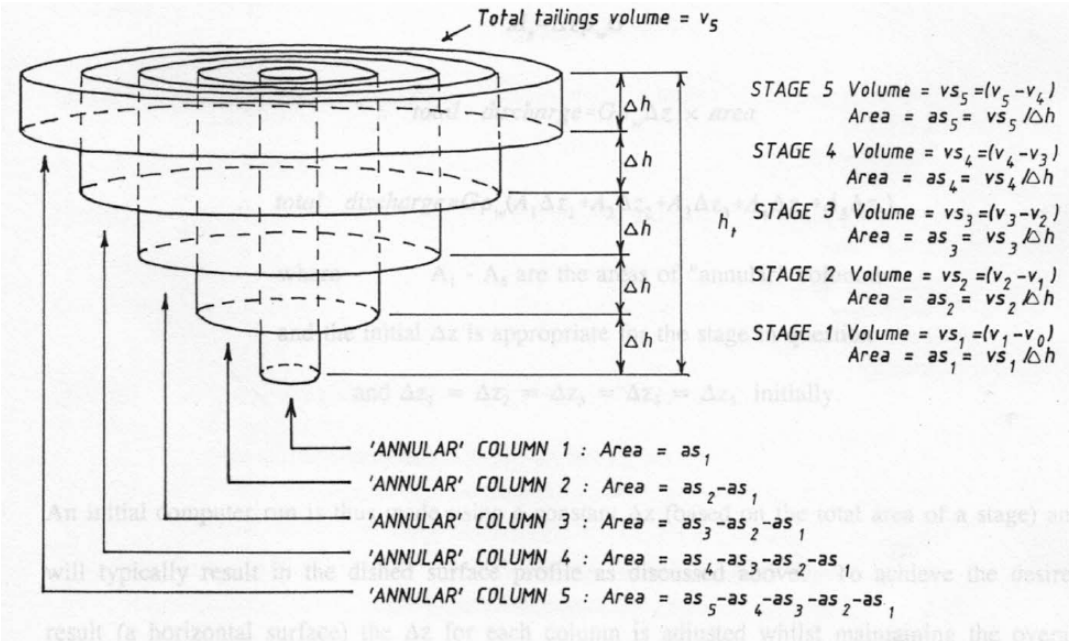
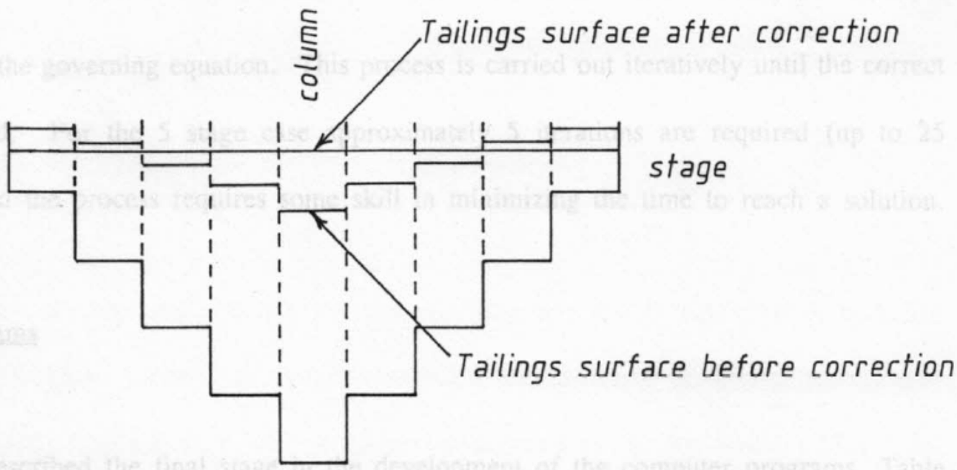
APPENDIX 5.2 CONSOLIDATION MODEL A



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.

ERA

APPENDIX 5.3 CONSOLIDATION MODEL B

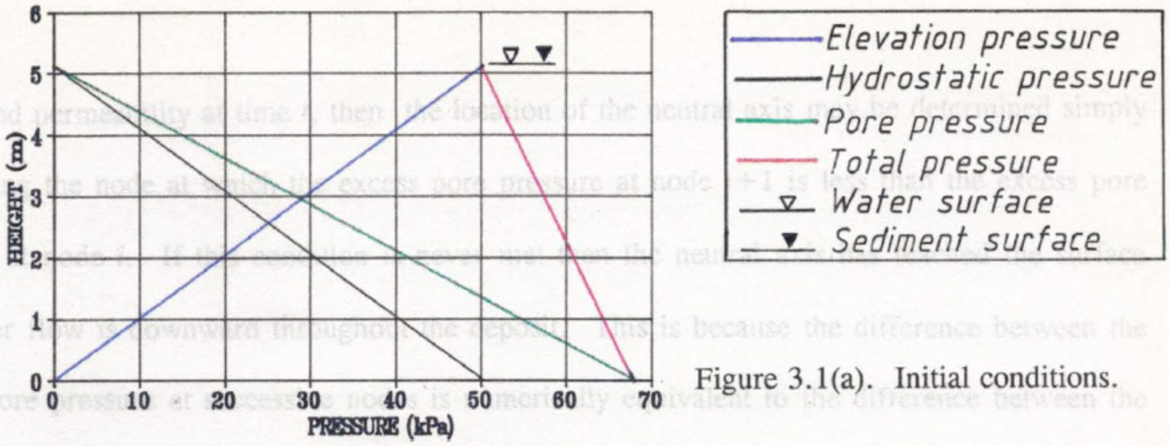


Figure 3.1(a). Initial conditions.

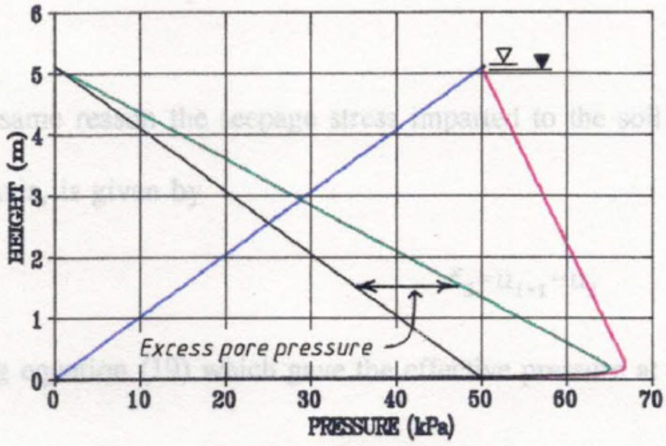


Figure 3.1(b). Conditions immediately after opening base drain.

ERA

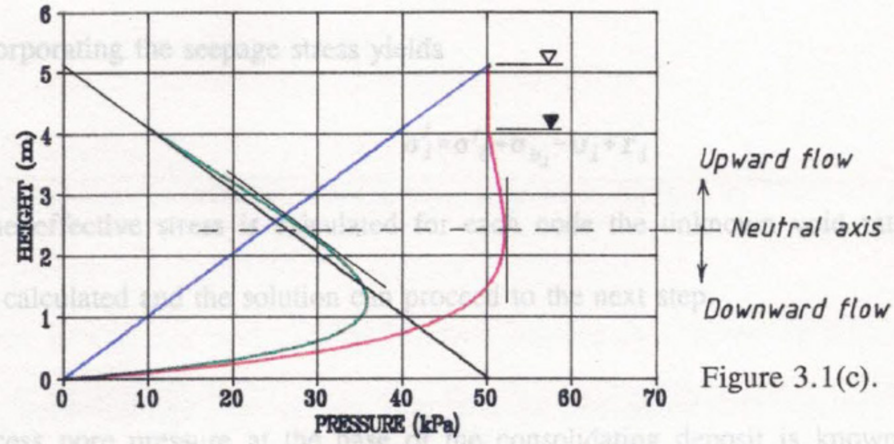


Figure 3.1(c). Intermediate case.

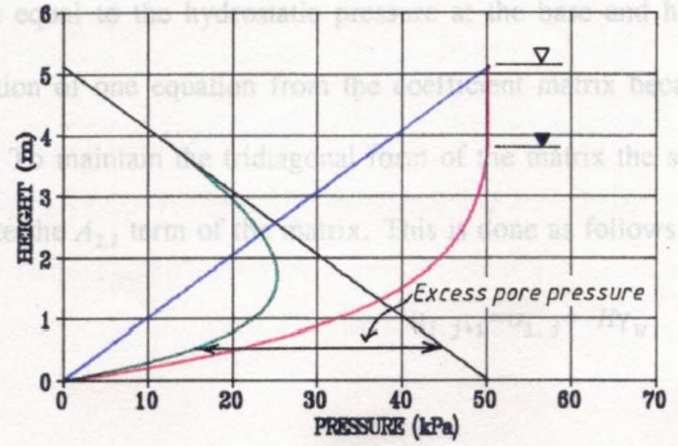


Figure 3.1(d). Approaching equilibrium conditions.

Figure 3.1. Pore pressure conditions in an underconsolidated slurry.

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APPENDIX 5.4 KEY KNOWLEDGE NEEDS

Note: KKN questions shown in greyed-out text have been closed out (i.e. required information has been attained) or removed (i.e. clearly no longer required, or covered in other KKNs)

LANDFORM REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
LAN1	Erosion	Baseline	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?	Baseline information on gully characteristics and formation (e.g. extent/occurrence and distribution of gullies of differing size and complexity, rate of 'knick-point' retreat) in natural landforms is needed. This information can be obtained from appropriate imagery and will be used to assess whether the extent, rate and magnitude of gully formation predicted for the rehabilitated site will vary significantly from those observed in comparable non-mine disturbed landforms in adjacent areas.	SSB
				LAN1B. What are the baseline rates of sediment transport and deposition in creeks and billabongs?	The risk of bedload sediment transport from the rehabilitated site is generally considered to be low because of the ability to manage it through appropriate mitigation measures (e.g. sedimentation basins). However, information on natural bedload yields in Magela and Gulungul creeks is needed to distinguish mine-derived bedload from natural yields and monitor the effectiveness of mitigation measures. If the mitigation measures are not effective, this information would also be used to assess potential impacts to aquatic ecosystems.	SSB
LAN2	Erosion	Baseline	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)?	Identification of major landscape-scale processes or extreme events that could adversely affect the stability of the rehabilitated landform is needed to assess whether there are any potential risks associated with these processes that could result in mass failure and containment of tailings for at least 10,000 years. This information is likely to be available in existing reports and will be used to assess potential impacts on landform stability (see LAN2B).	SSB
				LAN2B. How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?	Information to assess the degree to which major landscape-scale processes or extreme events could affect the stability of the rehabilitated landform is being addressed and will be further sought from the available literature.	BOTH
LAN3	Erosion	Predicting	LAN3. Predicting erosion of the rehabilitated landform	LAN3A. What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?	The shape (e.g. slope) and surface characteristics (e.g. particle size, roughness, riplines, drainage) of the rehabilitated landform will influence erosion rates. These characteristics and their effect on erosion rates can be assessed through an iterative modelling approach using CAESAR-Lisflood. Information on proposed landform characteristics should be used to optimise landform design. This could include using 'geomorphic reclamation' processes, which are the characteristics (e.g. slope curvature/length) of the pre-mining or adjacent landscape. These will be calculated and used to inform the design of the final landform.	BOTH
				LAN3B. Where, when and how much consolidation will occur on the landform?	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.	ERA

LANDFORM REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
				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)?	Some input parameters for the landform evolution model may be influenced by local conditions and these need to be understood to maximise the accuracy of the model predictions. Examples of parameters include: • sediment settling velocity, • shear stress and roughness, • rate of weathering for waste rock, • effect of vegetation succession and fire on suspended sediment transport, and • impact of extreme rainfall events and scenarios over time on suspended sediment transport. Validation of bedload predictions could be undertaken by comparing measured parameters from the trial landform and the rehabilitated Pit 1 landform (e.g. bedload, suspended sediments) with the model outputs at both plot and catchment scale.	SSB
				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)?	In order to assess the effectiveness of the final landform design (including any integral control structures), it will be necessary to identify and understand the erosion characteristics (extent and magnitude of gully formation; denudation and erosion rate; potential for groundwater expression) that may result under the different model scenarios.	SSB
				LAN3E. How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?	Suspended sediment has the potential to impact on aquatic ecosystems downstream of the rehabilitated site. Turbidity/suspended sediment should be monitored on the constructed Pit 1 final landform to determine what loads are likely to be released from the mine site and to assist with the calibration/validation of model predictions of suspended sediment transport at the catchment scale. The significance of suspended sediment that may be transported from land application areas will also need to be assessed. This assessment is commensurate with the level of soil disturbance associated with remediation of these areas.	BOTH

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
WS1	Biodiversity and ecosystem health	Source	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)?	A comparative assessment of contaminants of potential concern (COPCs) and their respective source(s) (e.g. waste rock, tailings/pore water, groundwater, soils) is needed, including consideration of any 'hotspots' that may be present on the rehabilitated site (e.g. groundwater under the plant area, GCT2 area, LAAs, billabong/stream sediments). This information contributes to whole-of-site contaminant transport modelling to predict post-closure water quality and will inform the rehabilitation and risk management of the site.	ERA
				WS1B. What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?	For each contaminant source present on the rehabilitated site, physical, chemical and other factors that affect, or interact to affect, contaminant mobilisation need to be identified and assessed. This information contributes to whole-of-site contaminant transport modelling to predict post-closure water quality and will inform the rehabilitation and risk management of the site.	ERA
WS2	Biodiversity and ecosystem health	Pathway	WS2. Predicting transport of contaminants in groundwater	WS2A. What is the nature and extent of groundwater movement, now and over the long-term?	Knowledge of current and post-closure groundwater movement is required, both within the rehabilitated site and to the off-site environment. This is being achieved through numerical model predictions that consider the implications of changes to the groundwater movement due to the mine closure and recovery, i.e. the return to a stable state of levels, contaminant concentrations, flow paths and the influence of sea-level rise on groundwater flow, after rehabilitation. The most appropriate monitoring locations for calibration and verification of models needs consideration. This information contributes to whole-of-site contaminant transport modelling to predict post-closure water quality and will inform the rehabilitation and risk management of the site.	ERA
				WS2B. What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?	There is a need to determine whether conservative modelling or reactive modelling provides a worse-case for contaminant transport within the groundwater pathway. Reactive modelling examines physical and chemical factors that influence contaminant transport within the groundwater pathway (e.g. pH, redox conditions) and interactions amongst these (e.g. COPC mixtures). Identification of these factors (and their significance) informs contaminant transport modelling to predict the downstream concentrations of COPCs.	ERA
				WS2C. What are predicted contaminant (including nutrients) concentrations in groundwater over time?	The contaminant concentration in the groundwater system will vary with time due to the development of geochemical reactions at the source and movement of contaminants through the groundwater. Understanding of the variation of contaminant concentration will be used to determine the timing and amount of contaminant that may reach a receptor affecting the health of the ecosystem. Knowledge of the concentrations of COPCs in groundwater informs contaminant transport modelling used to predict the downstream concentrations of COPCs and inform rehabilitation and risk mitigation strategies.	ERA

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
WS3	Biodiversity and ecosystem health	Pathway	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?	Detailed information on current and future hydrological conditions for catchments both within the RPA and adjacent/downstream areas is required. The effect of sea-level rise on the surface waters flow also needs consideration. The timing and magnitude of surface water flows informs contaminant transport modelling used to predict the on-site and downstream concentrations of COPCs.	ERA
				WS3B. What concentrations of contaminants from the rehabilitated site will aquatic (surface and ground-water dependent) ecosystems be exposed to?	Determination of the concentrations of COPCs that aquatic ecosystems (including riparian vegetation) will be exposed to from the rehabilitated site needs to be based on the integration of modelling predictions for both groundwater (WS2) and surface water (WS3). Predicted COPC concentrations in surface and groundwaters can then be compared against water quality guideline values or other locally-derived biological effects information (for ground-water dependant species) in order to assess whether aquatic biodiversity and ecosystem health are exposed to risk following rehabilitation. (To address this KKN, information from WS3D is first required.)	ERA
				WS3C. What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?	There is a need to determine whether conservative modelling or reactive modelling provides a worse-case for contaminant transport in the surface water pathway. Reactive modelling examines physical and chemical factors that will influence contaminant transport and toxicity (e.g. pH) and interactions amongst these (e.g. COPC mixtures). Identification of these factors (and their significance) informs contaminant transport modelling used to predict the downstream concentrations of COPCs.	ERA
				WS3D. Where and when does groundwater discharge to surface water?	Information on the locations and timing of groundwater discharge to surface water is required to assess the significance of this contaminant transport pathway. Improved understanding of groundwater/surface water interactions informs contaminant transport modelling used to predict the downstream concentrations of COPCs.	BOTH
				WS3E. What factors are likely to be present that influence contaminant transport (including nutrients) between groundwater and surface water?	Factors that could influence movement of contaminants, and limit or increase their concentration from groundwater to surface water, include geology, topography, aquifer geometry and hydraulic characteristics. Identification of these factors (and their significance) informs contaminant transport modelling to predict the downstream concentrations of COPCs.	ERA
				WS3F. What are the predicted concentrations of suspended sediment and contaminants (including nutrients) bound to suspended sediments in surface waters over time?	When suspended sediments are transported from the rehabilitated site, they could affect aquatic ecosystem health directly (e.g. habitats/biota effects) and/or indirectly (e.g. transport of bound contaminants). Knowledge of the concentrations of suspended sediments and associated contaminants informs contaminant transport modelling to predict the downstream concentrations of COPCs.	BOTH

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				WS3G. To what extent will the interaction of contaminants between sediment and surface water affect their respective qualities?	Contaminants in surface water may accumulate in sediments to concentrations above those at which biological effects could be expected. Conversely, contaminants in sediments may resuspend into the water column and reduce water quality. An understanding of the factors affecting the flux of contaminants between surface waters and sediments is required to determine if closure criteria will protect both environmental compartments.	BOTH
				WS3H. Where and when will suspended sediments and associated contaminants accumulate downstream?	If contaminants from the rehabilitated site accumulate in downstream sediments, it is possible that they could affect aquatic ecosystem health directly and in the short term (e.g. to benthic biota) and/or in future through re-mobilisation of deposited contaminants. Knowledge of locations and likely timing for deposition of suspended sediments and associated contaminants informs the assessment of risk to aquatic ecosystems.	ERA
WS4	Biodiversity and ecosystem health	Receptor	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?	Although there is currently substantial knowledge on baseline water quality and biodiversity in surface waters during early dry season (recessional) flow periods, information on water quality and biota for other periods of surface water flow and inundation (i.e. both wet and dry seasons, stream channels and billabongs) is limited. More complete information will allow a more comprehensive assessment of whether predicted (modelled) concentrations of COPCs transported from the rehabilitated site are likely to impact on downstream aquatic ecosystem health. Hyporheic and stygofauna communities in the Magela Creek sand beds are poorly understood and the significance of their contribution to ecological processes to the biodiversity of the ARR is unknown. The environmental conditions sustaining these (e.g. water quality, flow), and other groundwater dependent ecosystems (e.g. dry season water sources for riparian vegetation) are also unknown. If these communities are ecologically important, their potential sensitivity to increased solute loads needs to be assessed (WS7C). This information helps determine if specific closure criteria are needed to protect these communities.	SSB
WS5	Biodiversity and ecosystem health	Receptor	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?	Some COPCs transported from the rehabilitated site, e.g. uranium and sulfate, will bind to organic matter and benthic sediments in downstream ecosystems, in particular, the shallow lowland billabongs. The long-term risk of accumulation of these COPCs in sediment to biodiversity or ecological processes needs to be assessed for both the creek and billabongs. This information will inform management of the rehabilitated site and, in relation to sulfate in particular, any ongoing need to manage this COPC in surface and groundwater. Such a risk assessment would include analyses of the temporal trends in COPC concentrations in the sediments and, for sulfate, the predicted budget for billabongs (i.e. Coonjimba, Georgetown, Gulungul) to assess the risk of acid sulfate sediment formation and associated potential impacts on aquatic biodiversity and ecosystem health.	BOTH

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				WS5B. What are the factors that influence the bioavailability and toxicity of contaminants in sediment?	Closure criteria for U in sediments were derived using sediments from Gulungul Billabong, as they are representative of the major depositional zones in and outside of the RPA (i.e. shallow backflow billabongs). However, if physico-chemical conditions (e.g. pH, TOC) of sediments differ from those in Gulungul Billabong, this may affect the toxicity of COPCs, and the closure criteria may not be appropriate. Knowledge of the influence of bioavailability and toxicity modifying factors in sediments helps derive closure criteria specific for different sediment conditions.	SSB
				WS5C. What would be the impact of contaminated sediments to surface aquatic ecosystems?	If predicted COPC concentrations in sediments are likely to reach a threshold where there is a risk that they could be mobilised into surface waters, the potential impacts to these aquatic ecosystems need to be assessed.	*Removed November 2019*
WS6	Biodiversity and ecosystem health	Receptor	WS6. Determining the impact of nutrients in surface water on aquatic biodiversity and ecosystem health	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?	The effects of ammonia on local species under local conditions need to be quantified. The toxicity of ammonia is highly influenced by pH and temperature, which can vary substantially between billabongs and streams, and seasonally. This research also needs to include assessment of toxicity to freshwater mussels, which have been reported as particularly sensitive to ammonia, an important component of the local aquatic ecosystem and a highly-valued food source for traditional owners. This information assists in deriving site-specific closure criteria for ammonia.	*Closed out May 2020*
				WS6B. Can Annual Additional Load Limits (AALL) be used to inform ammonia closure criteria?	A review of the literature supporting AALLs is needed to understand their continuing relevance. It needs to be determined whether ammonia loads could be considered in the same context as the AALLs.	ERA
				WS6C. Will the total loads of nutrients (N and P) to surface waters cause eutrophication?	Contaminant transport modelling will predict loads of nutrients that downstream surface waters are likely to receive from the rehabilitated site. This information should be used to assess if there is a risk of eutrophication to downstream surface waters.	ERA
WS7	Biodiversity and ecosystem health	Receptor	WS7. Determining the impact of contaminants in surface and ground-water on aquatic biodiversity and ecosystem health	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios?	Water quality limits that have been derived for individual toxicants do not incorporate potential interactive (e.g. additive, synergistic, antagonistic) effects of toxicant mixtures or other modifying effects occurring in the field (e.g. pH, temperature, DOC). This knowledge informs the development and application of closure criteria for COPCs.	SSB
				WS7B. What is the risk associated with emerging contaminants?	Contaminant research has been prioritised on a risk basis, but the continued gathering of contaminant knowledge before and during the mine's transition into a rehabilitated site may result in the identification of new or emerging contaminants of potential concern (e.g. contaminated sites studies and where the risk profile of a contaminant changes through increased knowledge of effects or exposure). Where such contaminants are identified, they need to be assessed using a tiered, risk-based approach.	BOTH

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
				WS7C. Are current guideline values appropriate to protect the key groups of aquatic organisms that have not been represented in laboratory and field toxicity assessments (e.g. flow-dependent insects, hyporheic biota and stygofauna)?	Current guideline values are derived from a limited suite of laboratory tests and, where possible, validated using field-effects data. Some (sandy) stream-dwelling species, which have been reported as sensitive to contaminants, are not represented in these data sets and their sensitivity to COPCs are unknown. This knowledge will indicate if closure criteria are protective of these taxa and identify any phase of the hydrograph of receiving stream environments that represents greater risks to stream biota than other phases.	SSB
				WS7D. How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota?	Acidification events, and associated increases in dissolved metal concentrations, have been observed in on-site waterbodies (e.g. Coonjimba Billabong, RP1) as a result of acid sulfate soil formation associated with elevated sulfate concentrations from the mine. These events typically occur during re-wetting events in the early wet season and in most cases are short-lived (days, weeks). In order to fully inform management actions for sulfate in surface and groundwaters (see WS5A), biological-effects studies of the impacts to such receiving waters should be undertaken to examine short (during events) and longer-term (seasonal, interannual) changes to biodiversity and ecological processes.	*Removed November 2019*
				WS7E. How will Mg:Ca ratios influence Mg toxicity?	An understanding of the Mg:Ca ratio of seepage water from various sources and how this affects toxicity is required. The gathering of field (or semi-field) effects data for mine released waters (including groundwater sources) mixed with receiving waters would provide supporting evidence.	*Closed out May 2020*
				WS7F. Can a contaminant plume in creek channels form a barrier that inhibits organism migration and connectivity (e.g. fish migration, invertebrate drift, gene flow)?	Previous studies in Magela Creek have demonstrated avoidance by fish of mine wastewater discharges, indicating potential reduced recruitment to upstream sites. Information on seasonal movement and dispersal of organisms needs to be considered and combined with groundwater contaminant modelling data, in order to assess potential for impaired movement and connectivity in streams.	SSB
				WS7G. What concentrations of contaminants will be detrimental to the health of (non-riparian) aquatic vegetation?	The guideline values for COPCs were derived using a limited species range that included one aquatic macrophyte (*Lemna*) with a relatively short exposure duration (4 days). Apart from their inherent biodiversity and conservation values, the diverse aquatic plant communities in billabongs and along littoral portions of the creeks constitute critical habitat for other biota, and for this reason are deserving of more detailed investigation than just the limited laboratory information available for the single species. Laboratory and field studies under a range of realistic exposure scenarios or across existing contaminant gradients in onsite waterbodies should be undertaken to assess the potential sub-lethal impacts of COPCs on aquatic vegetation in these aquatic ecosystems and thereby determine if healthy aquatic habitats can be maintained following rehabilitation.	BOTH

WATER AND SEDIMENT REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				WS7H. What concentrations of contaminants will be detrimental to the health of riparian vegetation?	Riparian vegetation, particularly that growing along the banks of the major drainage lines (Magela and Gulungul creeks) may be seasonally exposed to elevated concentrations of contaminants in shallow groundwater after minesite rehabilitation. An assessment of the potential sub-lethal impacts of COPCs on germination and early growth of representative species (e.g. through pot trials) will assist in determining if healthy riparian habitats can be maintained following rehabilitation.	SSB
WS8	Biodiversity and ecosystem health	Receptor	WS8. Determining the impact of suspended sediment on aquatic biodiversity and ecosystem health	WS8A. What are the physical effects of suspended sediment on aquatic biodiversity, including impacts from sedimentation and variation in sediment characteristics (e.g. particle size and shape)?	Suspended sediments can have various physical effects on aquatic ecosystems, such as habitat alteration (e.g. deposition), light attenuation and subsequent influence on primary productivity and physiological effects on organisms (e.g. inhibition of reproduction/growth, fish gill function). The magnitude of the effects of suspended sediments can vary according to their characteristics. For example, larger particle sizes are more likely to result in impacts associated with deposition (e.g. smothering of habitat), whereas smaller particle sizes are more likely to result in impacts upon filter feeding organisms. An assessment of potential impacts of suspended sediment on aquatic biodiversity should be based on predicted characteristics of sediments that may be transported from the rehabilitated site.	SSB
				WS8B. To what extent does salinity affect suspended particulates, and what are the ecological impacts of this?	Salinity can affect behaviour of suspended particles by processes such as flocculation and may affect the rate at which the particles settle from the water column. The potential for high-salinity waters associated with the rehabilitated site (e.g. evapo-concentration in billabongs during the dry season) to affect behaviour of suspended particulates (e.g. increased deposition rates) and subsequent ecological impacts (e.g. infilling of billabongs) needs to be assessed.	*Removed May 2020*

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
RAD1	Human and ecosystem health	Source	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?	Waste rock, buried tailings and contaminated soils on land application areas represent potential sources of radionuclides to the environment from the rehabilitated site. The radionuclides of concern are those of the uranium and actinium decay series because they occur at elevated concentrations in the source materials. Radionuclides of the thorium decay series are not of concern, as they do not occur at elevated levels in the source materials. Knowledge of the activity concentrations of uranium and actinium decay series radionuclides in waste rock, tailings and land application area soils is needed to model activity concentrations in the environment post-rehabilitation, which in turn are needed to estimate radiation doses to the public and wildlife. The knowledge could be acquired through radionuclide measurements on existing waste rock, tailings and land application area soils.	ERA
RAD2	Human and ecosystem health	Pathway	RAD2. Radionuclides in aquatic ecosystems	RAD2A. What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?	Increased radionuclide activity concentrations in surface water and sediment due to contaminated water arising from the rehabilitated site could result in radiation doses above natural background to the public and wildlife. Knowledge of the increases in activity concentrations of uranium and actinium decay series radionuclides in surface water and sediment is needed to estimate these doses. The knowledge could be acquired through modelling of: • radionuclide releases to surface water via runoff and groundwater pathways from the rehabilitated site • the mixing of released radionuclides in surface water • radionuclide partitioning between sediment and water. Furthermore, the modelling of radionuclide releases could be based on an element with high solubility to provide conservative estimates of activity concentrations.	ERA
RAD3	Human and ecosystem health	Pathway	RAD3. Radon progeny in air	RAD3A. What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?	Radon (a radioactive gas) will be emitted to the atmosphere from the rehabilitated site due to the decay of radium-226 in surface waste rock. The inhalation of radon progeny radionuclides produced through the decay of emitted radon could result in radiation doses above natural background to the public. Knowledge of radon and/or radon progeny concentrations in air is needed to estimate these doses. This knowledge could be acquired by modelling the atmospheric dispersion of radon from the rehabilitated site, using site-specific data (as necessary) for parameters such as: • radium-226 activity concentrations in surface waste rock (RAD1A) • radon exhalation rates for waste rock • dry and wet season meteorological conditions.	SSB

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME

KKN No.	ER Link	Category	Title	Questions	Description	Responsibility (SSB/ERA/BOTH
				RAD3B. If an assessment using conservative values shows a potential issue with meeting closure criteria (3A and 7A): What is the equilibrium factor between radon progeny and radon in air?	If the modelling under RAD3A gives radon concentrations in air, then knowledge of the equilibrium factor between radon progeny and radon will be needed to obtain radon progeny concentrations for dose modelling. If needed, site-specific knowledge on equilibrium factors could potentially be acquired through simultaneous measurements of radon and radon progeny concentrations in ambient air off-site of the operating mine.	*Removed November 2019*
				RAD3C. If an assessment using conservative values shows a potential issue with meeting closure criteria (3A and 7A): What is the unattached fraction of radon progeny in air?	The dose coefficient for radon progeny depends on the proportion of radon progeny attached and unattached to aerosols. If needed, site-specific knowledge on the unattached fraction could be acquired through simultaneous measurements of radon progeny attached and unattached to aerosols in ambient air at locations off-site of the operating mine.	*Removed November 2019*
RAD4	Human and ecosystem health	Pathway	RAD4. Radionuclides in dust	RAD4A. If an assessment using conservative values shows a potential issue with meeting closure criteria (4B and 7A): What is the resuspension factor (or emission rate) of dust emitted from the final landform?	If the modelling under RAD4B uses a resuspension factor approach to estimate the release of radionuclides in dust from the rehabilitated site to the atmosphere, then site-specific knowledge of dust resuspension factors or emission rates may be needed. If needed, this knowledge could be acquired through measurements of radionuclide activity loadings in dust and activity concentrations in ambient air.	*Removed November 2019*
				RAD4B. What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	The inhalation of radionuclides in dust emitted to the atmosphere from the rehabilitated site could result in radiation doses above natural background to the public. Knowledge of airborne activity concentrations of radionuclides in dust is needed to estimate these doses. This knowledge could be acquired by modelling the atmospheric dispersion of radionuclides in dust from the rehabilitated site, using site-specific data (as necessary) for parameters such as: • activity concentrations of uranium and actinium decay series radionuclides in surface waste rock (RAD1A) • resuspension factors (or emission rates) of radionuclides in dust from waste rock • dry and wet season meteorological conditions.	*Closed out November 2019*
				RAD4C. If an assessment using conservative values shows a potential issue with meeting closure criteria (4B and 7A): What is the activity median aerodynamic diameter of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	The dose coefficient for radionuclides in dust depends on the activity median aerodynamic diameter (i.e. size) of the aerosol. If needed, site-specific knowledge on activity median aerodynamic diameter could be acquired through radionuclide measurement of size fractionated dust samples collected using cascade impactors.	*Removed November 2019*

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
RAD5	Human and ecosystem health	Pathway	RAD5. Radionuclides in bushfoods	RAD5A. What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?	The ingestion of uranium and actinium decay series radionuclides bioaccumulated in bush foods could result in radiation doses above natural background to the public. Radiation dose assessments for the human food chain use concentration ratios to predict radionuclide activity concentrations in food items from those in the surrounding soil or water. A sizeable body of knowledge exists on concentration ratios for uranium decay series radionuclides. However, there is effectively no knowledge (site-specific or otherwise) on concentration ratios for actinium decay series radionuclides. The actinium decay series radionuclides of potential concern include actinium-227 and protactinium-231, which have relatively high ingestion dose coefficients. Knowledge on concentration ratios for these radionuclides could potentially be acquired through sampling and measurement on bush foods and associated soils and waters after development of radiochemistry separation and measurement techniques for actinium-227 and protactinium-231.	SSB
RAD6	Human and ecosystem health	Receptor	RAD6. Radiation dose to wildlife	RAD6A. What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?	Wildlife dose assessments are generally based on a small number of organism groups representative of the broad variety of species present in the environment. This is because it is not usually practical to sample and perform radionuclide analyses on all species present. Knowledge of representative organism groups could potentially be acquired from reviewing ecological information about the species present in the local environment and generalising them up to a small number of representative organism groups. Alternatively, broad wildlife groups defined by international bodies (e.g. International Atomic Energy Agency) or within wildlife dose assessment tools (e.g. ERICA) could potentially be used. When selecting representative organism groups, consideration should be given to any rare, threatened or culturally significant species that may be present in the local environment.	*Closed out November 2019*

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				RAD6B. What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?	The bioaccumulation of uranium and actinium decay series radionuclides in wildlife could result in radiation doses above natural background to those wildlife. Standard dose assessment tools for wildlife use whole organism concentration ratios to predict radionuclide activity concentrations in wildlife from those in the surrounding soil or water. Whole organism concentration ratios of uranium decay series radionuclides have been derived for some (but not all) types of wildlife using site-specific data. There is effectively no data (site-specific or otherwise) for deriving whole organism concentration ratios for actinium decay series radionuclides, specifically actinium-227 and protactinium-231. Knowledge of whole organism concentration ratios for uranium and actinium decay series radionuclides could potentially be acquired by one or more of the following methods: • sampling and radionuclide measurements on organisms and associated soil or water to derive additional site-specific values • review and analysis of international databases (e.g. Wildlife Transfer Database) and publications to fill gaps in site-specific values • use of surrogate organism and analogue element approaches to fill gaps in site-specific values.	SSB
				RAD6C. What are the tissue to whole organism conversion factors for uranium and actinium series radionuclides for wildlife represented by the representative organism groups?	Standard dose assessment tools for wildlife use whole organism concentration ratios to predict radionuclide activity concentrations in wildlife from those in the surrounding soil or water. Most site-specific data on radionuclide activity concentrations in wildlife is tissue-specific, as it was originally collected to support human food chain dose assessments. The data need to be converted to whole organism values to be useful in wildlife dose assessments. Knowledge on tissue to whole organism conversion factors could be acquired by one or more of the following methods: • review and analysis of existing site-specific data to reconstruct whole organisms from individual tissues using a mass balance approach • sampling and radionuclide measurements on the individual tissues comprising whole organisms • review and analysis of international databases and publications • use of surrogate organism and analogue element approaches to fill knowledge gaps.	SSB

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME

KKN No.	ER Link	Category	Title	Questions	Description	Responsibility (SSB/ERA/BOTH)
				RAD6D. What are the dose-effect relationships for wildlife represented by the representative organism groups?	The potential radiation risk to wildlife can be evaluated by comparing whole organism dose rates to environmental reference levels, which generally represent the dose rates at which radiation effects in organisms may begin to occur. Environmental reference levels derived by international bodies are currently used within the rehabilitation standard for radiation protection of the environment. If needed, dose-effect relationships for specific organism groups could be derived by one or more of the following methods: • laboratory studies within which aquatic and terrestrial organisms are chronically exposed to known activities of radionuclides and the effects on key biological endpoints (i.e. mortality, morbidity, reproduction and genetic mutations) observed • review of international databases (e.g. FREDERICA) and publications.	*Removed May 2020*
				RAD6E. What is the sensitivity of model parameters on the assessed radiation doses to wildlife?	Radiation dose modelling for wildlife uses a large number of parameters. The potential variability in parameter values used in the modelling can cause variability in the estimate of the dose to wildlife. Sensitivity analysis is a standard method that can be used to identify key parameters causing variability in modelling results. Understanding the variability in dose modelling results due to each input parameter is important so that research to acquire additional site-specific knowledge (if needed) can be appropriately prioritised and targeted.	ERA
RAD7	Human and ecosystem health	Receptor	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?	The pathways through which the public can be exposed to radiation due to the rehabilitated site are: • inhalation of radon progeny and radionuclides in dust • ingestion of bush foods and drinking water • external gamma The statutory limit on radiation dose to the public applies to the dose above natural background from all sources and exposure pathways summed. The assessment of radiation dose to the public due to the rehabilitated site requires an analysis of each exposure pathway for a clearly defined scenario of future land use. Parameterisation of exposure pathways can be made using existing knowledge and that acquired under RAD1A, RAD2A, RAD3A, RAD3B, RAD3C, RAD4A, RAD4B, RAD4C and RAD5A. Knowledge on future land use to develop a quantitative scenario against which radiation doses can be assessed can potentially be acquired by : • consultation with traditional owners • review of the literature or other records for information on historic use of the area	ERA

HEALTH IMPACTS OF RADIATION AND CONTAMINANTS REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				RAD7B. What is the sensitivity of model parameters on the assessed doses to the public?	Radiation dose modelling uses a large number of parameters to estimate doses to the public. The potential variability in parameter values used in the modelling can cause variability in the estimate of the dose. Sensitivity analysis is a standard method that can be used to identify key parameters causing variability in modelling results. Understanding the potential variability in the estimated dose due to each input parameter is important so that research to acquire additional site-specific knowledge (if needed) can be appropriately prioritised and targeted.	ERA
RAD8	Ecosystem health	Receptor	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?	Wildlife may drink water from waterbodies affected by the mine but their intake profile from these sources is not aligned with the models of intake on which livestock drinking water guidelines are based (e.g. infrequent, occasional use versus longer-term frequent use). Livestock drinking guidelines are probably not appropriate for small wildlife or taxa such as reptiles. An assessment of the risks associated with both chronic and acute impacts to all large and small terrestrial wildlife needs to take into account how much of an animal's consumption is likely to come from poor quality sources associated with the rehabilitated site. This information will determine if specific water quality closure criteria are required to protect large and small terrestrial wildlife.	ERA
RAD9	Human health	Receptor	RAD9. Impacts of contaminants on human health	RAD9A. What are the contaminants of potential concern to human health from the rehabilitated site?	Identification of the COPCs that may be elevated in soil (e.g. landform and LAAs) or water (e.g. creeks and billabongs) is a key first step in assessing potential risks to human health. A screening approach to identify those COPCs with higher toxicity (from relevant drinking water guidelines) and which may also be present in the environment due to the rehabilitated site should be undertaken. This will inform whether closure criteria for human health are required.	ERA
				RAD9B. What are the concentration factors for contaminants in bush foods?	Human food-chain assessments of COPC exposure use concentration factors to quantify transfer from the environment (e.g. soil and water) to food items. This is particularly the case for prospective assessments, where exposure estimates are made from predicted soil or water COPC concentrations using concentration factors.	SSB
				RAD9C. What are the concentrations of contaminants in drinking water sources?	Dietary exposure to COPCs in drinking water will be proportional to the COPC concentrations in the water and the amount consumed.	ERA
				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 total dietary intake of each COPC needs to be assessed and compared to relevant guideline values to determine the acceptability of the exposure in a human health context.	ERA

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
ESR1	Ecosystem similarity	Ecosystem similarity	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?	Baseline information on terrestrial vegetation composition and structure at scales that adequately capture and explain heterogeneity in natural ecosystems is required. This information, historical or new, will be used in the development of closure criteria and to assess whether vegetation growing on the rehabilitated site is similar to reference sites observed in non-mine disturbed ecosystems in adjacent areas. Examples of compositional and structural characteristics of vegetation include species abundance, and density, number of species, size class distribution of trees and shrubs, vegetation strata (e.g. canopy or ground cover) and hollow abundance. Such information would ideally be based on large-scale survey methods (e.g. remote sensing) that will better capture the spatial and temporal variation than the historical smaller scale ground-based surveys. Accompanying environmental measurements are also required in order to identify factors accounting for the variations in vegetation. Identifying factors responsible for observed ecological patterns may assist in revegetation planning and establishment.	SSB
				ESR1B. Which indicators of similarity should be used to assess revegetation success?	The proposed vegetation similarity indicators have been drawn from the National Restoration Standards (Standards Reference Group SERA 2016) and include species composition, number of species, vegetation strata, tree/shrub class size distribution and vegetation distribution ('naturalness'). Closure criteria will be developed for these indicators and applied for each of these to assess the degree of similarity between vegetation growing on the rehabilitated site and that observed in non-mine disturbed ecosystems in adjacent areas. Indicators will be developed for both understorey and overstorey vegetation.	*Closed out November 2019*
				ESR1C. What values should be prescribed to each indicator of similarity to demonstrate revegetation success?	Once appropriate similarity indicators have been identified, specific value(s) for each need to be established that account for the expected range in natural spatial and temporal variability (i.e. avoidance of single numbers). This information will be used in the development of closure criteria and to assess whether vegetation growing on the rehabilitated site is progressing acceptably towards that observed in non-mine disturbed ecosystems in adjacent areas, the extent of such progress, and whether it has achieved an agreed level of similarity. The indicator values may vary according to the spatial scale at which they are derived and this dependence needs to be understood for future applications.	BOTH

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
ESR2	Ecosystem similarity	Ecosystem similarity	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?	Much baseline information on terrestrial fauna community structure in natural ecosystems adjacent to the mine site is already available, but additional information may be required. This reference information will be used to characterise fauna communities in natural ecosystems adjacent to the mine site, the extent of variation in the fauna and the factors that influence such variation. This context will be used in the development of faunal community closure criteria and to measure and interpret progress of fauna communities in the rehabilitated site towards those in adjacent suitable reference locations. For vertebrates, such information would ideally be based on contemporary fauna survey methods (e.g. camera trapping) that will better capture the spatial and temporal variation than the historical survey techniques.	BOTH
				ESR2B. What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?	The establishment of vegetation does not guarantee that suitable habitats for terrestrial fauna colonisation are available, particularly early in the ecosystem restoration process. Information is needed on the time that it may take before the rehabilitated site can be expected to naturally develop key fauna habitat features (e.g. tree hollows); if this is likely to be many years, options for habitat enhancements will need to be examined (e.g. nesting boxes, rock piles).	BOTH
				ESR2C. What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?	The risk that introduced animals could impede the re-establishment of fauna and the long-term sustainability of faunal communities needs to be assessed. This is likely to be particularly important early in the ecosystem restoration process, when the rehabilitated landscape could provide optimal habitat for introduced animals (e.g. ideal conditions for predators) and before suitable habitats for native fauna are established (e.g. fallen logs, tree hollows for refuge). This information will inform the need for mitigation measures, such as active management of introduced animals and/or establishment of habitat enhancements that favour native fauna.	BOTH
ESR3	Ecosystem similarity	Ecosystem similarity	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)?	The ability to establish the full range (or an appropriate complement) of native vegetation species from the reference ecosystem needs to be demonstrated. While this has been shown in initial trials for over 35 framework species, there is far less available evidence for the successful establishment of a diverse suite of understorey species. This information will be sought from the literature, and from ongoing research including trials on the Ranger Trial Landform and, in future, on the Pit 1 rehabilitated site. The information will provide necessary assurance that it is possible to establish vegetation communities on the rehabilitated site that will be similar to adjacent non-mine disturbed ecosystems.	ERA

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
ESR4	Ecosystem similarity	Ecosystem similarity	ESR4. Determine the incidence and abundance of introduced species in natural ecosystems adjacent to the mine site, including Kakadu National Park, and their potential to impact on the successful rehabilitation of Ranger mine	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?	Information on the composition and abundance of introduced species in areas adjacent to the rehabilitated site is required, both to assess the risk that these ecological stressors may pose to successful ecosystem restoration and to demonstrate that their presence on the site is not higher than in adjacent to areas. This information will be required throughout the restoration process to inform trigger points for implementing mitigation strategies (e.g. early detection of pests or weeds may allow for ready cost-effective eradications). Further research may be required to inform management options that (i) result in control of pests and weeds but (ii) do not prevent the successful restoration of native species and communities.	SSB
ESR5	Long term viability	Ecosystem Sustainability	ESR5. Develop a restoration trajectory for Ranger mine	ESR5A. What are the key sustainability indicators that should be used to measure restoration success?	The proposed indicators of long-term viability and ecosystem function (sustainability) of the restored ecosystem have been drawn from the National Restoration Standards (e.g. Standards Reference Group SERA 2016). These indicators include recruitment of revegetation, nutrient cycling, faunal usage, habitat availability, resilience to fire, extreme weather events, pests and diseases. Other attributes to be considered are external exchanges (e.g. habitat connectivity, physical conditions (e.g. nutrient availability), and absence of threats (e.g. weeds). This information will be used in the development of closure criteria and to assess whether ecosystems established on the rehabilitated site will be similar to those observed in natural non-mine disturbed ecosystems in adjacent areas.	BOTH
				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?	Restoration trajectories will be required to assess the achievement of closure criteria that are expected to be reached after a period of time (e.g. decades) from the initial establishment. The trajectory approach outlined in the National Ecological Restoration Standards is based on modelling of a desired and/or expected trajectory pathway, distinguishing the desired pathway from possible undesired states, and selecting points within the desired trajectory that represent milestones leading to agreed closure. This should be based on previous regional revegetation studies, either at Ranger or elsewhere, and response of the savanna ecosystems to disturbance. The model should also consider scenarios (e.g. fire and weeds) that capture key aspects of revegetation establishment and natural disturbances. This information should also be used to identify and plan for management of risks and should form the basis for design and assessment of monitoring programs and results.	BOTH

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH)**
ESR6	Long term viability	Ecosystem Sustainability	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?	Exposure of vegetation (both revegetation and existing native vegetation) to contaminants could occur from a number of sources on the rehabilitated site, such as waste rock, contaminated soils and groundwater. Integrated surface and groundwater modelling should identify areas of the rehabilitated site that may act as potential hotspots for increased concentrations of contaminants (see KKN WS1A), such as magnesium sulfate. The concentrations of contaminants available for uptake by terrestrial plants needs to be understood in order to assess whether there may be a risk to vegetation establishment and long term sustainability. For waste rock, which represents an unnatural substrate and plant medium, the assessment is conducted separately through KKN ESR7D.	BOTH
				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?	Contaminants and/or other stressors associated with the operation of Land Application Areas have altered and impaired the structure and health of vegetation. While the presence of multiple stressors confounds the ability to isolate specific causes of impaired plant health, the identification of plants tolerant to multiple stressors (including contaminants) may assist in revegetation planning and establishment (e.g. selection of species best suited to locations of contaminant build-up and/or water-logging) and in assessing plant health, over the longer-term).	ERA
ESR7	Long term viability	Ecosystem sustainability	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?	There are likely to be substantial differences between waste rock and natural soils in nutrient concentrations (e.g. P, N, Mg, exchangeable K and S) and rhizobia/mycorrhizal fungi available to plants. Combined with a potential lag in the timing at which effective nutrient cycling processes develop in the waste rock, nutrient deficiency may impair the establishment and sustainability of healthy vegetation communities. Targeted monitoring of processes, including soil available nutrient levels and plant nutrient status in established vegetation, compared to levels in soils and plants in reference sites, can provide evidence (i.e. empirical data) of progression to a self-sustaining nutrient cycle. This information will assist in determining whether an active nutrient maintenance regime may be required for a period of time following rehabilitation.	ERA

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
				ESR7B. Will sufficient plant available water be available in the final landform to support a mature vegetation community?	Plant available water in waste rock substrate may be limited. Studies on the trial landform have demonstrated water holding capacity of the landform is comparable to the natural reference system. Despite uncertainties in measurements and modelling, the trial landform studies indicate that the waste rock of 4 m thickness may support mature vegetation similar to adjacent areas over short dry seasons but possibly not during longer dry seasons. Further information is needed to determine the availability of water in the waste rock substrate, such as: • influence of waste rock depth on water holding capacity • water availability at greater depths (e.g. 4-8 m) and ability of plants to access this (e.g. maximum rooting depths) • influence of waste rock particle size and pore spaces • contribution of understorey to evapotranspiration rates • uncertainty associated with water balance models and sensitivity of input parameters. These factors will need to take into account location (e.g. elevation and aspect) on the final landform.	ERA
				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?	There is uncertainty about whether key ecological processes required to support sustainable vegetation communities will occur on the rehabilitated landform. It has also been assumed that rapid weathering of waste rock will occur to form rudimentary soil materials but there is little information to demonstrate that this will be applicable across the rehabilitated site (i.e. all types of waste rock materials). This information can be used to determine whether specific mitigations may be needed (e.g. addition of fines, mulch).	ERA
				ESR7D. Are there any other properties of the rehabilitated site that could be attributed to any observed impairment of ecosystem establishment and sustainability, including vegetation and key functional groups of soil fauna?	Apart from plant available water and nutrients, other factors need to be identified in the event that ecosystem establishment and sustainability are impaired. These factors may include, for example, sub-optimal light conditions for tubestock or water-logging of the landform at initial planting.	ERA

ECOSYSTEM RESTORATION REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	**Responsibility (SSB/ERA/BOTH**
ESR8	Long term viability	Ecosystem Sustainability	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?	Fire can present a significant risk to long term sustainability of restored ecosystems. The current strategy is to exclude fire from revegetation areas for the first 5-7 years following initial planting, followed by the gradual introduction of fire to rehabilitated areas. With the large spatial extent of fires in the region, management of fires is a cross-jurisdictional issue and needs to be managed for ecosystem restoration success at multiple scales. More specific information is needed to determine the most appropriate fire management regime over time, from initial introduction to a regime that is similar to surrounding areas, including consideration of sensitive plant and animal species. Recent research in Kakadu National Park that modelled the effects of fire regimes on overstorey population dynamics would be particularly relevant to this knowledge need.	ERA

CROSS-THEME REHABILITATION THEME						
KKN No.	**ER Link**	**Category**	**Title**	**Questions**	**Description**	
CT1	Biodiversity and Ecosystem Health	Risk	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?	It is important to assess cumulative risk as examining risks individually does not address the interaction between risks and their iterative effects. An integrated conceptual model will capture the interactions between multiple risks (e.g. landform stability, revegetation and contaminant exposure) and assessment endpoints (receptors). The integrated model and assessment will be continually tested and improved as part of best practice and include outputs from all other KKNs.	BOTH
CT2	World Heritage values	Heritage Values	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?	There are areas within the Ranger Project Area that exhibit World Heritage Values for which Kakadu is listed, and documentation of these may assist decision-makers in incorporating the site into Kakadu National Park once closure has been achieved.	BOTH

ERA Energy Resources of Australia Ltd

6 Best practicable technology

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Cover photograph: Ranger Mine (August 2020)

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APPENDICES

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
ARRTC	Alligator Rivers Region Technical Committee
BC	Brine Concentrator
BPT	Best Practicable Technology
CCWG	Closure Criteria Working Group
CRF	Cemented Rock Fill
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DPIR	Department of Primary Industry and Resources (now DITT)
EDR	Electro Dialysis Reversal
ER	Environmental Requirements
ERA	Energy Resources of Australia
HDS	High Density Sludge
ITWC	Integrated Tailings and Water Closure (Prefeasibility assessment)
MNES	Matters of National Environmental Significance
MTC	Minesite Technical Committee
NP	National Park
OHS	Occupational Health and Safety
RL	Relative Level
RO	Reverse Osmosis

Abbreviation/ Acronym	Description
RPA	Ranger Project Area
SSB	Supervising Scientific Branch
TSF	Tailings Storage Facility
VSEP	Vibratory Shear Enhanced Processing
WTP	Water Treatment Plant

6 BEST PRACTICABLE TECHNOLOGY

6.1 Introduction

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 Environmental Requirements (ERs) within Section 3 specify that:

> *12.1 All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT*
>
> *12.2 Where there is … agreement … that the primary environmental objectives can be best achieved by … (an) action which is contrary to the Environmental Requirements … and which has been determined in accordance with BPT, that proposed action should be adopted*
>
> *12.3 All environmental matters not covered by these Environmental Requirements must be dealt with by the application of BPT.*

The definition of BPT in the ERs establishes a framework for assessment of currently available technology at any point during the operational and rehabilitation phases of mine life, rather than the ERs specifying particular technologies which may become obsolete (Supervising Scientist 2000).

A method to allow assessment of BPT was proposed by the Supervising Scientist Branch (SSB) and published in their 2000/2001 Annual Report (Supervising Scientist Division 2001). This has been historically used by Energy Resources of Australia Ltd (ERA) to support major proposals for amendment to the Ranger Authorisation.

The current ER definition of BPT and an explanation of each BPT clause is presented in Table 6-1.

Table 6-1: Explanation of relevant matters/criteria to be included in BPT assessment

Environmental Requirement Clause	**Explanation**
Annex A - 12.4 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 factors below 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 must be 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.

Environmental Requirement Clause	Explanation
(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 should be 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 should be 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, on Aboriginal land surrounded by Kakadu National Park (NP), remote from high population density cities. Hence the level of protection required for the environment and community is very high and the technology chosen should be 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 should be reviewed periodically to determine whether or not recent advances have been made that would result in enhanced environmental protection. Technology installed at the Ranger Mine in accordance with BPT should be reasonably allowed to fulfil its serviceable life with due consideration given to the advances in technology and the amount of serviceable life expended.
(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 must be incorporated into BPT assessment. This includes where the introduction of new technology would 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.

Source: (Supervising Scientist Division 2001)

The determination of BPT for the closure of Ranger Mine was primarily undertaken during the 2011/12 Integrated Tailings, Water and Closure Prefeasibility Study (ITWC PFS) (Johnston and Iles 2013), included as Appendix 6.1.

Sections 6.2.9 and 6.2.10 present the outcomes of the ITWC study. The outcomes of the supplementary BPT assessment for additional tailings treatments conducted in September 2016 are provided in Section 6.2.11.

Several rehabilitation/closure activities were identified for standalone assessment via the Minesite Technical Committee (MTC). BPT assessments will accompany each application submitted to the MTC for assessment, as per the provisions outlined in the Ranger Authorisation. A summary of those submitted to date are provided in Section 6.3.

6.1.1 BPT assessment criteria

Early BPT assessments for the Ranger Mine ranked technology alternatives against the criteria presented in Section 6.1. For the ITWC PFS, ERA ensured that the issue of BPT was considered from the outset by all members of the study team.

Updates were presented to stakeholders at various stages throughout the study on progress of the assessment of BPT. Details of these meetings are included in the stakeholder engagement register presented as Appendix 4.1 and included nine presentations to the Alligator Rivers Region Technical Committee (ARRTC) between 2011 and 2016 and a presentation to the Closure Criteria Working Group (CCWG) in October 2016.

BPT has been a principal driver of the project and adoption of this procedure ensured that proposals emerging from the prefeasibility study would be demonstrably consistent with the requirements of BPT.

In considering the best procedure for ensuring the BPT concept became a driver for the project, as well as an assessment tool at its completion, ERA has developed a more detailed assessment matrix than had been applied in the past.

The 25 criteria that were used in the ITWC PFS and subsequent BPT assessments to rank technology alternatives for closure 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 values of Kakadu NP?
- Whilst 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 being considered 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 and how robust is it in response to variations in feed and consumables? Effective, highly robust options would rank highly.
- Does the standard of environmental protection achieved by the option meet the highest standards achieved in uranium mining elsewhere in the world?
- Does the capital cost of the option ensure its adoption would contribute significantly to the overall project value?
- How robust is the option with respect to variations in rainfall and requirements on the timing of mill closure?

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 ensure its continued viability?
- Is the process operationally reliable? That is, will it have high availability, or will it be sensitive to the failure of single plant items?
- Would the option be difficult to maintain?
- Would the operating costs associated with the option have a large impact on overall project value?

Rehabilitation and closure:

- Would adoption of the option ensure the establishment of a revegetated site using local native species with a low maintenance regime?
- Would the option ensure the establishment of 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?
- Would the option enable the establishment of stable radiological conditions on the rehabilitated site that will ensure that health risks to members of the public meet Australian standards and are as low as reasonably achievable?
- Would adoption of the option ensure agreed water quality criteria are met in creeks draining the mine site and appropriate ecosystem rehabilitation standards are achieved for water bodies on the rehabilitated landform?

- Would adoption of the option ensure all tailings produced at the Ranger site are physically isolated from the environment for a period of 10,000 years and any contaminants arising from the tailings will not result in any detrimental environmental impact for at least 10,000 years?
- Would adoption of the option extend closure beyond Traditional Owner expectations and, in particular, beyond the requirements specified in the section 41 Authority?

Constructability:

- Would adoption of the option introduce significant health and safety risks to the workforce during the project construction phase?
- Will the option give rise to the need for significant land disturbance during construction, significant off-site environmental impact or require construction work near sites of cultural significance?
- Would adoption of the option lead to high construction complexity through difficult scheduling, complex logistics or significant manpower requirements?

The new criteria remain consistent with the original six broad matters in the formal definition of BPT.

Implicit within the Traditional Owner Culture and Heritage, Protection of People and the Environment and Rehabilitation and Closure criteria is an assessment of the option against

- the Ranger Mine closure criteria themes (Section 8)
- the various Matters of National Environmental Significance (MNES) protected by the controlling provisions of Part 3 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) which include the World Heritage living cultural and environmental values and the Ramsar wetland values

6.1.2 BPT ranking, weighting and scoring

The BPT assessments incorporate a 5-level technology ranking system where a ranking of three indicates that the option meets industry standards (Table 6-2).

The final BPT score for each technology option is calculated using the rank of the option against each of the criteria.2 The BPT score essentially summarises performance of the option against current international performance standards. The score for an option which achieves the highest rating for all criteria would be 100 whilst an option that meets standards for all

2 BPT score = $100\Sigma_{i=1,N} (s_i - 3)/(N.2)$ where si is the score for criterion i and N is the total number of criteria for which a score was recorded. Only criteria for which a score was recorded (rather than a UTE or NA result) were included in the summation process.

criteria would score 0 and an option that achieves the lowest rating for all criteria would score -100.

In addition, two types of show-stopper results were possible. A hard show-stopper was 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 initial assessment demonstrated that adoption of an option could result in intrusion on a sacred site. A soft show-stopper would be 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 issues 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.

Table 6-2: BPT technology and ranking system

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.
UTE	Unable-to-evaluate (UTE) - insufficient information available to allocate a rank to a criterion.
NA	Not applicable (NA) - the criterion was not applicable to the option being considered.

6.2 Completed closure-related BPT assessments

6.2.1 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 continues 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 is 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 has 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 does not require a BPT assessment. However, the reduction in crest height to a level that enables the completion of dredging presents 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 therefore 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 6-3).

Most of these 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 negate 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 justify the selection of option A2 over option A3.

The BPT assessment matrix for TSF North Notch Stage 3 is included in Appendix 6.1.

Table 6-3 BPT assessment options and overall ranks for North Notch Stage 3

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.	0.0
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.	0.0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0.0
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-stopped
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

6.2.2 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 Tailings Storage Facility (TSF) and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material in situ in versus disposal in Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 is required to consider this subfloor material. The deconstruction of the TSF does not occur until 2024 and, as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works. In order to finalise the Pit 3 capping design, ERA needed to complete an assessment to determine if Pit 3 was a viable option for the final storage of TSF subfloor material and, subsequently, gain stakeholder acceptance of this assessment. Based on the outcomes of a BPT assessment, an application was submitted to the Director of Mining Operations, DPIR (now DITT) for approval in March 2020. The application updated in June 2020 following stakeholder feedback and the DPIR (now 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 6-4). Option 1 was developed as a "worst-case" scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, at this stage, 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 6-4 BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	**Option description**	**Overall Rank**
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
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	Initial show-stopper

Option	Option description	Overall Rank
	secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	
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 comparatively evaluate 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 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.

Option 3a.1 (Pit 3, 2 m, secondary cap) was the highest rank of the Pit 3 transfer scenarios, second highest rank overall and resulted in the second lowest number of soft show-stoppers overall (4 out of 10). This option scored -17.6 and indicated it could meet or exceed current standards for Revegetation, Cultural Heritage, Environmental Protection, and Erosion aspects. However, soft show-stoppers were identified for Living Culture, Ecosystems & Natural World Heritage, Community Health and Safety, and Radiation (Closure). This option scored equal lowest for Water (“1”) as the solute egress modelling outputs indicated a significant magnesium loading to the environment. All other Pit 3 options received overall ranks of less than -20.

The options 3a.2, 3a.4, 3b.1 and 3b.2 were hard show-stopped based on initial assessment indicating that these would not be practical approaches.

The BPT assessment matrix for TSF subfloor material management is included in Appendix 6.1.

6.2.3 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 overall rankings (31 – 44.4) and differed marginally in the weighting of individual criteria namely robustness, CAPEX, schedule and construction complexity (Table 6-5).

Table 6-5 BPT Overall ranking for HDS recommissioning and release

Option	Option description	Overall rank
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

Option	Option description	Overall rank
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.

The BPT assessment matrix for HDS plant recommissioning is included in Appendix 6.1.

6.2.4 Subaqueous tailings deposition into Pit 3

Report: *Application Pit 3 Tailings Deposition, 2019*

In preparation for cessation of mining and processing activities at Ranger Mine an assessment of 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
- accelerate backfilling with consolidated tailings (ERA, Alan Irving & Associates 2019).

Following detailed assessment of various subaqueous deposition configurations and multi-spigotted, subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 (GHD 2019) to assess the range of potentially viable deposition options. To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria (Section 6.1.1).This resulted in an overall ranking calculated for each option (Table 6-6).

Table 6-6 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 the majority 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. This would negatively impact on the closure schedule and result in ERA unlikely to meet the closure date of January 2026.

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 depostion from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected as this combination also facilitates achievement of the target completion date of 2026.

The BPT assessment matrix for tailings deposition options for Ranger Pit 3 is included in Appendix 6.1.

6.2.5 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 was 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 its 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)
- erosion and sediment control features have been refined based on conceptual designs developed in 2017

The DEM was also provided to the MTC for assessment and SSB feedback is included in the change application report (ERA 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework were developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works support ERAs continued backfilling of Pit 1 in preparation for initial tree planting of the Pit 1 landform surface scheduled to commence in early 2021.

An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the *Mining Management Act* (NT) and 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
- 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 (Section 6.2.5)

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 considered to be optimal. In particular, bulk backfilling of Pit 1 is nearly complete are there are no major competing alternatives for the bulk backfill methodology. The final landform design, originally described in 2006, continues to be revised based on changing stockpile material grades, volumes and locations. When refining the landform design, revisions are made with consideration of several goals:

- adherence to landform design criteria (general physical attributes)
- minimise disturbance outside of the existing disturbed area footprint
- reduction of the visual impact of the landform by eliminating the use of batter slopes
- general reduction in slope gradients, resulting in improved view-shed from Magela Creek
- minimise rehandling of material on closure
- consideration of material grades, volumes and their locality in the landscape at cessation of mining

Alongside these goals, as revision of the final landform construction occurs, requirements at the forefront of consideration are the need 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.

6.2.6 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 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 has 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 used to assess 27 options with potential to process the WTP brines. 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 take to an order of magnitude assessment level. A second, tier II, 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 tier II BPT assessment showed the Brine Squeezer (Figure 9-1) 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 have been used to inform a tier II assessment and revise the relevant criteria of the 2013 BPT assessment, using the same BPT options screening criteria and ranking system. 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 6-7) However, given the sensitivity of the ranking to minor variation in rankings for each category, the spread in scores across the three options was not considered material.

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 proposed plant, to be installed in the existing sand blast yard, comprises three trains, providing for 99 percent availability of two trains (1 standby/cleaning).

Table 6-7 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

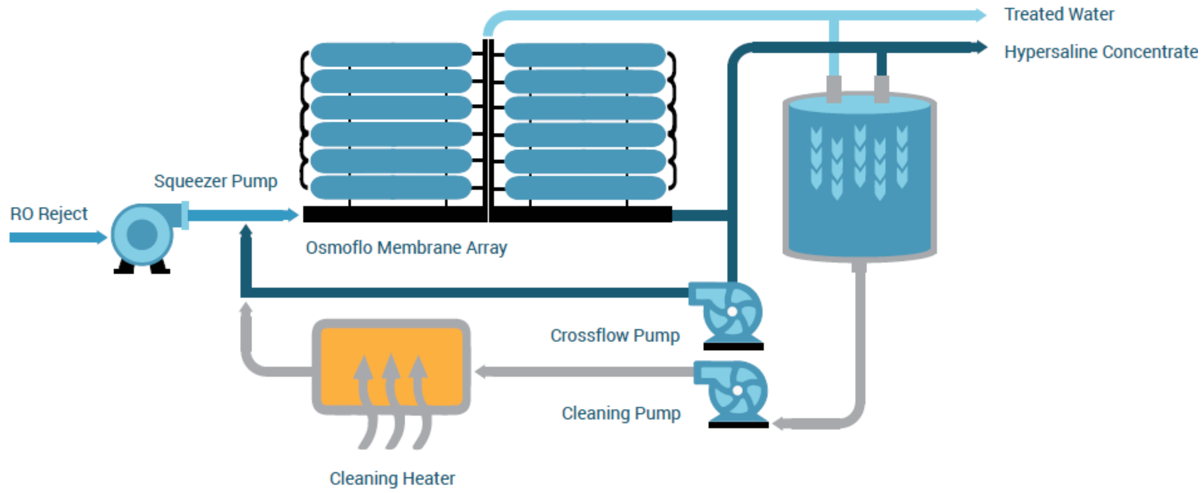

Figure 6-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

The Osmoflo Brine Squeezer has the capacity to reduce the WTP brine contribution to process water by 200 to 1,000 ML/year. Based on this, the installation and operation of the Brine Squeezer meets the 2017-18 Ranger Water Management Plan objectives three and four:

- minimise unnecessary additions to the pond water and process water inventories
- optimise pond and process water treatment, and disposal mechanisms

The outcome of the BPT assessments showed the Brine Squeezer to be the highest ranking option, leading to its selection for acquisition, construction and commissioning of a Brine Squeezer to treat WTP brines. Commissioning of the Brine Squeezer commenced in June 2019, with the plant expected to be fully available for the 2019/2020 wet season.

The BPT assessment matrix for brine minimisation is included in Appendix 6.1.

6.2.7 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 blackjack 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 Environmental Requirements. 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 6-8).

Table 6-8 Black jack disposal options and best practicable technology assessment summary

Option	Option description	Overall rank
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

According the results of this BPT assessment, Tellus' National Geological Repository (Option A1) received the highest overall rank, with 50 points. The second highest was Scholer's Waste Oil Incinerator, total ranking of 23.8 points. To further support Scholer's Waste Oil Incinerator (Option A2), ERA will need to complete an air quality study and confirm that the incinerator will include environmental air pollutant control mechanisms – e.g. baghouse, scrubber, etc.

Although Tellus ranked higher, at the time of the assessment it was yet to receive final approval and licencing to accept low-level radioactive waste. In April 2019, local government approval was secured to develop the facility following approval by the Commonwealth government in January 2019. Tellus has completed Stage 1: Enabling works and Stage 2A: Installation of a permanent village. The project is on track for Stage 2B: Balance of works by August 2020.

6.2.8 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 6-2) continued until December 2014 whilst simultaneously submissions were made for the construction of the R3D underground mine. 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.

A BPT assessment of the closure involved a 5-level technology ranking system, where a ranking of three meets industry standards. A final BPT score for each technology option was calculated through summing an assessment of the technology against applicable BPT criteria.

The primary objective of the assessment was to determine which combination of options constituted BPT for 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
- 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 takes into consideration ground conditions and potential heavy mobile equipment limitations (i.e. gradient, manoeuvrability, etc). The assessed option and BPT outcomes are presented in Table 6-9.

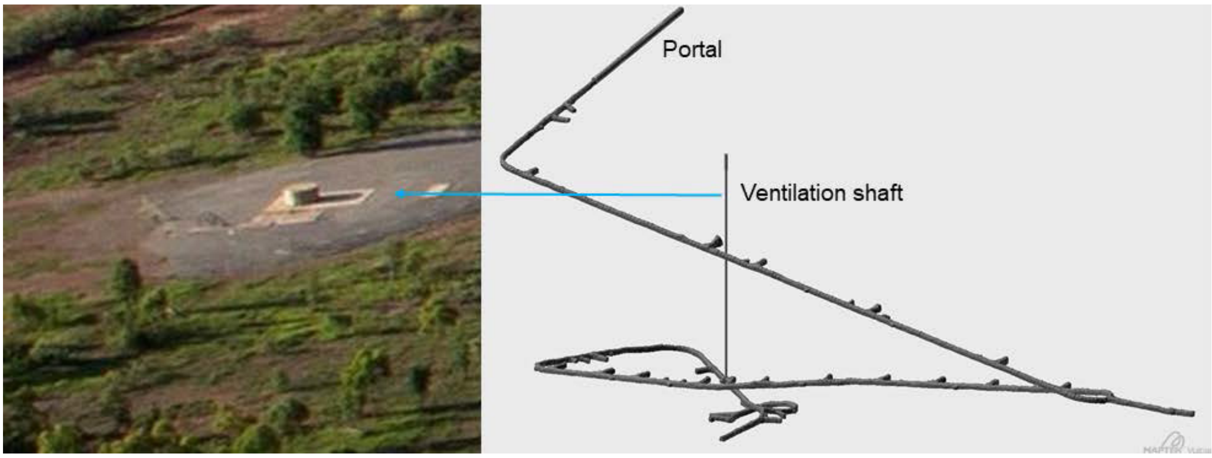

Figure 6-2: Aerial view of the ventilation shaft and underground infrastructure

6.2.8.1 Decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped on the basis of 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, fitness for purpose, whilst option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7.

6.2.8.2 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 in 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 therefore, ranked as the preferred option for portal closure.

Table 6-9: 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

Option	Option Description	Overall Rank
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

6.2.8.3 Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped on the basis of 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. However, for its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, 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.

6.2.8.4 Outcome

On the basis of the BPT assessment, preliminary tier 2 risk assessment and supporting technical studies, ERA propose a staged decommissioning and closure of the R3D exploration decline described in the '*Ranger 3 Deeps exploration decline decommissioning plan*' (Murphy 2018). The closure activities include the care and maintenance activities before final closure. Final closure includes backfilling the ventilation shaft, allowing the decline to flood to below the weathered zone, backfilling the decline above the weathered zone and dismantling and cutting the multi-plate steel tunnel down to ground level and covering with waste rock to blend with the final landform.

The BPT assessment matrix for R3D is included in Appendix 6.1.

6.2.9 Integrated tailings, water and closure prefeasibility study one technical options assessment

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study: 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.

To assess the available technical options, separate BPT workshops were conducted to assess the following project components:

- tailings reclamation, transfer, treatment and deposition within Pit 3
- process water salt management and disposal within Pit 3, and
- final landform construction, revegetation and ecosystem reconstruction.

6.2.9.1 Tailings management

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described below, along with the key conclusions as a result of rating each option.

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 6-10).

Table 6-10: 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 assessments. 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 is 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 include high costs to construct, install and operate, and the maintenance requirements would be high. 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 as an option to potentially reduce dispersion of solutes in groundwater if required[3], 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 both would be sensitive to rainfall (a dry pit would be required).

Conclusions from rating options for tailings

The principal conclusions arising from the BPT workshop on tailings management were:

- dredging is the preferred tailings reclamation method

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[3] 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.

- cementation is not currently considered viable as a treatment method
- 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.

6.2.9.2 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 and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table 6-11).

Table 6-11: 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 OHS 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 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 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 on the brine injection option.

6.2.9.3 Final landform construction, revegetation and ecosystem rehabilitation

The assessment process adopted in the BPT workshop on landform construction, revegetation and ecosystem reconstruction was different to that adopted for tailings management and salt treatment and disposal. The landform reconstruction and revegetation program has gone through significant options analysis and refinement over several years and there are no longer major competing alternatives for their implementation.

Rather than assessing options and completing the ranking; each of the current plans for landform construction, revegetation and ecosystem reconstruction were reviewed against each criteria to identify possible options for improvement and to record any uncertainties.

Focus was given to closure schedule to determine the nature of any risks to completion of rehabilitation by 2026 as required under the section 41 Authority.

The BPT assessment matrix for tailings treatment is included in Appendix 6.1.

6.2.10 Prefeasibility study two: closure strategy and plan

After a thorough options review and the application of a detailed BPT assessment, available technical options were narrowed down to core technical options which relate to tailings management (dredged tailings with thickened tailings transferred to Pit 3 vs dredged tailings with thickened and filtered tailings transferred to Pit 3) and salt management (brine injection vs crystallisation). In all cases the option for transfer of tailings from the TSF to Pit 3 is by dredging, thickening then pumping.

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
- 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 6-12.

Table 6-12: 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

Strategy	Brine strategy	Tailings strategy	Milling end
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

6.2.10.1 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 which 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 6-3.

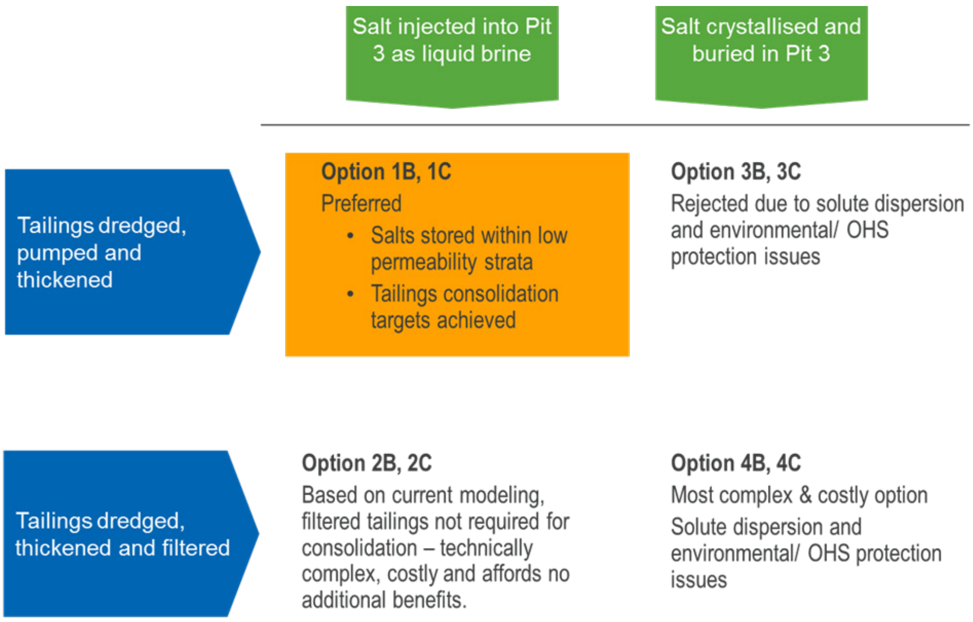

Figure 6-3: Outcomes of the stage 1 assessment

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.

6.2.10.2 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 if an extension beyond the 2026 closure date could be negotiated. Table 6-13 lists the options assessed in Stage 2.

Table 6-13: 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 on the basis of 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
- schedule: both extended options scored lower than the primary options under the schedule criterion

6.2.11 Supplementary integrated tailings, water and closure prefeasibility study BPT assessment

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.

The initial PFS 1 BPT assessment for tailings treatment included thickening as part of all options assessed. At the time of the ITWC PFS thickening was considered to be the base case for two reasons:

- to remove process water from the tailings prior to pumping over to Pit 3, thereby reducing the costs of pumping this water back to the TSF
- to assist in achieving final consolidation targets in Pit 3, to allow for backfill and completion of rehabilitation by 2026 as required under the section 41 Authority

Further test work, modelling and analysis undertaken since 2012 and the effective consolidation outcomes currently being achieved in Pit 1 has indicated thickening may not be required. To determine if there were options without thickening that could be BPT; a supplementary workshop was conducted on 8 September 2016.

The primary additional treatments considered in the assessment were scenarios associated with unthickened tailings deposition into Pit 3, including:

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

Tailings treatments brought forward from the previous ITWC BPT assessments include:

- thickened tailings (A1)

- thickened and filtered tailings (A7)
- thickened, filtered and cemented tailings (A8)

A summary description of each option is provided later in this section.

Several key assumptions were identified during the assessment, which were taken into consideration when ranking individual strategies, including:

- processing to January 2021
- any additional process water treatment required would be in the form of an additional Brine Concentrator or expansion of the existing infrastructure
- use of lime as the preferred neutralisation option

6.2.11.1 Thickened tailings (A1)

The ITWC treatment options analysis assumed all tailings would be thickened as a base case. Under this option, tailings are to be reclaimed from the TSF by dredging and dewatered in a thickener prior to pumping the thickened tailings to the mined-out Pit 3. A schematic of the thickening option is presented as Figure 6-4.

The rationale was to reduce the volume of tailings deposited and thus the rate of rise, reducing time taken for consolidation and reduce the pumping costs associated with process water return from Pit 3. The plan was to implement thickening 12 months after the commencement of dredging.

The Ranger Mine mill thickens the tailings stream to approximately 50 weight percent solids prior to deposition in Pit 3, whilst the proposed TSF reclamation dredge will progressively reclaim the subaqueous tailings producing a 28 weight percent solids stream. Thickening prior to transfer to Pit 3 will increase the solids content to approximately 60 weight percent.

Consolidation modelling has shown the thickened tailings will achieve consolidation targets.

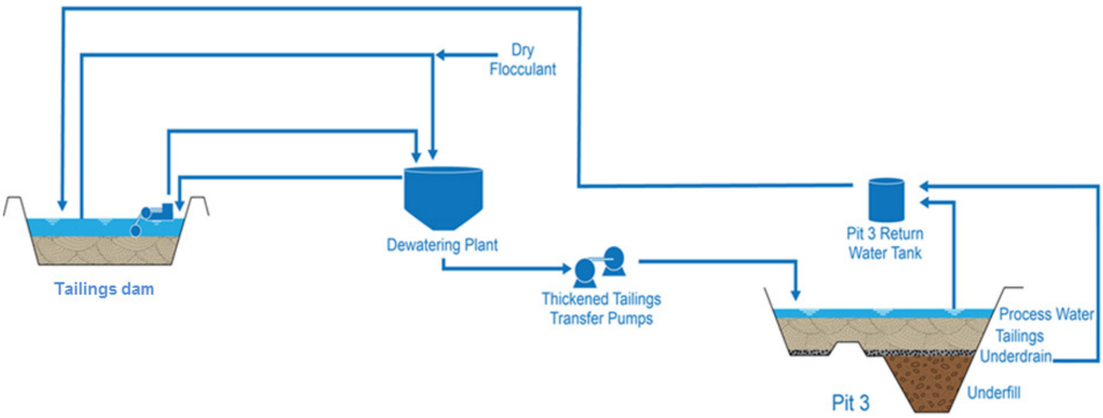

Figure 6-4: Thickened tailings flow sheet

6.2.11.2 Unthickened tailings (A2)

The unthickened tailings strategy involves the direct transfer of dredged tailings from the TSF to Pit 3, where it is allowed to naturally consolidate over time.

Dredged tailings have a solids density of approximately 28 weight percent. Following deposition in Pit 3, the tailings undergo sedimentation and release water and achieve an initial settled density. Sedimentation testing has shown that unthickened mill tailings discharged at 28 percent solids rapidly settle to about 55 percent solids whilst thickened mill tailings discharged at 50 percent solids settle to 56 percent solids; indicating that unthickened tailings may be a viable option.

Consolidation modelling was conducted to determine if any unthickened options would be able to achieve the consolidation targets by the schedule date of January 2026. Modelling demonstrated that consolidation could not be achieved without prefabricated vertical drains (wicks) to assist with the consolidation.

Based on this result, the option of unthickened tailings without further treatment was hard show-stopped.

6.2.11.3 Unthickened tailings with wicks (A3)

Consolidation modelling demonstrated the unthickened tailings option with the installation of wicks can achieve the required amount of consolidation by 2026.

Pit 1 has provided a working demonstration of the effectiveness of tailings dewatering and consolidation via the installation of prefabricated vertical wick drains. In 2012, 7,554 wicks were installed into the pit to assist with dewatering, ahead of capping and rehabilitation. The wicks were installed within the top 40 m of the tailings mass to dewater the upper level of the tailings and promote tailings consolidation, thus establishing a stable surface upon which to commence bulk backfill activities. A pre-load waste rock layer is placed over the tailings mass, designed to activate the vertical wicks by compressing the tailings and forcing the water in the pit to travel to the surface via the wicks and natural drainage patterns to decant towers located at the lowest points in the pit. Pumps, located in the decant towers, transfer the process water back to the process water system for treatment. Current consolidation modelling predicts that over 99 percent of the pore water in Pit 1 will be expressed within the first six years of consolidation. The installation of wicks in Pit 1 has proven to be an effective alternative technology to thickening and/or thickening with additional treatments.

6.2.11.4 Unthickened tailings with extended water treatment (A4)

This strategy is a variation on strategy A2 but includes extended water treatment past 2026, by way of construction and commissioning of an additional BC or expansion of the existing plant. Under this option, the landform over Pit 3 is surcharged and the tailings are able to complete consolidation. Process water expressed during consolidation would be captured and treated. This option is similar to the 5B and 5C in the ITWC PFS2 stage 2 BPT assessment.

The need for a second BC or expansion of the existing BC was based on the expected operational life span of the existing BC, not the volume requiring treatment.

6.2.11.5 Unthickened tailings, with inline agglomeration and wicks (A5)

Inline agglomeration involves the dosing of tailings with a flocculent, (i.e. a synthetic water-soluble polymer or aqueous liquid with dispersed particulate solids) that potentially reduces the dry density of tailings in the pit after consolidation (Figure 6-5).

A feasibility study was conducted in 2014 to quantify the costs and risks associated with inline agglomeration. The option was proposed as an alternative to the construction and operation of a high compression thickener. The feasibility study in 2014 followed laboratory scale testing (i.e. a scoping study) undertaken in May 2013, which demonstrated the viability of depositing flocculated tailings just above the floor of Pit 3 from a launder or pipe laid along the pit's haulage ramp. The study estimated that inline agglomeration could potentially reduce the tailings transfer costs, process infrastructure, flow sheet complexity and the risks associated with thickening the tailings from the TSF and managing foreign objects. However, if this option were to be adopted, the consolidation target would not be achieved without the installation of wicks.

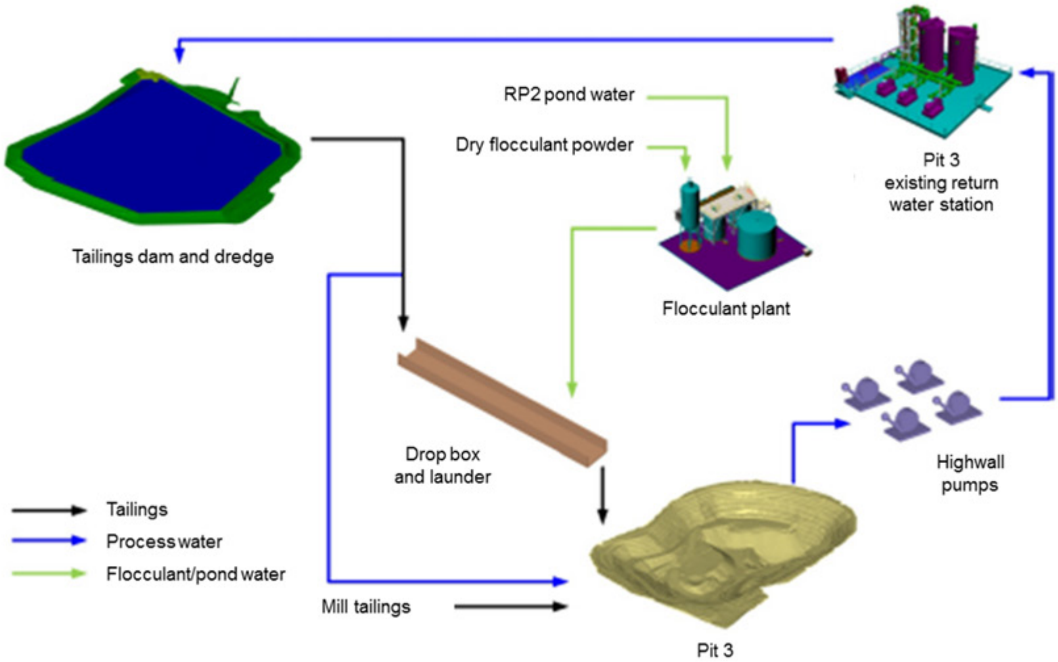

Figure 6-5: Inline agglomeration flow sheet

6.2.11.6 Unthickened tailings with neutralisation and wicks (A6)

Neutralised tailings are an alternative to cementation of tailings (Figure 6-6) and were thought to potentially lock up contaminants in the tailings, preventing detrimental environmental impact for 10,000 years. This treatment involves adding a reagent to the tailings stream to bind (reduce mobility) or precipitate solutes and/or radionuclide. Two examples of this method are:

- addition of lime, similar to the existing Ranger processing plant but to a higher pH target, and
- addition of spent liquor from the Gove Alumina Refinery – e.g. hydrotalcite [($Mg_6Al_2(CO_3)(OH)_{16.4}(H_2O)$)] precipitates.

Test work and analysis of this option determined a number of advantages and disadvantages (Table 6-14).

Table 6-14: Tailings neutralisation advantages and disadvantages

Advantages	Disadvantages
• avoids pipeline solidification issues associated with cementation • simpler process compared to cementation • avoids capital in cement facility, mixing and tremie/pump • lime neutralisation is proven technology at Ranger	• methods (i.e. hydrotalcite) not proven at Ranger • medium – high opex costs • 10,000 year stability not known • impact of expressed water solute loading and composition on water treatment not known • tailings would be more permeable than cemented tailings • impact on consolidation not known

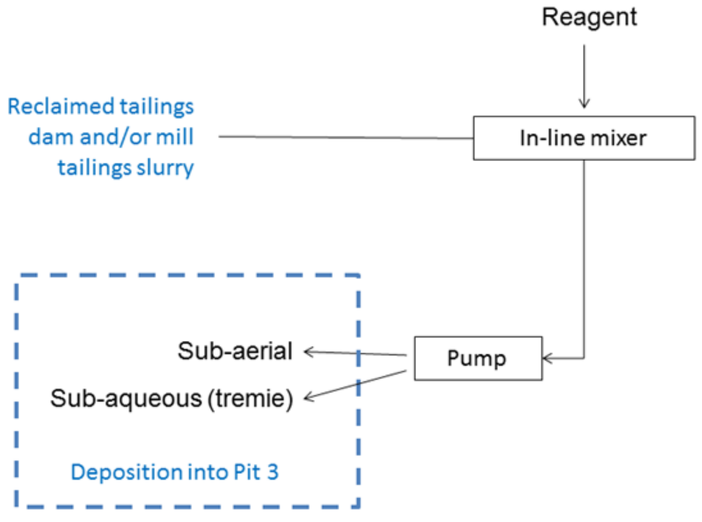

Figure 6-6: Tailings neutralisation flow sheet

6.2.11.7 Thickened and filtered tailings (A7)

Thickening followed by filtration was an option considered as part of the original BPT and was therefore included as part of this supplementary assessment.

The primary purpose would be to ensure prompt consolidation of tailings in Pit 3 and thus effectively eliminate tailings settlement after deposition. The proposed filter plant would process both the reclaimed thickened tailings from the TSF and the mill tailings using pressure filters. The filter cake would then be transferred via a conveyor system to a truck load out bin, hauled to Pit 3 and spread by dozers (Figure 6-7). Tailings filtration studies established that:

- pressure filtration was required to dewater mill tailings
- vacuum filtration was inappropriate technology for dewatering the whole tailings stream and was only suitable for dewatering the coarse size fractions.

The major advantages of filtered tailings over thickened tailings are:

- when placed and compacted the filtered tailings will reach a high overall density and a relatively low permeability. Thus, filtered tailings will express a negligible quantity of process water after placement, reducing post-closure water treatment
- filtered tailings will produce negligible settlement allowing earlier access for backfilling, thus accelerating the overall closure schedule.

However, compared with thickened tailings the main disadvantage of filtering is that Pit 3 must be dry before the tailings can be placed. This requires the construction of another process water dam. Other disadvantages include higher capital and operating costs, and increased health, safety and environment risks during operations.

6.2.11.8 Thickened, filtered and cemented tailings (A8)

Cementation of tailings was an option considered as part of the original BPT and therefore included as part of this supplementary assessment. Due to the high-water content of tailings, the solids concentration would need to be raised by both thickening and filtration in an appropriate plant before cementation occurred. Without this pre-treatment, cement consumption and the associated costs would be extraordinarily high and drying times would be long.

Tailings would be split with one fraction passing through a thickener and the other through a filtration plant and a hopper prior to combining both outputs in a mixer with a tailored mixture of cement and water. The mixer output would be held in a tank for conditioning prior to being pumped to Pit 3 (Figure 6-8).

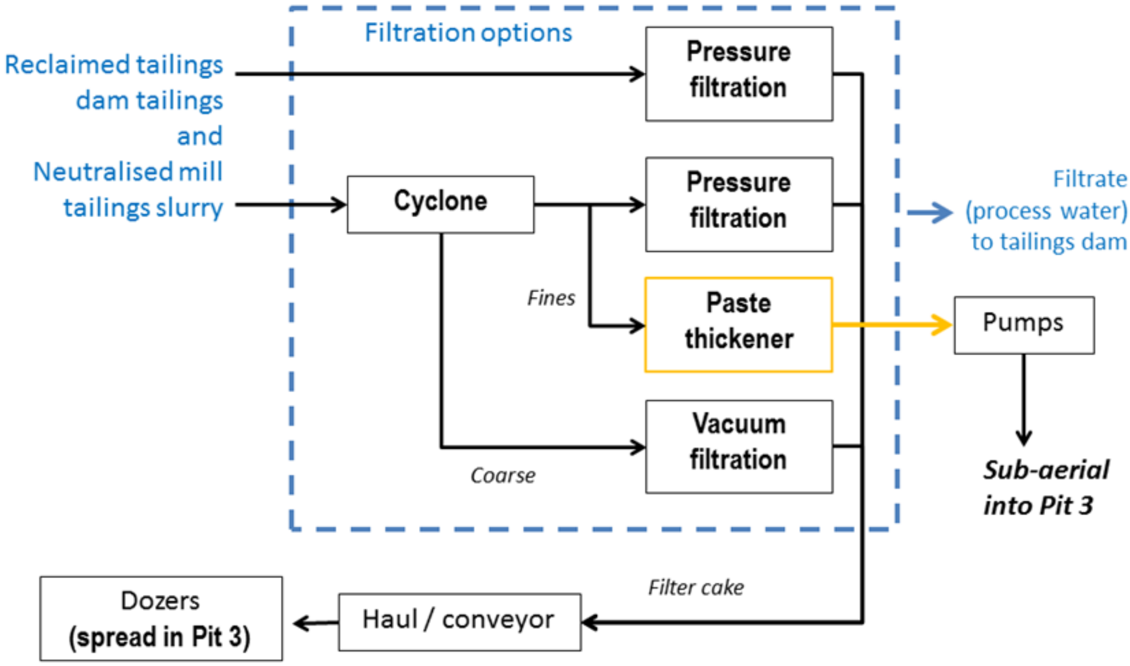

Figure 6-7: Tailings filtration flow sheet

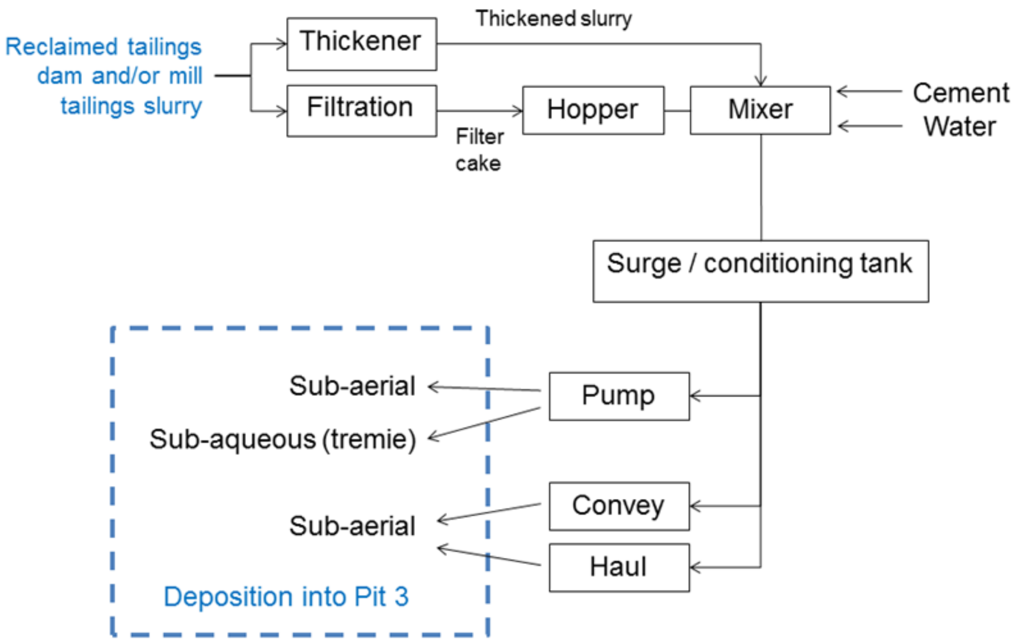

Figure 6-8: Thickened, filtered and cemented tailings flow sheet

6.2.11.9 BPT analysis of tailings treatment options

The eight options outlined in Section 6.3.11.1 to 6.3.11.8 were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment; the results are presented in Table 6-15. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table 6-15: 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

The full BPT assessment matrix resulting from the September 2016 workshop is shown in Appendix 6.1

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) has 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 Portland 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.

6.2.11.10 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. Further modelling indicates that tailings consolidation in Pit 3 can be achieved within the 2026 timeframe using this option.

The final closure strategy, and its implementation, is discussed in detail in Section 9.

6.3 ALARA and BPT

Several ERs require impacts to be as low as reasonably achievable (ALARA). ER 1.2(e) requires that environmental impacts within the RPA are as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. In addition to requiring impacts on the RPA that are ALARA, the term ALARA also applies to:

- exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (ER 1.2c),
- radiation health risks to members of the public (ER 2.2b)
- radiation protection of workers and the public (ER 5)
- impacts on the RPA from hazardous materials and waste (ER 6)
- management of excavated material (ER 7)

Traditional Owners have expressed an expectation that rather than achieving ALARA, rehabilitation in the riparian zones uses is as high as is technically possible and the level of contamination is as low as technically possible.

The ALARA concept is well defined and practiced in the world of radiation protection. The terms “ALARA” and “optimisation of protection” are now interchangeable in International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) documents (IAEA 2010).

The objective of optimisation is to achieve an appropriate balance between the efficient use of protection resources and the risks. The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. The ALARA procedure is well established for radiation protection but not directly transferable to non-radiation assessments.

Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable. Byrant et al. (2017) reasons that the terms “achievable” and “practicable” are in practice the same. Other assessment approaches include Best Available Technology. These processes use multi-criteria decision frameworks similar to the ERA BPT assessment. A further similarity between ALARA and BPT is the common phrase about considering economic and social factors.

ERA has researched and documented a process for the application of ALARA with respect to non-radiological hazards to demonstrate that environmental impacts on the RPA and exposure to chemical pollutants are ALARA. The process (Appendix 6.2) adopts recommendations from the international literature to implement an holistic framework that combines options and risk assessments to derive and demonstrate an ALARA outcome. The process can also consider options that would result in levels of contamination in the riparian zones that are as low as technically possible.

This holistic ALARA process was developed in consultation with stakeholders. Discussions with the NLC and GAC regarding ALARA and the process are continuing. This will help refine the process for application.

6.4 Future BPT assessments

BPT assessments will be held for all future applications, and where any other further decisions on technology arise. Such planned applications include Pit 3 closure, TSF deconstruction and the final landform

6.5 References

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APPENDIX 6.1: BEST PRACTICABLE TECHNOLOGY ASSESSMENT MATRICES

BPT assessment matrix for North Notch 3

						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

BPT assessment matrix for North Notch 3 *continued*

						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

BPT assessment matrix for TSF subfloor material management

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						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

BPT assessment matrix for TSF subfloor material management *continued*

						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	Environmental Protection	CAPEX	Occupational Health & Safety	Inherent availability and reliability	Revegetation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)
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

BPT assessment matrix for TSF subfloor material management *continued*

						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

BPT assessment matrix for TSF subfloor material management *continued*

						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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning)

					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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning) ***continued***

					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

BPT assessment matrix for treatment of low solute process water (high density sludge plant recommissioning) *continued*

					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

BPT assessment matrix for tailings deposition options for Ranger Pit 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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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

BPT assessment matrix for tailings deposition options for Ranger Pit 3 *continued*

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	

BPT assessment matrix for brine minimisation

	Inadequate	Poor	Acceptable	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

BPT assessment matrix for brine minimisation *continued*

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

BTP assessment matrix for blackjack waste disposal

						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										

BTP assessment matrix for Ranger 3 Deeps

						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				

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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
	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								

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for Ranger 3 Deeps *continued*

						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

BTP assessment matrix for ITWC prefeasibility study

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	

BTP assessment matrix for ITWC prefeasibility study *continued*

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

BTP assessment matrix for ITWC prefeasibility study *continued*

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

BPT assessment matrix for supplementary assessment - tailings treatment

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

ERA

BPT assessment matrix for supplementary assessment - tailings treatment *continued*

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

BPT assessment matrix for supplementary assessment - tailings treatment *continued*

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

		Show stopper column setting			Rehabilitation and Closure						Constructability		
					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

APPENDIX 6.2: ALARA & BPT FOR RANGER MINE CLOSURE

ERA Energy Resources of Australia Ltd

ALARA & BPT for Ranger mine closure

The process for identifying if impacts on the Ranger Project Area after closure are as low as reasonably achievable.

Author(s): Michelle ILES

Issued Date: 10/8/2020

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	Name	Position	Signed	Date
Originator	Michelle ILES	Principal Advisor Environmental Strategy	Michelle Iles	4/8/2020
Checked	Sharon Paulka	Manager, Closure	Sharon Paulka	04/08/2020
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EXECUTIVE SUMMARY

The Commonwealth Environmental Requirements (ERs) for closure of Ranger mine include: possible incorporation of the site into Kakadu National Park; onsite (i.e. within the Ranger Project Area) impacts that are as low as reasonably achievable (ALARA); and, protection of the people, ecosystem, and World Heritage and Ramsar wetland values of the surrounds. To comply with the ERs, the closure of the Ranger mine must be implemented in accordance with Best Practicable Technology (BPT) process described in the ERs.

In addition to requiring impacts on the RPA that are ALARA, the term ALARA also applies to:

- exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (1.2c),
- radiation health risks to members of the public (2.2b)
- radiation protection of workers and the public (ER5), impacts on the RPA from hazardous materials and waste (ER 6) and management of excavated material (ER 7).

Traditional Owners have expressed an expectation that rehabilitation in the riparian zones is *as high as is technically possible and level of contamination must be as low as technically possible.*

The ALARA concept comes from the field of radiation protection. ALARA and “optimisation of protection” are interchangeable in International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) documents (IAEA 2010). Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable (ALARP). The terms “achievable” and “practicable” are in practice the same and are widely accepted as such. Other assessment approaches include Best Available Technology (BAT). All have similarities with the ERA BPT approach.

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result. It is not driven by numeric values. The quality achieved with the chosen option is ALARA.

ALARA is a top down approach to risk assessment compared to pollution/environmental risk control as a bottom up approach. Nga et al (2000), who discuss the opposing philosophies of ALARA and pollution risk control, and numeric targets versus ALARA, say:

> *The current framework for managing public exposures to chemical carcinogens has been referred to as a “bottom up approach.” Risk is typically evaluated for each source and an acceptable risk range …, is established. The lower risk of this range is then established as an “upper bound” goal. Risk managers seek to achieve protection at the “upper bound” goal by limiting exposure or removing the environmental contamination. If this goal is not achievable after the considerations of technical feasibility, cost, and other factors, the risk manager may decide to accept a “lower bound” goal within the risk range that could lead to a less stringent level of protection.*

The top-down strategy involves aggregating risks from all sources and setting an upper bound dose limit, then using the ALARA principle to reduce the risk.

The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. These guideline values will protect the ecosystem from any change to biodiversity which is the management goal for outside the RPA. The management goal for on the RPA is impacts that are ALARA. The numerical risk targets set for high level ecosystem protection can be exceeded and a less stringent level of protection accepted if it can be shown that the lower bound is what is achievable after considering multiple criteria such as the technical feasibility, cost and other factors, ie is ALARA.

Nga et al (2000) recommend a flexible risk management framework and assessing multiple or cumulative risks as an approach to dealing with both the top down ALARA approach, and the bottom up numeric values approach. Bryant et al (2017), describes an holistic framework to undertake such a combined options-risk assessment to derive an ALARA outcome.

Adopting the approach demonstrated by Bryant et al (2017), a BPT assessment coupled with ERA's risk management processes can be used to identify closure options that provide an ALARA outcome.

The issue of weighting different criteria to demonstrate the sensitivity of cultural criteria against costs was requested by the Traditional Owners and can be implemented with the BPT assessment tool. This will provide information to support discussions on what is reasonable; a decision that will be made through discussions in the appropriate forums. Information is provided in this document to support discussions on the issue of what is reasonable, and points given on how the BPT assessment tool can be used to weight different assessment criteria to inform these discussions.

1 BACKGROUND

The Ranger uranium mine (Ranger/Ranger mine) is located within the Ranger Project Area (RPA) adjacent to Jabiru, approximately 260 kilometres east of Darwin in the Alligator Rivers Region of the Northern Territory. The RPA is surrounded by Kakadu National Park (KNP), 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.

Energy Resources of Australia Ltd (ERA) has owned and operated the Ranger mine since the commencement of operations in 1980.

Under the current operational approvals, ERA is required to cease mining and milling operations by 8 January 2021, with final rehabilitation and closure activities completed by 8 January 2026.

The operation and closure of Ranger mine must be conducted in accordance with the Commonwealth Environmental Requirements.

1.1 Environmental Requirements

The Commonwealth Environmental Requirements (ERs) for Ranger, appended to the section 41 Authority, set out 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. The *Mining Management Act* also requires the Ranger Authorisation to incorporate, by reference, the ERs. The ERs were revised in 1999 to be inclusive of conditions relating to rehabilitation (Commonwealth of Australia 1999).

The ERs specify primary and secondary environmental objectives.

The Primary Environmental Objectives are:

- Protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds (ER 1 and 2),
- As Low As Reasonably Achievable (ALARA) environmental impacts on the RPA (ER 1.2e)
- ALARA exposure of Aboriginals and other members of the regional community to radiation and chemical pollutants to (1.2c),
- ALARA radiation health risks to members of the public (2.2b)

The Secondary Environmental Objectives state that:

- Water from site must not jeopardise the Primary Environmental Objectives (ER 3.1)
- The RPA must be returned to a state in which it could be incorporated into Kakadu National Park (ER 2.1)
- All aspects of the Ranger ERs must be implemented in accordance with Best Practicable Technology (ER 12.1).

- ALARA is required for radiation protection of workers and the public (ER5), impacts on the RPA from hazardous materials and waste (ER 6) and management of excavated material (ER 7).

The Supervising Scientist Branch interprets BPT as the technology that is consistent with achieving the primary environmental requirements and ranks highest when considering world's best practice, cost-effectiveness, proven effectiveness, Ranger's location, the age of equipment and social factors (Supervising Scientist 2001).

ALARA is well defined and practiced in the world of radiation protection. There is a need to understand its application with respect to non-radiological hazards to demonstrate that environmental impacts on the RPA and exposure to chemical pollutants are ALARA.

1.2 Traditional Owner expectations

This document discusses the regulatory requirement for impacts on the RPA that are ALARA, and processes and frameworks for determining what ALARA is.

While this is necessary, it is important to note that Traditional Owners reported concerns with trying to integrate cultural values within 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).

Garde (2015) also expressed the views of the Traditional Owners on ALARA and BPT stating "*…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 principle of 'as low as reasonably achievable' 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 Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC) reiterated this and provided additional (draft) information on their position on ALARA for onsite water bodies (email from Chris Brady 8/4/2020).

> *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 principle of "as low as reasonably achievable" 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.

A final NLC/GAC position paper is in preparation.

The information in this document, while aimed at clarifying how to determine what impacts are ALARA, can also provide a starting point for how the process can be adapted to consider the expectations of the traditional owners, particularly with respect to the riparian zones.

2 ALARA

ALARA is the acronym standing for 'As Low As Reasonably Achievable', used to define the principle underlying optimization of radiation protection: radiation exposure must be kept as low as reasonably achievable, taking economic and social factors into account. ALARA for radiation protection is integrated into national regulations globally. Regulations will vary from country to country, but will contain requirements on optimisation and on how to achieve ALARA (IAEA, 2010).

ALARA and "optimisation of protection" are interchangeable in ICRP and IAEA documents. (IAEA 2010). In the latest Recommendations (ICRP, 2007), the acronym ALARA is not used; optimisation of protection is used instead.

The objective of optimisation is to achieve an appropriate balance between the efficient use of protection resources and the risks.

ICRP Publication 103 (ICRP, 2007) defines optimization of protection (and safety) as *the process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account.*

Several countries have extended the concept of ALARA to non-radiation work health hazards and have changed the term to As Low As Is Reasonably Practicable (ALARP). Byrant et al 2017 reasons that the terms "achievable" and "practicable" are in practice the same and are widely accepted as such.

2.1 ALARA versus numerical risk targets

The issue of ALARA as a top down approach to risk assessment, compared to pollution/environmental risk control as a bottom up approach has long been acknowledged (eg Domotor et al 1999, Nga et al 2000)

Nga et al (2000) discuss the opposing philosophies of numerical risk targets versus the ALARA principle:

The current framework for managing public exposures to chemical carcinogens has been referred to as a "bottom up approach." Risk is typically evaluated for each source and an *acceptable risk range …, is established. The lower risk of this range is then established as an "upper bound" goal. Risk managers seek to achieve protection at the "upper bound" goal by limiting limiting exposure or removing the environmental contamination. If this goal is not achievable after the considerations of technical feasibility, cost, and other factors, the risk manager may decide to accept a "lower bound" goal within the risk range that could lead to a less stringent level of protection.*

In contrast, a "top down" approach that sets an upper bound dose limit and couples with site specific As Low As Reasonably Achievable Principle (ALARA), is in place to manage individual exposure to radiation. While radiation risk are typically managed on a cumulative basis, exposure to chemicals is generally managed on a chemical-by-chemical, medium-by-medium basis.

In contrast, the dominant framework for managing individual radiation exposures has been described as a "top down" approach. The top-down strategy involves aggregating risks from all sources and setting an upper bound dose limit, then using the ALARA principle to reduce the risk.

The water quality objectives adopted by SSB as rehabilitation standards for water leaving the RPA are an example of numerical risk targets. These guideline values will protect the ecosystem from any change to biodiversity which is the management goal for outside the RPA. The management goal for on the RPA is impacts that are ALARA. The numerical risk targets set for high level ecosystem protection can be exceeded and a less stringent level of protection accepted if it can be shown that the lower bound is what is achievable after considering multiple criteria such as the technical feasibility, cost and other factors, ie is ALARA.

ALARA is a top down approach where a dose limit is derived which cannot be exceeded and a process is followed for pushing exposures even lower. (It also includes setting a dose constraint as a target and trying to keep below that.)

These two approaches are based on opposite philosophies. Nga et al (2000) recommend a flexible risk management framework and assessing multiple or cumulative risks as an approach to incorporating both issues.

The following sections show how this can be achieved through coupling the ALARA procedure, which includes an options assessment process, the BPT tool as the options assessment matrix and ERA's risk management system.

2.2 The ALARA procedure

The ALARA procedure is a stepwise options assessment process followed to arrive at an option that represents the most acceptable result rather than a process to derive a numeric values. The quality achieved with the chosen option is ALARA as indicated by the following statements:

EAN (2019), citing ICRP Publication 101 (ICRP, 2006), says *ALARA is an obligation of means, and not an obligation of results, in the sense that the result of ALARA depends on processes, procedures, and judgements and is not a given value of exposure.*

Successful optimisation focuses on the effective use of robust processes to evaluate situations rather than on specific numerical results (NEA & CRPPH, 2012).

ALARA, as applied by DOE, is not a numerical level or limit, but rather a process which is to be used to ensure that appropriate factors are taken into consideration in arriving at decisions (Domotor et al, 1999).

This is demonstrated by Figure 1 (taken from Oudiz et al, 1986) which shows that ALARA is the result achieved by selection of the best option.

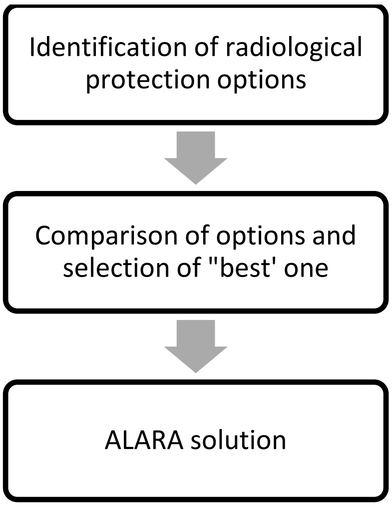

Figure 1 The main features of the ALARA procedure (Oudiz et al. 1986)

IAEA (2010) states *An ALARA approach may identify the need for an ALARA study of a specific situation. The study may include the following steps (see also European Commission "ALARA from theory to practice", report EUR 13796, 1991[1]):*

- Define the problem,
- Make a preliminary analysis of the type and level of doses,
- Define the radiation protection options,
- Quantify, where possible, the impact of these options in terms of cost, dose, time, etc. For some factors a qualitative assessment may be necessary
- Compare the options,
- Make a sensitivity analysis,
- Select and implement an optimized solution.

EAN (2019) reviewed and updated the European Commission report cited above and say that the basic steps remain the same.

[1] Listed in the Reference section of this report as Lochard et al (1991).

2.3 Applying the ALARA procedure to non-radiological hazards

Bryant et al (2017) discusses the work and ALARA procedure cited by IAEA (2010) above describing the ALARA procedure as being **generic and applicable to radiological and non-radiological hazards.** They modified the steps of the ALARA procedure referred to above to sit within a framework for an holistic assessment of multiple hazards (Figure 2) and used it to demonstrate they had reduced radiological and non-radiological hazards and risks to ALARA/ALARP.

The steps in the framework in Figure 2 are discussed below in terms of how they are, or could be applied, by ERA to demonstrate that:

- if the closure strategy, and aspects of it, are consistent with Best Practical Technology (BPT) and are supported by a sound risk management system, then
- the resulting (predicted or measured) environmental impacts, and chemical and radiation exposure to members of the public are ALARA.

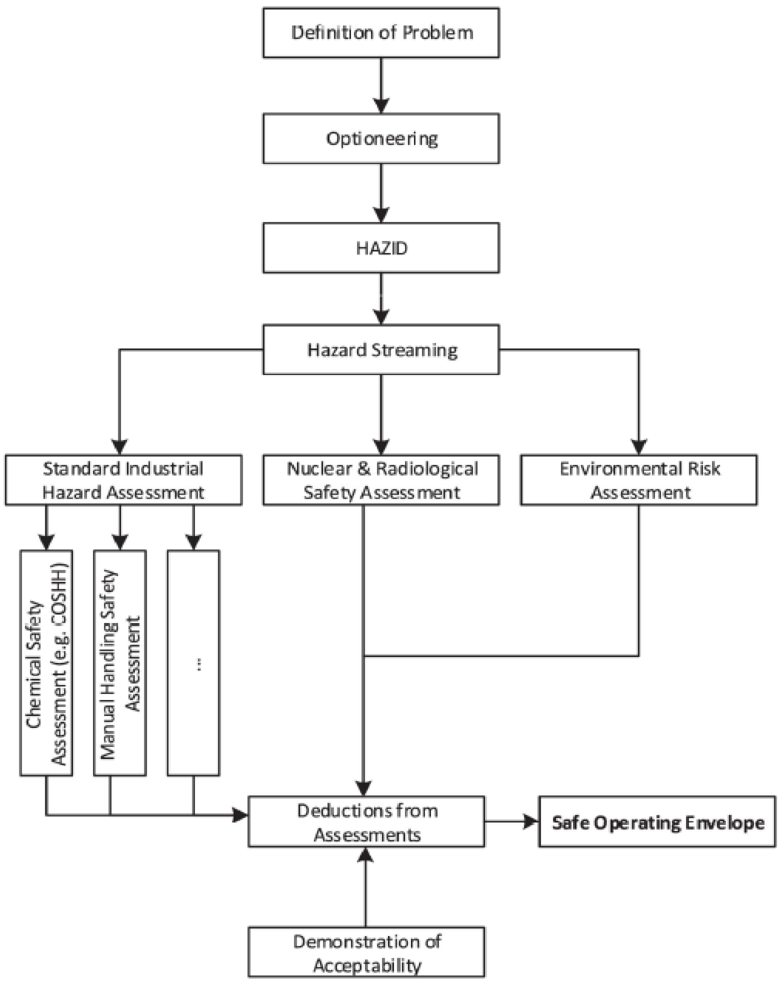

Figure 2 Framework for the integration of risks from multiple hazards into a Holistic ALARA/ ALARP demonstration (from Bryant et al 2017).

2.3.1 Steps 1 & 2: Problem definition and Optioneering

Bryant et al (2017) state that the first two steps *Problem definition* and *Optioneering lay the foundation to the ALARP argument. First there must be a clear definition of the problem, and then an optioneering assessment to identify possible solutions to the problem and select a preferred option or options.*

2.3.1.1 Problem definition

The clear definition of the problem is usually the activity that ERA is seeking approval for. There are several options for implementing these activities and these options are assessed. The problem will be described during the initial stage of the options assessment. This will all be described in the application for approval of the activity.

2.3.1.2 Optioneering

IAEA 2010 identifies cost-benefit analysis, cost-effectiveness analysis and multi-criteria decision analysis as useful decision-aiding tools for implementing ALARA.

Cost benefit analysis is useful in radiation protection where costs per unit of radiation dose protection are well established. However only costs and doses are analysed, other important factors such as social factors are ignored. Multi-criteria decision analysis is preferable as it can focus on multiple attributes and use a scoring scheme that can accommodate qualitative and linear or non-linear quantitative data. ICRP (1990) recommends multi-criteria decision analysis.

In radiation protection the ALARA approach is used to optimise radiation doses, whereas the "Best Available Technique" (BAT) approach is used to ensure effluent releases from a source are appropriately controlled. Both are considered optimisation techniques and can be complimentary to each other. The phrase "best available techniques" tends to be used more often in western Europe, whereas the term "optimisation" is used more globally. (NEA & CRPPH, 2012).

Other terms with similar meaning are also used in effluent management, such as Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM) (Bryant et al 2017). These concepts apply to water, air, and soil and can be extended to general environmental protection.

BAT is identified through evaluating the trade-off between what can done to reduce discharges and what is a reasonable (or unreasonable) cost to pay for that reduction. The term "reasonable" requires an inherent value judgement to be made with social and ethical concerns to be factored in and may differ for different countries. (See Section 3 for a discussion on reasonable.)

To comply with the ERs, the closure of Ranger must be implemented in accordance with Best Practicable Technology (BPT). BPT is similar to BAT and can be applied to issues broader than effluent management. Like BAT, BPT is tool for optimising technologies and strategies adopted by ERA for the Ranger site.

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 (SSD, 2001). In considering the best procedure for ensuring that the BPT concept became a driver for identifying the best 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 remain consistent with the original six broad matters in the formal definition of BPT.

Bryant et al (2017) list the following six key steps in an optioneering assessment; dot points at each step show the similarity to the ERA BPT process.

I. Define requirements (e.g. functional requirements that must be met by the solution).
    - This is the technical objective of the BPT

II. Identify options
    - The alternative options being assessed in the BPT analyses. The selection of these options are supported by site-specific requirements, studies and recommendations from industry experts.

III. Define selection criteria-Assurance (including radiological safety, conventional safety, and environmental risks), engineering, business, etc
    - These are described in the BPT scoring matrix which also includes assessment criteria for Culture & Heritage and themes linked to the Environmental Requirements for closure. Different weights can be assigned to different categories to ensure protection of more highly valued aspects. This would need to be agreed by stakeholders.

IV. Analyse options-Assess against criteria
    - This is the BPT assessment.

V. Scoring and ranking-Rank the options based on the assessment of the options
    - The BPT assessment process compares different management options and ranks them against each other based on scores for each of the BPT criteria.

VI. Down selection-Identify preferred option(s)
    - All scores are combined to a single value and the different options ranked. The option with the best score is deemed to be BPT.

2.3.2 Steps 3 & 4: Hazard determination and streaming

Hazards are identified for the preferred option and allocated to an assessment stream based on type of hazard (eg nuclear/ radiological, industrial or environmental) and level of risk. The hazards are then assessed in an approach proportionate to the hazard/risk. (Bryant et al 2017). This agrees with advice from international bodies who say optimisation of protection is not only about choosing the best options, those options need to be implemented effectively meaning management systems have an important role in effectively implementing the ALARA and BAT concepts (NEA & CRPPH, 2012).

ERA has a mature HSE management system in place that is certified to ISO14001:2016 and AS4801:2001. This includes numerous individual management plans related to protecting the environment and human health and covering topics including, but not limited to, water, tailings, weeds, radiation, occupational health, culture and heritage, hazardous materials, mineralised material, waste management etc.

The ERA HSE Management System is designed along the principles of continuous improvement and generally follows the layout of the Plan, Do, Check, and Review cycle which is common to many international standards. The scope of its HSE MS includes the mining, processing and rehabilitation of uranium ore resources at the Ranger Mine including maintenance and ancillary services.

This system assists ERA to comply with internal and external commitments, demonstrates a system of continual improvement in operational performance and assists ERA in achieving environment, safety and health excellence.

The approach ERA has taken to risk assessment has been developed to identify hazards, aspects and opportunities in advance of project or activity implementation. The resulting risks and impacts to the business, people, property, assets and the environment are recorded and evaluated, and strategies are developed to manage them. The framework is consistent with recognised Australian standards and corporate management standards and practices including AS ISO 31000:2018 Risk Management – Principles and guidelines, AS/NZS ISO 14001 Environmental Management Systems and internal Rio Tinto and ERA standards and commitments.

During the Ranger Mine closure feasibility study, a series of risk assessment workshops were completed to further develop the Ranger closure risk register. These were conducted in accordance with the ERA hazard identification and risk management standard (ERA 2018) and the *Rio Tinto HSEC-C-01 HSEC Risk Assessment Group Procedure*.

In June 2019 the environmental risk assessment published in the 2018 Ranger mine closure plan (MCP) was updated with the outcomes of the feasibility study risk assessment and to consider the comments received from the Supervising Scientist on the 2018 MCP risk section.

Section 10 of the 2019 MCP (ERA 2019) presents a summary of the ERA approach to closure related risk assessment and the outcomes of the then most recent closure risk assessment. Outcomes from more recent risk assessments will continue to be reviewed and additional risks identified during internal or external workshops (e.g. the cumulative risk assessment currently being run by Supervising Scientist Branch (SSB)) will be considered in future iterations of the Ranger MCP.

2.3.3 Step 5: Deductions and safe operating envelope

Bryant et al 2017 go on to say *The output of the various assessments should be reviewed in combination, to ensure that there are no conflicts, for instance any controls or mitigations put* *in place for one hazard type have not created any new hazards, or impacted any of the other hazard assessments. These deductions are then used to define the Safe Operating Envelope (SOE). This review should be undertaken by a SQEP panel, who have a demonstrable understanding of the various hazard types. The SOE includes any bounding conditions, engineered and/ or managerial safety controls (and requirements placed on the controls, including maintenance), which are to be implemented by the facilities safety management arrangements. Where the bounding conditions are key physical parameters which inform the facilities of specific limits of safe operation, for instance, limits on the quantities of hazardous materials that may be present in a facility.*

Assessment of risks has been ongoing at Ranger for several decades and resulted in strict operational requirements and a large number of environmental and engineering studies over the years.

The risk management approach adopted for the Ranger Closure Project is one of integrated and iterative risk identification and assessment processes applied as inputs to key project stages and activities. All key risks relevant to the project are in a single risk register, with risks owned by ERA and the Project team members as required to ensure effective management of risks and implementation of risk treatment plans. Separate registers exist to cover the HAZID / HSEC risks and technical risk which are managed via the engineering management plan.

This approach contributes to a holistic application of risk management techniques across all risk areas including strategic, technical, commercial, safety and environmental that meets the intent of ERA and Rio Tinto project risk management protocols while providing a best-for-project risk management solution.

Change management procedures are followed for mitigations being introduced, and representation of multiple working groups and disciplines in risk assessments reduce the potential for conflicts with risk mitigation. Major projects undergo internal and external review by teams of subject matter experts doing deep dives into identified risks and management strategies. Strategies and mitigations plans form part of applications assessed by stakeholders.

There has also been ecological risk assessments for the closure of Ranger which lead to the review of the Key Knowledge Needs for closure. Research projects are being conducted by ERA and SSB to address these. Many of these studies result in safe operating envelopes.

Some examples of safe operating envelopes for the closure of Ranger include:

- Targets for consolidation of tailings, limits on the level of tailings placed in pits, and targets for extraction and treatment of pit tailings flux, and process water.
- Limits for water quality at the lease boundary, and for treatment plant discharges.
- Maximum operating level for process water in Pit 3 and the TSF and maximum drawdown rates in the TSF.
- Waste segregation, ie rock grade control and burial of higher grades at depth.
- Closure criteria.

- Engineered and/ or managerial safety controls (and requirements placed on the controls, including maintenance) identified in the Ranger Closure Feasibility study.
- Shaping of landform based on landform evolution studies.
- Thickness of cover for radiation protection and plant available water.
- Tailings buried for 10,000 years.
- Critical controls, SOPS, and accredited management systems.

2.3.4 Step 6: Demonstration of acceptability

The final step is demonstration of acceptability. Assumptions underpinning the hazard/risk assessment need to be substantiated to demonstrate that they can be met. *The extent of substantiation should be proportionate to the level of risk reduction and confidence required for the safety measure. This may range from compliance with relevant standards, to a more in-depth assessment of failure modes or through life limiting factors.* (Bryant et al 2017).

This is achieved at ERA through the large body of research and studies that are undertaken (as part of Rio Tinto feasibility studies, ongoing technical studies to implement the closure strategy, and to address key knowledge needs for protection of the ecosystem during operations, closure and post closure) and applications for approval for major activities and the annual Mine Closure Plan. These studies and applications are peer reviewed through a number of stakeholder committees.

Relevant standards for the closure of Ranger mine include the SSB rehabilitation standards and ERA closure criteria which are based generally on the ERs and specifically on national regulations and guidelines, eg radiation dose limits, dietary standards, local and default water quality guideline values.

Predictive modelling is used to demonstrate that the closure strategy will result in compliance with relevant standards. Reports on these models contain sensitivity assessments and are peer reviewed. Examples of such models are:

- Derivation of water quality standards based on ecotoxicological models
- Solute transport models.
- Landform stability and erosion models.
- Tailings consolidation models.
- Plant available water models.
- Models of ecosystem establishment trajectories.
- Radiation dose assessments.

Measurements of contaminants and remediation plans are also peer reviewed.

Discussions of the risks, options and BPT assessments, supporting studies, mitigations and monitoring form part of each application submitted for approval for key closure activities. The applications and processes described in the applications are in effect the same as the safety case demonstrating ALARA/ALARP described by Bryant et al 2017.

3 REASONABLENESS

Agreeing on what is reasonable will involve all stakeholders working together to discuss their different views and expectations. This will be dealt with through the relevant stakeholder committees; eg Ranger Minesite Technical Committee, Relationship Committee. Some information is provided here to provide some working points and references for those groups.

In the UK, the statutory guidance to Part IIA of EPA 1990 (Chapter C, DETR Circular 02/2000) sets out very specific criteria for the identification of Best Practicable Technique for the determination of appropriate remediation requirements.

Part 5 The Reasonableness of Remediation (provided in Appendix 1) provides guidance on the determination by the enforcing authority of what remediation is, or is not, to be regarded as reasonable having regard to the cost which is likely to be involved and the seriousness of the harm or of the pollution of controlled waters to which it relates.

Advise on cost and reasonableness

The advice is that a remediation action is reasonable if the cost assessment shows benefits justifying the cost. The benefits to consider are the resulting from the contribution that the action makes, either on its own or in conjunction with other remediation actions, to:

(a) reducing the seriousness of any harm or pollution of controlled waters which might otherwise be caused; or

(b) mitigating the seriousness of any effects of any significant harm or pollution of controlled waters.

A necessary condition of an action being reasonable is that there is no alternative scheme which would achieve the same purposes or standard of remediation for a lower overall cost (bearing in mind that the purpose of any remediation action may relate to more than one significant pollutant linkage).

Such an assessment should include the preparation of an estimate of the costs likely to be involved and of a statement of the benefits likely to result. This latter statement need not necessarily attempt to ascribe a financial value to these benefits.

The BPT assessment framework for assessing different options for remediation activities considers the environmental outcome and costs associated costs with each option/mitigation strategy[2].

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[2] Note; costs in future BPT assessments don't consider the many mitigation strategies that have already been adopted to reduce risks associated with mine closure; for example; waste segregation, tailings burial, pond and process water treatment, placement of reactive materials at depth, wick placement and tailings deposition methods to accelerate tailings consolidation, etc.

Advise on environmental harm and reasonableness

The advice on evaluating the seriousness of environmental harm for the purposes of assessing the reasonableness of any remediation, should include consideration of:

(a) whether the significant harm is already being caused;

(b) the degree of the possibility of the significant harm being caused;

(c) the nature of the significant harm with respect, in particular, to:

(i) the nature and importance of the receptor,

(ii) the extent and type of any effects on that receptor of the significant harm,

(iii) the number of receptors which might be affected, and

(iv) whether the effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the receptor has already been damaged by other means and, if so, whether further effects resulting from the harm would materially affect its condition, and

(ii) the relative risk associated with the harm in the context of wider environmental risks.

Much of this will be considered in the BPT assessment itself. Useful reports for interpreting the results of the BPT and studies informing it in the context of the above suggestions include, for example:

- BMT (2018, 2019) reports on indicators for primary environmental objectives, environmental values of water on and off the RPA, descriptions of drivers of ecosystem stress, ecosystem component characteristics and vulnerability (which includes reversibility and implications of exposure characteristics such as duration, intensity, seasonality etc.).
- SSB reports on biological effects of contaminants and monitoring results.
- Relative risks from mining compared to landscape scale risks such as weeds, feral animals, climate change etc. (eg Bayliss et al 2012, 2015, 2016; Humphrey et al 2016).
- Climate change predictions for the region (will be reported as part of the current ERA closure climate change assessment).
- Reports on the Kakadu National Park environment (eg BMT, 2010).

4 CONCLUSIONS

ERA's practices and procedures for options assessments and risk management and mitigation are aligned with the ALARA procedure.

Considering the terms ALARA and optimisation of protection are interchangeable, and that choosing the best technology is a form of optimisation (NEA & CRPPH, 2012), BPT is therefore a tool for identifying the ALARA solution, and is the tool ERA must use to do this according to both the ERs and the Ranger Authorisation.

Therefore, ERA proposes the option that is considered BPT represents the best option of achieving impacts that are ALARA. However, the final decision on what is reasonable needs to be agreed between stakeholders through the relevant committees.

Some information that may assist those discussions in provided in this document. Also, the BPT process can include weighting of different assessment aspects/criteria which means the BPT tool can be adjusted to test the sensitivity of the different options, or aspects of an option, to different assessment criteria (eg Cultural and heritage values, cost, time, safety). This will provide information to help the stakeholders come to an agreement on what is ALARA.

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C.29 The statutory guidance in this Part is issued under section 78E(5)(c) and provides guidance on the determination by the enforcing authority of what remediation is, or is not, to be regarded as reasonable having regard to the cost which is likely to be involved and the seriousness of the harm or of the pollution of controlled waters to which it relates.

C.30 The enforcing authority should regard a remediation action as being reasonable for the purpose of section 7 8E(4) if an assessment of the costs likely to be involved and of the resulting benefits shows that those benefits justify incurring those costs. Such an assessment should include the preparation of an estimate of the costs likely to be involved and of a statement of the benefits likely to result. This latter statement need not necessarily attempt to ascribe a financial value to these benefits.

C.31 For these purposes, the enforcing authority should regard the benefits resulting from a remediation action as being the contribution that the action makes, either on its own or in conjunction with other remediation actions, to:

(a) reducing the seriousness of any harm or pollution of controlled waters which might otherwise be caused; or

(b) mitigating the seriousness of any effects of any significant harm or pollution of controlled waters.

C.32 In assessing the reasonableness of any remediation, the enforcing authority should make due allowance for the fact that the timing of expenditure and the realisation of benefits is relevant to the balance of costs and benefits. In particular, the assessment should recognise that:

(a) expenditure which is delayed to a future date will have a lesser impact on the person defraying it than would an equivalent cash sum to be spent immediately;

(b) there may be a gain from achieving benefits earlier but this may also involve extra expenditure; the authority should consider whether the gain justifies the extra costs. This applies, in particular, where natural processes, managed or otherwise, would over time bring about remediation; and

(c) there may be evidence that the same benefits will be achievable in the foreseeable future at a significantly lower cost, for example, through the development of new techniques or as part of a wider scheme of development or redevelopment.

C.33 The identity or financial standing of any person who may be required to pay for any remediation action are not relevant factors in the determination of whether the costs of that action are, or are not, reasonable for the purposes of section 78E(4). (These factors may however be relevant in deciding whether or not the enforcing authority can impose the cost of remediation on that person, either through the service of a remediation notice or through the recovery of costs incurred by the authority; see (section 78P and the guidance in Chapter E.)

The Cost of Remediation

C.37 The enforcing authority should furthermore regard it as a necessary condition of an action being reasonable that:

(a) where two or more significant pollutant linkages have been identified on the land in question, and the remediation action forms part of a wider remediation scheme which is dealing with two or more of those linkages, there is no alternative scheme which would achieve the same purposes for a lower overall cost; and

(b) subject to subparagraph (a) above, where the remediation action forms part of a remediation package dealing with any particular significant pollutant linkage, there is no alternative package which would achieve the same standard of remediation at a lower overall cost.

C.38 In addition, for any remediation action to be reasonable there should be no alternative remediation action which would achieve the same purpose, as part of any wider remediation package or scheme, to the same standard for a lower cost (bearing in mind that the purpose of any remediation action may relate to more than one significant pollutant linkage).

The Seriousness of Harm or of Pollution of Controlled Waters

C.39 When evaluating the seriousness of any significant harm, for the purposes of assessing the reasonableness of any remediation, the enforcing authority should consider:

(a) whether the significant harm is already being caused;

(b) the degree of the possibility of the significant harm being caused;

(c) the nature of the significant harm with respect, in particular, to:

(i) the nature and importance of the receptor,

(ii) the extent and type of any effects on that receptor of the significant harm,

(iii) the number of receptors which might be affected, and

(iv) whether the effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the receptor has already been damaged by other means and, if so, whether further effects resulting from the harm would materially affect its condition, and

(ii) the relative risk associated with the harm in the context of wider environmental risks.

C.40 Where the significant harm is an "ecological system effect" as defined in Chapter A, the enforcing authority should take into account any advice received from English Nature.

C.41 In evaluating for this purpose the seriousness of any pollution of controlled waters, the enforcing authority should consider:

(a) whether the pollution of controlled waters is already being caused;

(b) the likelihood of the pollution of controlled waters being caused;

(c) the nature of the pollution of controlled waters involved with respect, in particular, to:

(i) the nature and importance of the controlled waters which might be affected,

{ii) the extent of the effects of the actual or likely pollution on those controlled waters, and

(iii) whether such effects would be irreversible; and

(d) the context in which the effects might occur, in particular:

(i) whether the waters have already been polluted by other means and, if so, whether further effects resulting from the water pollution would materially affect their condition, and

(ii) the relative risk associated with the water pollution in the context of wider environmental risks.

C.42 Where the enforcing authority is the local authority, it should take into account any advice received from the Environment Agency when it is considering the seriousness of any pollution of controlled waters.

C.43 In some instances, it may be possible to express the benefits of addressing the harm or pollution of controlled waters in direct financial terms. For example, removing a risk of explosion which renders a building unsafe for occupation could be considered to create a benefit equivalent to the cost of acquiring a replacement building.

Various Government departments have produced technical advice, which the enforcing authority may find useful, on the consideration of non-market impacts of environmental matters.

Energy Resources of Australia Ltd

7 Risk assessment and management

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Cover photograph: Tailings Storage Facility (March 2019)

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
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
1G project	1 Gigalitre project
AAPA	Aboriginal Areas Protection Authority
ALARA	As Low As Reasonably Achievable
ARR	Alligator Rivers Region
ARRAC	Alligator Rivers Region Advisory Committee
ARRTC	Alligator Rivers Region Technical Committee
ASS	Acid Sulfate Soils
BC	Brine Concentrator
BMM	Bulk Material Movement
CCTV	Closed Circuit Television
CIP	Closure Implementation Plan
CLM	Contaminated Land Management
CPT	Cone Penetration Testing
DEM	Digital Elevation Model
EOI	Expression of Interest
ER	Environmental Requirements
ERA	Energy Resources of Australia Ltd
ERISS	Environmental Research Institute of the Supervising Scientist
FIFO	Fly In Fly Out
FS	Feasibility Study
GAC	Gundjeihmi Aboriginal Corporation
GIS	Geographic Information System
HDS	High Density Sludge
H&S	Health and Safety
HSE	Health, Safety and Environment
HSEC	Health, Safety, Environment and Communities
ITWC	Interim Tailings, Water and Closure
KNPS	Kakadu Native Plants
LAA	Land Application Area

Abbreviation/ Acronym	**Description**
LEM	Landform Evolution Model
MBL	Mine Bore L
MCP	Mine Closure Plan
MOL	Maximum Operating Level
MTC	Minesite Technical Committee
NP	National Park
OBS	Osmoflow Brine Squeezer
OHS	Occupational Health and Safety
OMM	Operations Maintenance Manual
OPSIM	Operation Simulation Modelling
P50, P70, P90	50th percentile, 70th percentile, 90th percentile
PCBs	Polychlorinated Biphenyl
PFS	Prefeasibility Study
QA	Quality Assessment
RBS	Risk Breakdown Structure
RCCF	Ranger Closure Consultative Forum
RP2	Retention Pond 2 – also denotes other retention ponds used on site – e.g. RP1, RP3, RP6
RPA	Ranger Project Area
RSA Archer	Risk Management Tool
RSO	Radiation Safety Officer
TARP	Trigger Action Response Plan
SIA	Social Impact Statement
SSB	Supervising Scientist Branch
TDS	Total Dissolved Solids
TO	Traditional Owner
TSF	Tailings Storage Facility
TSS	Total Suspended Solids
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 (ERA 2018) and ERA Closure Risk Management Plan (CDM.03-0000-MR-PLN-00001). 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 and control measures. 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 a number of assessments undertaken as part of the Ranger closure feasibility study during 2018, with the outcomes presented in the 2018 Mine Closure Plan. In 2019, following the completion of another closure risk review and release of the 2018 Mine Closure Plan, the risk register was updated to incorporate the comments received from stakeholders. The closure risk register continues to be regularly reviewed and updated.

An overview of the risk management standards and requirements is included in Section 7.1. The following sections describe the key standards and requirements, outcomes of previous risk based assessments relevant to closure, the risk assessment process and the outcomes of the 2020 risk review. The updated closure risk assessment is provided in Appendix 7.1.

7.1 Standards and requirements

ERA developed the Hazard Identification and Risk Management Standard (ERA 2018) to ensure that all hazards, aspects and opportunities for a particular project are identified and all impacts to the business, people, property, assets and the environment are assessed, with strategies developed to manage these risks. This 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 [2]AS4801 national standards. The basic AS/NZS ISO 31000 process as detailed in Figure 7-1 below will be the procedural framework for management of risks on the Ranger Closure.

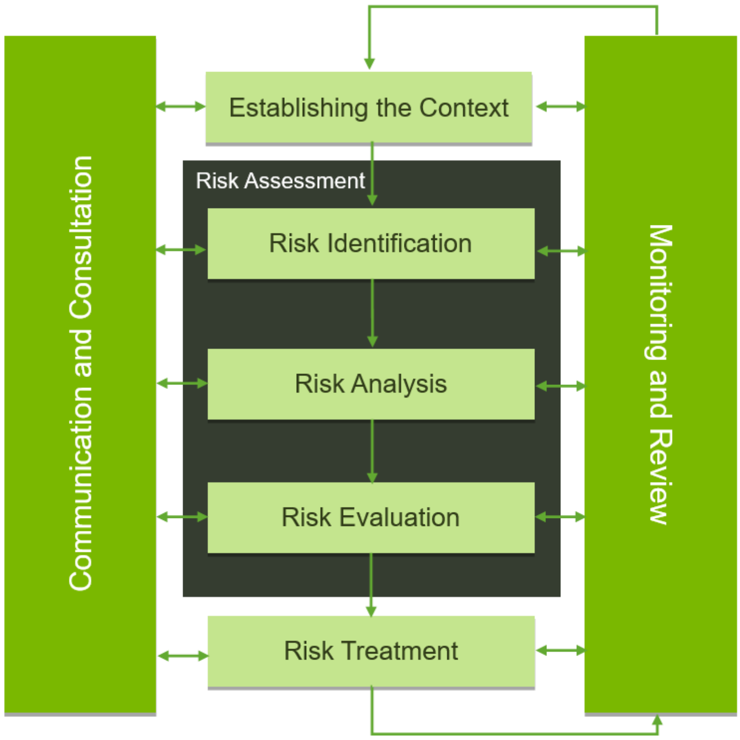

Figure 7-1: - ISO 31000 Risk Management Process

The risk identification and assessment process generates a comprehensive list of risks (threats and opportunities) that have the potential to prevent, degrade, delay or enhance the Project goals and objectives.

Potential events are clearly defined to identify the nature, likelihood, magnitude and severity of impacts.

[2] AS4801 has been superseded by ISO 45001. ERA will move to ISO 45001 in 2021

Each event will be analysed to identify plausible causes and establish causal pathways. Causes and hazards associated with the risk are assessed singularly and cumulatively. Preventative and mitigating controls are identified directly related to the causal pathways and the application of the Hierarchy of Controls considered for each control identified. This management process is consistent with the following national and corporate management standards:

- AS/NZS ISO 14001 Environmental management systems – specification with guidance for use
- AS4801[2] 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 standard
- Rio Tinto Health, Safety and Environment (HSE) management system – Element 3 hazard identification and risk assessment
- 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, to minimise risk through the implementation of effective controls that enable:

- the protection of attributes for which the Kakadu National Park (NP) 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 all potential environmental closure risks through several risk assessments completed to date.

The outcome of past and recent risk assessments and modelling studies (solute transport, tailings consolidation etc.) inform the assessment, along with sources, pathways and receptors as discussed previously with stakeholders (Bartolo et al. 2013).

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. The following risk assessments were reviewed:

- 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 TSF 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. This risk analysis takes controls into consideration.
- 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 at the time. As part of the scoping, the BPT options were considered in the risk assessment in addition to incorporating previous risk assessment outcomes.
- 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. The risks presented in this MCP are the health, safety, environmental and community risks extracted from this register.
- 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.
- Covid-19 risk review, 2020: This risk review was completed to address potential threats to mine closure as a result of Covid-19 impacts.
- 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 Review 2020: The purpose of this risk review 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 2020: 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. Examples are; water related risks, critical path, seeds and fire.

7.3 ERA closure risk assessment methodology

The following section describes the ERA closure risk assessment process. In summary, all closure risk assessments have been facilitated by competent personnel, involved a range of technical and subject matter experts, and followed the standard process described within the ERA and Rio Tinto hazard identification and risk management standard. The key elements of this process involve:

- 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
- developing action plans as required to support the implementation of effective control measure and assign accountabilities
- communicating risk information
- reviewing and updating risk, control 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. 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 setting 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 RPA. The risk assessment considered the threats that may occur during the closure (decommissioning, rehabilitation, early monitoring) and monitoring and maintenance phases.

Closure commences at the scheduled completion of processing in January 2021, and will continue to 2026. 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 will be implemented where required. The relinquishment phase will occur once monitoring has demonstrated the closure criteria have been achieved and a close-out certificate has been issued. It is in this period the site will be returned to the Traditional Owners, and the site may be incorporated within Kakadu NP in the future.

The scope of the closure risk assessment included risks associated with:

- ERA 'License to Close'
- engineering and design of mine closure
- implementation of mine closure activities
- implementation of maintenance and monitoring

The following aspects were excluded from the assessment:

- socio-economic related risks as this will form a separate assessment
- business economic and reputational risks
- closure and rehabilitation risks associated with the infrastructure immediately south of the Jabiru Airport (identified as the Jabiru field station currently and occupied by the ERISS)

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
- all existing ERA controls will continue to be applied where applicable
- 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 risks related to mine closure based on operational and planned closure activities.

The Project Risk Management process is intended to identify and manage risks not being managed under the existing business processes of ERA, contractors, consultants or suppliers (e.g. those risks that require additional management effort outside of existing procedures). Emphasis is on the development of purpose-specific, risk-based plans at various stages within the project delivery functions.

During management of each major deliverable, risks found to have a material impact to the project objectives (Class III and Class IV) shall be transferred to the closure project portfolio for ongoing monitoring and treatment.

7.3.5 Risk Relationships

All risks have a Risk Breakdown Structure (RBS) element selected within the risk database at the time of evaluation. The RBS element categorises the risk for all future reporting. A risk taxonomy must also be selected that allows for tracking and identification of similarly themed risks (e.g. hydrogeology, tailings transfer).

The risk breakdown structure includes:

- approvals
- studies
- tailings transfer
- Pit 3 capping
- demolition
- bulk material movement
- revegetation
- post-closure
- recruitment
- site wide
- process water capital works
- pond water treatment
- storage facilities
- Brine Concentrator operations
- HDS water treatment
- brine injection

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 will remain applicable during closure. Existing controls are taken into account when determining the risk ranking, thus the “residual” rather than the “inherent” (baseline) risk is determined in the final 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 threat. The risk classification is a function of the threat 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 considered to be 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 - Threats	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 risk class determination tables associated with the 5 x 5 risk matrix were referenced in order to determine a consequence and likelihood rating for each closure threat.

The consequence rating criteria (Table 7-3) 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.

The criteria for assessing the likelihood rating (Table 7-4) are used to assign a qualitative probability of occurrence that ranges from “rare” to “almost certain.”

It is noted that some risks are considered with reference to the 10,000 year timeframe. The likelihood rankings used by ERA do not span this timeframe; however, the consequence of the risk occurring any time within the 10,000 years is assessed. Based on this, the likelihood descriptors are considered appropriate.

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 threat to evaluate whether they will sufficiently mitigate the risk (Table 7-5). If the controls for any given threat 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 resolved via informal discussion or direct engagement	3 - Breaches resulting in formal notices or written warnings	4 - Breaches resulting in low-level fines or payments	5 - Breaches resulting in fines, settlements or payments that are material at the Site level	6 - Breaches resulting in fines, settlements or payments that are material at the Business Unit level
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 risk as a part of normal project activities.

Communication is also supported by a formal project risk reporting process, as outlined in Figure 7-2 Figure 7-2 Risk Reporting Structure below.

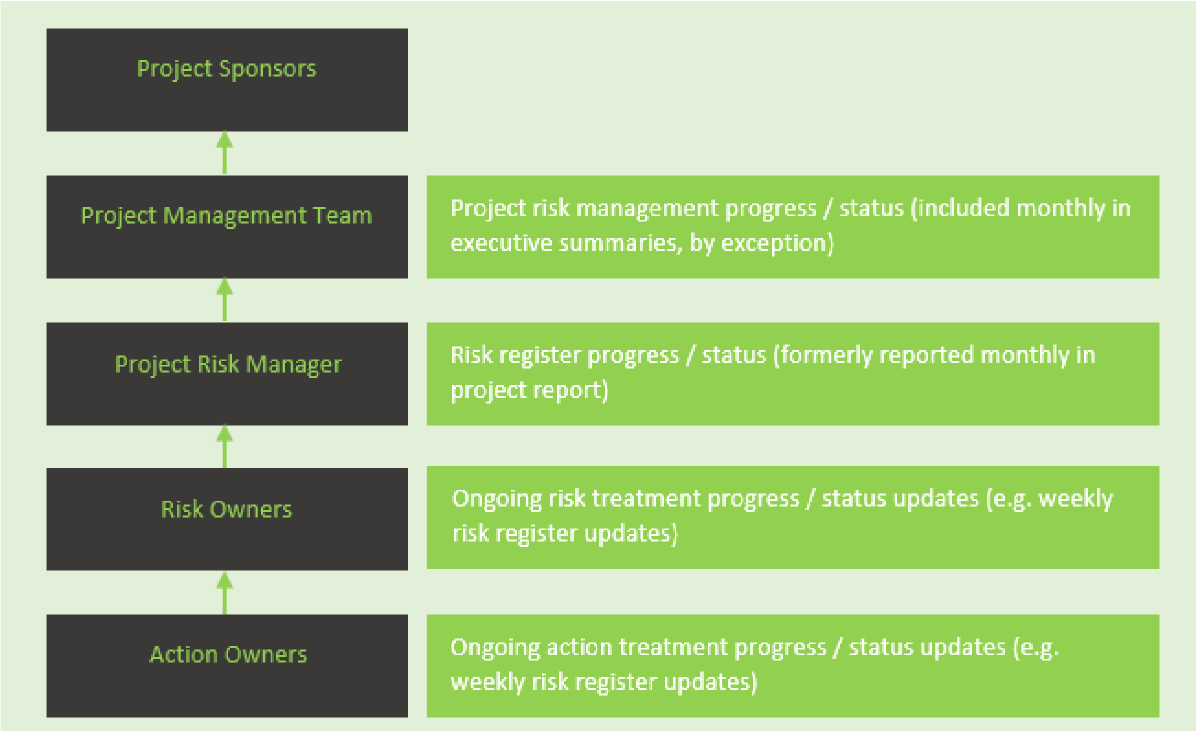

Figure 7-2 Risk Reporting Structure

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 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'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.
- 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.

- 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

Figure 7-3 below shows the open 2019 risk class distribution against the open 2020 risk class distribution. There are 46 open risks as of June 2020 with three Class IV (Critical) risks, an increase of 2, seventeen Class III (High) risks, an increase of 3 and a reduction of 6 class II risks and no change to class I risks.

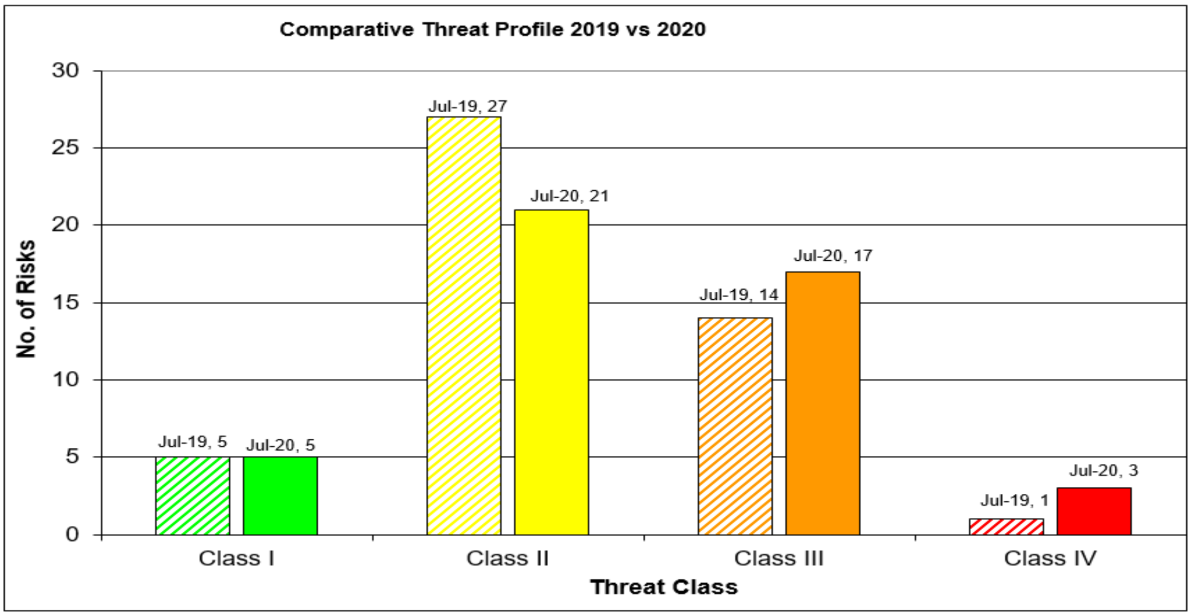

Figure 7-3 2019 risk profile vs 2020 open risk profile

7.4.1 Closure Class IV risks

A total of three Class IV (Critical) risks were identified following the review of the closure risk register in June 2020. The threats assigned this risk classification included:

- Failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu NP.
- Rainfall is greater than planned in the Water Model (P50) increasing the process water inventory requiring management, leading to later completion of process water treatment than planned
- Unable to inject brine into the underfill

The causes, impacts, existing controls, evaluation rationale and planned actions for each of the threats above are detailed within Appendix 7.1 and 7.2.

The Class IV risk detailed in the 2019 MCP, insufficient volume or quality of viable seed stock available for whole of site revegetation, was actively managed throughout 2019 and 2020 and has be re-evaluated to a Class III risk. Some of the actions completed during the past 12 months include the upgrade of the Ranger Nursery with increased security and fire protection, the evaluation of viability of historical seed, development of a seed tracking metric and the commencement of routine seed collection on the RPA. The current open actions for this risk are detailed within Appendix 7.1.

7.4.2 Closure Class III risks

A total of seventeen Class III (High) risks were identified following the review of the closure risk register in June 2020. The threats assigned with this risk classification included:

- Ranger Mine impacts the local economics
- contaminated material leaves site during closure activities
- inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), lead to inadequate water treatment tactics (critical path)
- insufficient volume or quality of viable seed stock available for whole of site revegetation
- large scale fire or natural disaster (e.g. cyclone) destroys immature vegetation
- low plant survival rates in the field during establishment and vegetation decline after/at establishment
- planned active process water treatment tactics (i.e. plant capacity) do not meet the assumed productivities modelled for site inventory reduction (critical path)
- process water exceeds MOL in Pit 3
- site condition at 8 Jan 2026 does not meet Stakeholder expectations
- solute transport outcomes do not match modelled behaviour, breaching closure criteria
- tailings exceeds MOL in Pit 3
- Tailings Storage Facility wall breached during deconstruction works while still in use
- increased TSS in process water feed to Brine Concentrator
- removal of remnant tailings takes longer than planned
- groundwater drawn into underdrain during operation of pumps

- subaqueously installed geotextile fails to meet design requirements for geotechnical strength
- brine storage assumptions do not meet the storage requirements for site salt inventory

The causes, impacts, existing controls, evaluation rationale and planned actions for each of the threats above are detailed within Appendix 7.1 and 7.2.

Figure 7-4 provides a snapshot overview of how the overall control effectiveness and the overall action status is managed through the RSA Archer Integrated Risk Platform in ERA. The overview indicates the health of the individual risks, actions and provides detail on the current trends.

Figure 7-4 Overall risk portfolio

Risk Record	Current Risk Class	Risk Matrix	Risk Matrix Values	Maximum Reasonable Consequence	Overall Control Effectiveness	Overall Action Status	Current Risk Trend
Failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu National Park [597589]	IV		107 - Threat-High-Possible	Environment,	Satisfactory	Resourced and On Track	Stable
Unable to inject brine into underfill. [504876]	IV		104 - Threat-Very High-Possible	Total Cost of Closure, Schedule Time,	Marginal	Resourced and On Track	Increasing
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. [504166]	IV		107 - Threat-High-Possible	Schedule Time,	Good	Resourced and On Track	Increasing
Increased TSS in process water feed to Brine Concentrator [691266]	III		117 - Threat-High-Unlikely	Schedule Time,	Satisfactory	Resourced and On Track	Stable

7.5 References

Bartolo, R, Parker, S, van Dam, R, Bollhöfer, A, Kai-Nielsen, K, Erskine, W, Humphrey, C & Jones, D. 2013. *Conceptual models of stressor pathways for the operational phase of Ranger Uranium Mine.* Supervising Scientist, Darwin. January.

Department of Industry, Innovation and Science (DIIS) 2016. *Leading Practice handbook: Risk Management*. Leading Practice Sustainable Development Program in the Mining Industry produced by the Department of Industry, Innovation and Science, Canberra.

Energy Resources of Australia Ltd 2018*. HSEC Hazard Identification and Risk Management. ERA Standard ER003*. Energy Resources of Australia Ltd, 12 July 2018.

Rio Tinto 2019. *Risk Management Standard. RIS-B-001*

APPENDIX 7.1 RANGER CLOSURE RISK ASSESSMENT

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
503350	Airport is unable to be retained and handed over to stakeholders	Lack of agreement between government and stakeholders on a future state and funding arrangement for airport.	Inability to maintain FIFO arrangement to end of Closure activities.	Involvement in Jabiru Stakeholder Planning Group. [503351]	Agreement likely due to the essential services provided by the airport, and the active participation within the Jabiru Stakeholder Planning.				Unrated	I		Handover of airport to new operator [503353]	Open
504214	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 concentration too low. Errors in site salt balance (additional salt mobilised due to lower than modelled process water pH).	Increased cost from alternative salt storage system. Increased schedule for alternate salt storage. Brine reaches the underdrain - potential shutdown of brine injection.	Brine concentrator operational quality assurance. [504259] Conductivity meter on the underdrain water flow. [504264] Flowrate measurement. [504270] HDS plant incorporated into water model. [504252] Manual water sampling. [504268] Underfill engineered with a 20% contingency (based on 100% of process water treated via BC). [504236] Underfill volume review of as-built undertaken (Mark Coghill Nov. 2016) and determined contingency of 20%. [504242] Water model contains assured salt balance module. [504247]	High level of confidence in brine storage space available. Contingency plans being finalised.	07/07/20 Annual risk workshop determined new action and no change to risk. EOI out for the development of an alternative brine disposal option	Stable	14/07/2020	Satisfactory	III		Contingency plan for brine injection system development [706768] Develop alternative contingency options for incremental storage of salt. [504326] Develop an action plan (Decision Tree) for response to brine break through into underdrain. [504328] Issue Expression of interest for the development of an alternative brine disposal option [726641] Re-instate brine injection and monitor/assess effectiveness. [726535]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
505289	Cannot achieve revegetation planting rates	Insufficient rest provisions in schedule. Dehydration. Assumed cycle times are optimistic. No cool rooms available. Little precedent for proposed process - semi-mechanised, waste rock. Cultural requirements for random planting pattern. Workforce not acclimatised to local conditions. Commercial payment structure. Workforce unfit for work - medical conditions, etc. Unknown medical conditions. Larger plants from nursery than planned.	Schedule delay. Additional cost for larger crews/additional resources to maintain schedule. H&S incident. Poor quality planting leading to higher mortality.	Existing H&S processes and procedures. [505290]	Lower productivity leads to increased resources to meet schedule. Increases revegetation costs by 25%.	07/07/20 Annual workshop determined no change.	Stable	21/07/2020	Unrated	II		Assess mechanically-assisted planting methods. [505294] Completion of the revegetation handover checklist [600371] Conduct heat-stress analysis of planting activities to inform thermal stress and hydration management plan. [505293] Incorporate stage 13 results into revegetation plan [600376] Utilise learnings from Pit 1 revegetation program to confirm assumed planting rates and update revegetation plan. [505292]	Open
505219	Cannot achieve the desired tailings surface for post-deposition activities in Pit 3	Uneven deposition of tailings. Excessive segregation. Uneven consolidation.	Delay in Pit 3 capping works. Difficulty collecting process water expressed from tailings (impacts dewatering). Extended consolidation. Failure of geotextile material (tearing). Eruptions of tailings through capping.	Consolidation modelling. [505220] Ongoing monitoring and modelling of tailings during deposition phase. [602110] Pit 3 capping methodologies. [505222] Pit 3 wicking design complete. [505223] Tailings Deposition Plan [505221] Pit 3 decant engineering design incorporating outcomes from tailings deposition plan and consolidation model. [505230]	Final engineering to be completed. Potential for several additional decant wells. Additional 3-month schedule delay. Potential to affect geotextiles, design and installation.	07/07/20 Annual risk workshop determined re-evaluation to class II.	Stable	14/07/2020	Marginal	II	Extremely difficult to manage (M3)	Confirm final deposition plan and tailings surface - Document required tailings capping method. [505232] Develop plan for re-profiling of tailings to occur in parallel with TSF cleaning. [505233] Incorporate engineering review immediately post tailings deposition into the CIP and schedule (CPT, wicking design etc). [505231] Update consolidation model based on latest Pit 3 Fugro survey and CPT testing. [505228]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
504047	Closure of Ranger Mine impacts on local economics	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.	Engagement with stakeholders on future state. [504049] Public updates through Town Hall meetings and local media. Closure schedule developed. [504050] SIA (social impact assessment) [504048] Continue local employment programs to build a future employable workforce. [504058] Support Commonwealth and NTG enquiries into local economic impact and opportunities through involvement in Jabiru Steering Committee. [504053]	It is possible that this will occur, but ERA is working closely with the community to ensure the transition is transparent. Increasingly Jabiru master plan vision may not happen in the time frame, no alternate economic model, this may add pressure to fund employment, housing rental etc.	07/07/20 Annual workshop determined that this risk is re-evaluated to class III due to the possibility of the Jabiru master plan taking longer to put in place, no alternate economic model, this may add pressure to fund employment, housing rental etc.	Increasing	21/07/2020	Unrated	III		Communicate ERA's plan for Jabiru exit (timing) when appropriate. [504056] Complete SIA refresh in particular the economic assessment portion. [504052] Develop sustainable programs, practices and support business development to align with Jabiru future. [504057] Provide relevant information to royalty recipients in half yearly update to support financial planning. [504054]	Open
505352	Contaminated material leaves site during closure activities.	Equipment and tooling is not appropriately decontaminated and taken off site by contractors. Inadequate checks undertaken. Poor communications with contractors. New contractors not familiar with processes. Not continuing induction processes.	Breach of Licence. Prosecution. Impact on community health. Impact to reputation.	Changes to controlled areas summarised in CIP. [505359] Contractor induction process. [505356] ERA Radiation Management Plan. [505353] Gated security. [505355] Physical radiation induction checklist. [505357] Random testing by RSO's. [505358] RSO's within org structure. [505354] Closure Implementation Plan [505361]	This may possible even with controls in place, moderate reputational impact (limited to NT based on last incident).	07/07/20 Annual workshop increased likelihood to possible as the risk is possible even with controls in place.	Increasing	21/07/2020	Unrated	III		Develop plan for controlled area's - include in CIP [505363] Ensure inductions and on-boarding materials make expectations clear to employees and contractors. [728994] Review existing radiation procedures during shutdown - include in CIP [505364] Review security and RSO resources [505365]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
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.	Breach of NT Heritage Act and Sacred Sites Act. Reputation impacted. Cost of remediation. Fines. Civil/criminal action. Loss of trust.	AAPA certificate. [505865] Access restricted to sites through signage and / or fencing. Cultural Heritage Management Plan for closure includes mitigation measures, incident process and additional security of sensitive sites. [505868] Cultural Heritage Management system including general induction and heritage induction. [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]	Cultural heritage GIS complete. All sites identified.	07/07/20 Annual workshop. Cultural heritage GIS complete. All sites identified. Unlikely to occur. Risk re-evaluated to class II.	Stable	15/07/2020	Satisfactory	II	Easily managed by entity (M1)	Build cultural heritage capacity with Djurrubu Rangers [616907] Cultural heritage management plan to be developed including mitigation measures [505872] Incident process captured in cultural heritage management plan [505874] Review the need for new AAPA certificate for rehabilitation. [505875] Review the roles required to have a cultural heritage induction. [505877]	Open
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]	Unlikely probability as management plans effective in preventing such a risk during operations, and will continue during closure works	07/07/20 Annual workshop determined no change to this risk.	Stable	21/07/2020	Unrated	II		Identify protection measures to remain in place based on post-rehab monitoring plan [506034] Investigate AAPA certificate schedule (including what point it is no longer needed based on risk) [506033] Review land disturbance permit process for post-closure and rehab suitability [506035]	Open
694586	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, HME, construction facilities). Inability to agree upon location with stakeholders. Water treatment infrastructure is required post backfill of Pit 3.	Schedule overrun. Cost overruns. Potential offsite disposal (higher cost).	Closure schedule. [507994] Decontaminate and transport materials off-site. [694589] RP2 planned for Phase 2 demolition material. [694588]	Opened for MCP, but is well managed now RP2 will be used for disposal	07/07/20 Annual workshop determined risk to be trending down as RP2 is the alternative disposal location when approval comes through.	Decreasing	22/07/2020	Unrated	I	Easily managed by entity (M1)		Open

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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.	Non-compliance with ER 3.1. Increased uptake of metals.	ARRTC process and key knowledge needs developed. [500616] Bush food consumption restrictions to particular areas of the RPA may apply post closure. [694655] Closure criteria working group [507828] Site specific research undertaken against identified knowledge gaps. [499956] Stakeholder communication strategy and management e.g. traditional owners, MTC, ARRAC, ARRTC, technical working groups, community engagement. [693662] Stakeholder engagement. [518282]	Likelihood based on bio-accumulation potential in aquatic organisms on site. Small contribution of bush tucker from RPA to overall diet. Communication to address community concerns.	07/07/20 Annual workshop determined no change to this risk.	Stable	21/07/2020	Unrated	II	Extremely difficult to manage (M3)		Open
500751	ERA is not meeting community expectations for local employment	Number of total jobs available are reduced through closure. Some jobs require specialised skillsets. Lack of engagement with local community	Reduced economic and social benefit to community. Not being able to meet agreed ERA local employment targets; loss of reputation predominantly with federal government	Engagement with local community to identify opportunities under each work package. Potential for business to be formed and/or opportunity for existing businesses to grow. [602093] FS Closure Implementation Plan identifies packages of work suitable for local employment. [500753] Requirements defined under mining agreement. [500754]	Very low local employment during closure due to skills gap, unavailability of local labour, or poor planning.	07/07/20 Annual workshop determined no change to this risk.	Stable	21/07/2020	Unrated	II		Identify challenges/barriers for employment of local residents [500771] Include communication requirements into Community and Stakeholder Engagement Plan. [500774] Link with other local stakeholders to address work readiness e.g. A&OD, GAG, LLN. [500773] Revise local employment targets/strategy for closure [500763]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
693671	Erosion and gully formation across landform surface exposes contained tailings.	Rainfall is greater than anticipated (e.g. 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 - e.g. ripping and armouring where required. [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]	Rare likelihood due to existing controls being extensive.	07/07/20 Annual workshop determined no change to this risk.	Stable	21/07/2020	Unrated	II	Some difficulty in managing (M2)		Open

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504475	Excessive erosion impacts landform stability and revegetation success.	Final landform not matched to rainfall characteristics. Insufficient sedimentation control. Insufficient erosion control. Tailings not fully consolidated. Rainfall is greater than anticipated (e.g. 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 will be designed to minimise erosion and/or not cause erosion [602120] 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 used to design erosion controls. [504482] Landform Evolution Model (LEM) model has informed both landform design, erosion controls and sediment traps. [504476] LEM has climate change scenarios and a synthetic rainfall data set for 10,000 years. [504477] Revegetation strategy tailored to landform elements (e.g. slopes, gullies, etc.). [602118] Updated consolidated model with Pit 1 validation from monitoring data and CPT testing. Ongoing updates. [504481] Validation of consolidation models. [504479] Ongoing updates to consolidation model. [504496]	Ongoing rectification works during post-closure - earthworks and revegetation. No impact to closure schedule as in post-closure	07/07/20 Annual workshop determined LEM modelling from our RT expert shows results better than SSB model.	Decreasing	21/07/2020	Unrated	II		Complete landform flood study. [504485] Completion of the revegetation handover checklist [600371] Finalise ripping plan. [504494] Incorporate stage 13 results into revegetation plan [600376] Investigate interim sediment and erosion controls and provide sequencing plan [600381] Outcomes from flood study to inform drainage channels and sedimentation design. [504488] Provide DEM to SSB to run LEM modelling (assurance). [504490]	Open
505366	Exposure of people to radioactive materials during demolition and decommissioning.	Dust hang-up in Mill. Calciner residual material. SX tanks residual material. Poor decommissioning and cleaning post Mill closure. Incorrect demolition methodology. Lack of radiation support. Removal of density gauges.	Workers exposed have negative health impacts. Breaches of Licence conditions. Reputational impact. Schedule impact pending investigation.	Controlled areas. [505372]. Decommissioning and demolition plan. [505374]. Established standards of protection from radiation. (e.g. radiation protection system, PPE) [505367]. Inductions and training. [505373]. Medicals and monitoring. [505371] Membership of professional networks. [505370] Org structure currently includes RSO roles. [505368] Significant corporate knowledge and experience [505369] Closure Implementation Plan [767664]	New activities during decommissioning, only administrative controls therefore likelihood greater than Rare.	07/07/20 Annual workshop determined no change.	Stable	21/07/2020	Unrated	II		Develop detailed de-commissioning and decontamination plan for Milling area. [505411] Upload historic radiation records into national database. [505426]	Open

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597589	Failure to contain and/or eradicate Spigelia weed from the operations area causing infestation in Kakadu NP	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).	Dedicated resources to manage treatment [616678] External Stakeholder monitoring, managing and regular consultation [616681] Monthly reporting to weeds Branch of GOVT. [597593] Operational Weed Management plan [597591] Polaris ATV used for weed management [607791] Regular monitoring and surveys of Spigelia weed [597592] Site wide weed management plan [597590] Weed specific training (excl. Spigelia) [597594]	Consequences were determined based on the nominal financial impact compared to the costlier reputational impact. More recent review completed on 22/01/2020 (SRA workshop) where likelihood of risk occurring was increased due to increased germination (in previously unknown areas) from rainfall.	07/07/20 Annual workshop. Risk is considered stable until controls are validated, embedded and working. However if spread into the creek system it will be very hard to control.	Stable	13/07/2020	Satisfactory	IV	Some difficulty in managing (M2)	AFE procure and deliver Polaris ATV [597598] Develop and implement ERA staff weed (incl. Spigelia) training [597597] Develop annual report including review of program effectiveness to inform continuous improvement. [700452] Incorporate Spigelia into current processes and documentation [597596] Procure mini iPad for Spigelia weed monitoring [700453] Update induction to include weed awareness [616684]	Open
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 (e.g. buffalo)	Active feral animal management aligned with current operational practices. [694626] Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [602396]	Unlikely probability that feral numbers will be higher than surrounding as will be managed initially and then likely to be similar to surrounding populations as aim is to achieve similar environs	This risk will always be class II as it remains a risk but solid management practices are in place. Closure resources includes feral animal shooting resource.	Stable	7/04/2020	Unrated	II	Easily managed by entity (M1)		Open
506016	Final landform fails to meet biodiversity "similarity" indices.	Insufficient diversity and abundance of flora and fauna to meet defined trajectories. Changes in biodiversity survey techniques. Lack of artificial habitat to encourage fauna.	Non-compliance with ER 2.1. Requires adjustment to flora species list.		Unlikely due to the KKN's planned to address any gaps in understanding prior to finalisation of rehabilitation	Fortnightly risk meeting determined that risk was stable at this time.	Stable	8/12/2020	Unrated	II		Develop mitigation plan. [506018]	Open

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504633	Groundwater drawn into under drain during operation of pumps.	Location of the Bore. Bore not constructed to specification. Ground water seepage from additional sources.	Causes delay in schedule due to inability to inject brine and additional water treatment. Additional cost.	25 meters of grouting at the bottom of the hole. [707080] Conductivity meter on the underdrain water flow. [504634] Flowrate measurement. [504636] Location of bore in geologically-competent ground. [504637] Manual water sampling. [504635]	Failure of bore requires additional process water to be treated (100 Ml x 4 years) - continue to operate under drain.	07/07/20. Annual workshop determined risk is possible for now but will soon be unlikely due to outcome of bore rehabilitation and testing of the pumps.	Decreasing	15/07/2020	Satisfactory	III		Create a plan C (contingency) [608172] Ensure fortnightly meeting covers the operational philosophy of the bore. [726832] QA on bore construction. [504639]	Open
505272	Groundwater inflows to process water are greater than expected.	1G projects fail to prevent groundwater. Interception projects. MBL bores. Validation of water model fails to identify issues	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.	1G projects package [767670]	6 month extension for process water treatment.	07/07/20 Annual workshop considered risk stable at this time, no change.	Stable	21/07/2020	Unrated	II		Adequately resource 1G projects. [505275] Continue work to allow MBL to be reinstated. [505274]	Open

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504367	Inaccuracies or simplifications in the water model, excluding rainfall and water treatment rates (managed in other risks), leads to inadequate water treatment tactics (critical path).	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.	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.	Annual Water Model validation (external assurance). [504369] Regular bathymetric surveys of free process water inventory used to validate model. [504368]	6 month extension for process water treatment.	07/07/20 Annual workshop. Will keep as trending until information comes back from the consolidation model work in Late July	Increasing	15/07/2020	Satisfactory	III		Complete 1G project desktop review [678240] Conduct a 1G project workshop [678243] Implement approved water model management plan [678432] Update consolidation model [682602]	Open
694628	Increased aquatic weed establishment in RPA billabongs impacts Kakadu NP	Transfer from surrounding environment, vehicles, transient fauna. Transport of weeds from surrounding Kakadu NP.	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] Operational Weed Management plan [597591]	Paragrass is in the Kakadu NP - but not upstream from Ranger Mine	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	I	Some difficulty in managing (M2)		Open
691266	Increased TSS in process water feed to Brine Concentrator	High TSS due to the source of the process water (e.g. pit 3 or TSF silt carryover). Brine injection system not commencing as per schedule resulting in recirculating concentrated brine to TSF.	Impact to Brine Concentrator distillate production. Increased scaling through the Brine Concentrator. High TSS in brine could block the porous injection cavity.	BC feed can be drawn from the TSF [726836] Change in process water sampling point [726840] Silt curtain added to the pumps [706841]	Potential for schedule delay based on operation of the brine injection system.	15/05/20 Quarterly class III & IV workshop. Risk considered stable at this time. Removed control 700014.	Stable	6/01/2020	Satisfactory	III	Easily managed by entity (M1)	Commission brine injection system [700016] Ensure process water sampling point change is reflected in procedures. [726839] Ensure there is the ability to switch back to tailings dam as contingency [706852] Review additional injection wells [700018]	Open

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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 propagators. Lack of viable seed. Technical issues in the nursery - e.g. disease, procedures, equipment failures. Poor production rates. Poor nursery implementation planning. Low plant propagation success.	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]. 30% allowance for unviable seeds. [505251]. Alternative off site nursery available if required. [602401] Disease control activities in nursery. [505254] Expert propagation knowledge and implementation provided by existing contractor. [602399] Learnings from Pit 1 will be taken into remaining work - lead time for additional seeds & seedlings. [505256] Management of combustibles in nursery area. [505253] Nursery constructed on site [602400] Nursery secured. [505252] Planting and propagation trials successfully completed. [505255]	Insufficient volume leads to 6-month delay in revegetation. Stakeholder acceptance achieved through continued active management during post-closure.	07/07/20 workshop determined risk is increasing due to 1. Recent seed viability test wrote off some old seeds. 2. ERA/KNPS have limited knowledge/skill in raising tubestock in the cool weather (dry season) 3. Potentially further compressed planting towards the end of 2025. 4. Risks of major disease and failure of the irrigation system still present.	Increasing	22/07/2020	Unrated	II		Completion of the revegetation handover checklist [600371] Confirm seed collection and propagation plan has sufficient contingency. [505258] Incorporate stage 13 results into revegetation plan [600376] Investigate the use of tissue culture techniques for use at ERA. [728127] Review current nursery management controls for gaps. [505259]	Open

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504574	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/labour force to meet demand. Limited seed harvesting capacity. Loss of seed (fire, theft, disease, vermin, fungus) Loss of license to collect seed. Air conditioning fails in seed store. Variable seed viability after collection. Inadequate land access. Inadequate resources for seed collection.	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.	95% of stems for shrubs and trees will be planted via tube-stock rather than direct seeding (significantly less seed required) [602122] Alternative arrangement in place with suitable third party supplier for tube-stock propagation, including support with optimizing plant germination and propagation (i.e. maximize seed value) (e.g. MOU with Greening Australia) [504582] Backup air-conditioning in seed storage room. [504584] Contractor purchased required equipment. [504577] Current seed collection permit with KNP. [504576] Dedicated equipment for collecting grass seed [557230] Dedicated equipment for collection of seed i.e. EWP, brush harvester. [693553] ERA conducts annual seed collection on the Ranger Project Area (RPA). [504585] Fit for purpose nursery facility. [693556] Fit for purpose seed storage facility including climate control, security etc. [693557] 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. [504575] Quality assurance process applied to seed management (viability testing regime). [693559] Revegetation Management Plan. [504587] Seed management database, collection schedule and metric to manage performance. [504578] Site environment team collecting on lease. [504581] Stakeholder agreed tree and shrub species list. [504580] Two separate seed storage locations in use [726843] Handover process for handover between packages (e.g. decommissioning to demolition). [505281]	Further contingency actions in place to reduce the likelihood of a 1 year delay to the completion to the revegetation program to achieve the desired density and floristic diversity.	07/07/20 Annual workshop added an action and accepted risk at current evaluation.	Stable	15/07/2020	Good	III		Confirm details around MOU for Greening Australia and/or gain agreement in writing. [693562] Develop procedures for planning and management of seed collection. [693565] Develop seed collection contract. [693563] Develop seed collection procurement strategy [726845] Gain agreement with traditional owners re: alternative species that are more resilient to the waste rock substrate [557231] Incorporate stage 13 results into revegetation plan [600376] Price vegetative propagation as a contingency plan [557228] Renew seed collection permit with KNP. [504593] Review seed viability (including storage, handling, duration of viability) [504599] Secure Contract in place with seed and plant provider. [504595]	Open

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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] 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 [602396] Restricted access to revegetation areas [607816] Revegetation strategy designed to meet closure criteria for resilience (e.g. species mix, irrigation, weed monitoring, viability/germination rate/mortality rate/large scale failure contingency) [602395] Waste rock surface has low fire risk for 5-7 years post-planting. [505240] Weed control and fire management, including buffer zones (~200m surrounding revegetation). [602393]	Evaluation based on meeting rehabilitation requirements in Jan 2026. Cyclone or bush-fire event destroys large areas of revegetated zone. Loss of nursery, seed stocks and source plants due to cyclone would take longer to re-establish even using third party suppliers.	07/07/20 Annual workshop noted risk unlikely, however still class III as there is potential for cyclone to also take out nursery, seed stocks as well as the immature vegetation and this will take longer to re-establish even through third party suppliers. Additional action applied.	Stable	15/07/2020	Satisfactory	III		Develop / Update weed management plan for post closure [607819] Develop plan to manage fire risk to exclude fire from revegetated areas for first 5 years post planting [587522] Ensure associated management plans for nursery and emergency response address contingency management for seeds managed in both locations (nursery and Inganaar building). [726898] Include this risk in state and transition model [607817] Seed Collection Plan to allow for 20% large scale failure. Monitor actual collection against plan. [505247]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
694659	Legacy erosion areas persist post 2026.	Inadequate controls are implemented during the mine's operational phase.	Ongoing erosion and deposition in downstream drainage lines.	Erosion structures are incorporated into landform design - e.g. ripping and armouring where required. [693677] Establishment of vegetative surfaces to reduce erosion. [693676] Final designed landform does not contain slopes > 4%. [504480] Implementation of a QA program for landform construction and erosion controls. [693679] Land form erosion modelling by SSB. [504904] Ongoing maintenance of erosion structures and mitigation of gully formation, post decommissioning. [693678]	Unlikely as legacy erosion areas will be addressed in closure activities and monitoring will determine if there are erosion issues requiring remedial earthworks.	07/07/20 Annual workshop. Risk considered stable at this time, no change.	Stable	22/07/2020	Unrated	II	Easily managed by entity (M1)		Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
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. Note this risk does not include fire or extreme weather events - these are included in TD.01.10.	Reduction in floristic diversity and density. 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 from 20% to 40% (60% survival).	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. [504502] Irrigation for first 6 months post-planting. [504508] Plant available water modelling predictions indicate sufficient water holding capacity of waste rock to support vegetation [504503] Ripping of landform. [504506] Sub-surface compaction layers increase water holding capacity of waste rock [504513] Trial landforms completed to demonstrate viability of vegetation in waste rock. [504501] Use of biodegradable pots. [504507] Watering of plants (irrigation) in early stages but not long term. [504505]	Additional 20% of plants die. Sufficient seed and plant stock available to replant so only low schedule impact. Potential for up to $10m additional cost. Revegetation plan will be updated with experience on Pit 1 in 2020 - following this it is anticipated the likelihood will be reduced.	07/07/20 Annual workshop determined that the risk is trending down due to the good success of the pit 1 irrigation and planting trials. However, there is still work to validate the long term survival rates and matching the reference site to correct species and terrain to reduce mortality as well as increased confidence with long term watering abilities and outcomes.	Decreasing	20/07/2020	Good	III		Additional planting methods (i.e. plant guards, water crystals etc.). [504520] Assessment of particle size distribution of waste rock to inform PAW. [504530] Complete study / trial on understory development on waste rock (CDU and ERA studies). [504516] Completion of the revegetation handover checklist [600371] Conduct nutrient cycling study. [504525] Confirm assumptions contained within Plant Available Water Study. [504517] Finalise Revegetation and Post-Closure Management Plans. [504524] Further studies as per KKN's. [504518] Incorporate stage 13 results into revegetation plan [600376] NESP study into magnesium sulfate concentration in ground water impacting vegetation. [504532] Review assumed mortality rates in view of use of biodegradable pots. [504519] Stockpile drilling to inform perched water table. [504522] Update revegetation plan following experience from Pit 1. [504521]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
694597	Major native fauna do not return to landform.	Reduction in floristic diversity and density. 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	Reduced representation in functional groups. Unable to meet cultural criteria for a sustainable food and medicinal source. No fertilization some animal pollinated of flora groups Lack of sustainability of established ecosystems	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] Islands of translocated leaf litters and hummus (containing invertebrates) [694618] Ongoing liaison with KNP regarding fire, weed and feral animal management strategies [602396] Onsite water quality meets international guidelines for wildlife drinking water. [694602] Operational Weed Management plan [597591] Revegetation Strategy [694601] Weed control and fire management, including buffer zones (~200m surrounding revegetation). [602393] YFM001 Fire Management Plan [694615]	Unlikely probability due to the ability of fauna to egress from adjacent NP to rehabilitation sites	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II	Some difficulty in managing (M2)		Open
504069	No mechanism is currently available to allow access to RPA from 9th January 2026.	Section 44 agreement does not allow access to RPA beyond January 2026.	Standard of site closure cannot be maintained in early years causing legacy issues. Stakeholders seek to impose access arrangements on onerous terms.	Acknowledgement by stakeholders that certain monitoring and maintenance activites are required for a number of years post January 2026. [504071]	Long lead time until 2026 and good working relationship therefore unlikely the ability access will not be available.	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II		Confirm terms of access arrangements. [504074] Continue engagement with DIIS regarding access arrangements for post 9 January 2026. [504073]	Open
504895	Offsite disposal of blackjack is not possible due to inability of waste contractor to gain the necessary approvals.	Contractor cannot demonstrate facility meets environmental requirements. Incident at facility causes loss of operating license.	Onsite disposal option required.	Active engagement with preferred contractor. [505235] Contractor has received state approvals. [505236]	Approvals received, risk managed. 2nd option from BPT is implemented - onsite incineration.	07/07/20 Annual workshop determined no change. Covid-19 delays have been experienced.	Increasing	22/07/2020	Unrated	I		Continue engagement with contractor until contract in place. [504898]	Open

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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	Actions to manage this issue included in the Communities and Stakeholder Engagement Plan. [503406] Relationship committee meeting. [503405] Water monitoring program. External Relations team is on mailing list for enviro water monitoring to proactively manage media. [503404]	There is a low risk that the TO perceptions do not match that which has been achieved in rehabilitation.	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II		Capture details and strategy in the Communities and Stakeholder Engagement Plan [503408] Utilise interpreter during relationship committee meeting with Traditional Owners to ensure messaging on closure environmental and health risks are well understood [503409]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
504648	Planned active process water treatment tactics (i.e. plant capacity) do not meet the assumed productivities modelled for site inventory reduction (critical path).	BC does not achieve sustainable planned production profile. Two BC heat exchangers are inadequate to operate at full capacity due to higher TDS and higher brine flow rates (current design is 1 duty). BC upgrades not achieved or delayed (to 125%). Higher TDS impacts BC productivity. Implementation of brine squeezer delayed. Brine squeezer does not perform as planned. HDS plant (2 Ml/d) does not deliver planned treatment rates. Membrane process water treatment (squeezer-like) does not deliver planned treatment rates.	Additional process water treatment increases schedule beyond closure date - cost + legal/regulatory & reputational impacts. Increased cost from additional process water treatment through the BC. Increase cost from higher BC operating costs. 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.	BC evaporator vessel scaling issue understood and addressed. [504649] BC fan upgrade study planned. [504652] BC operation has reached a sustained rate of 115% with no fan upgrade and is operating consistently at a higher rate than in the current water model. [504651] BC seed cyclones upgraded. [504650] Brine squeezer being implemented - schedule in Water Model. [504653] Flowsheet for lime dosing developed; established the technical viability of lime dosing option - to be incorporated into future studies work. [504657] Perform bi-annual (6 monthly) re-baselines of the water model [749042] Pilot work completed for HDS. Existing plant being refurbished. [504655] Plan for pilot work for membrane process water treatment. [504656] Sensitivity analysis on current water model complete. [504658] Appoint project manager encompassing broader risk and consequence management [608164] Recommission existing HDS plant. [504666] Reinstate brine injection operation. [504668] MTC approval for release of process water treated through OBS [676904] Define a flowsheet for lime dosing and establish the technical viability of lime dosing option to feed into FS water tactics confirmation. [504664]	Membrane process water treatment requires more frequent membrane changes leading to increased operating costs. Worst case scenario is a smaller scale evaporator to make up the shortfall. Brine squeezer confidence.	07/07/20 Annual workshop increased likely (class III) due to brine squeezer confidence (12 months on schedule and significant cost).	Increasing	22/07/2020	Marginal	III		Assess the gap in current water treatment vs. required treatment [608163] Analyse and evaluate full implications of TDS on higher BC treatment rates [593630] Communicate results of analysis to management for action [593631] Complete engineering works for full OBS plant trial [673822] Complete FS on BC fan upgrade including the requirement for a third heat exchanger (BC FS Scope). [504662] Complete installation of upgraded seed cyclones into BC. [504660] Complete OBS pre-filtration trial [672328] Implement brine squeezer infrastructure. [504663] Kick off project 1g initiative [608165] Perform a 6 monthly re-baseline of the water model (H2 2020) [749452] Sensitivity analysis on current water model. [504665] Staged OBS plant trial - pilot plant trail to treat process water using brine squeezer technology. [675333] Undertake external study on optimization of existing process water treatment infrastructure [572907] Undertake external test work program on membrane technology for process water treatment. [504667] Undertake plant based trial of pre-filtration and brine squeezer treatment of process water [572906]	Open

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691265	Potential for limited pond water storage availability (2024/2025)	Pit 3 removal for RP2 spillage. Above average rainfall recorded. High volume/storage in RP2 and RP6. Limited capacity to treat pond water for release.	Site inundation/localized flooding. 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] OPSIM Water Balance [597533] Ranger Water Management Plan [700052] TARP for Pond Water Storage Levels [700061]	The evaluation relates specifically to off-site discharge. Inundation restricted to on-site only will have schedule and operational implications. ERA is currently not authorized to discharge pond water off-site under the current Ranger Authorization without approval from the Regulator. ERA have applied for authorization for pond water discharge off-site on limited occasions throughout ~40 years (LOM).	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II	Some difficulty in managing (M2)	Complete validation of the OPSIM water balance forecast [700074] Revise the TARP018 Pond water storage level above capacity [700073] Revision and approval of the 2024/2025 Ranger Water Management Plan [700072]	Open
504641	Process water exceeds 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.	Overflow of Pit 3. Requirement to store water in TSF stops dredging operations.	MOL proposed to stakeholders based on surrounding head data to ensure Pit 3 remains a sink. [504642] Ongoing survey of the TSF floor. [504645] Regular bathymetric surveys to determine process water inventory. [504644] Tailings quantities well understood - production data and Fugro survey. [504643]	Schedule delay on cleaning TSF due to water remaining in TSF. Overtopping pit is 1:1000 year flood event.	07/07/20 Annual workshop determined no change.	Stable	20/07/2020	Satisfactory	III		Gain approval for final Pit 3 MOL. [504647] Presentation on risk detail; causes, consequences, controls and actions to be provide to management [616899]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
505984	Radiation doses from the final landform exceed dose constraint.	Mineralised material left on surface (gamma, dust and radon). Exposed tailings. Solutes expressed to surface water and mobilised. Elevated levels of contaminant (metals) in bush tucker.	Non-compliance with ER 5.	Access restrictions to particular areas of the RPA may apply post closure to keep doses below dose constraint. [505988] Active water management strategy and inventory control. Air quality assessment completed. [505993] Air quality assessment completed [604171] Data from trial landform studies has informed the landform design and LEM. [505992] Dust control during decommissioning. [505986] Engineering dose constraint of 300 µSv per year will be applied. [505989] Final landform thickness reduces the likelihood of exposing tailings and radon emanation from tailings. [505987] Iterative landform design informed by LEM. [505991] Material movement planning and stockpile resource model to identify location of 1s and 2s rock. [505985] Storm water and erosion control, design and management structures. [505990]		07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II		Air quality assessment to be completed. [505997] Complete bush tucker monitoring and assessment. [505999] Complete surface water model [505995] Identify options for restrictions on land use post-closure. [505998] Radiological dose assessment to model the predicted annual doses to be completed. [505996]	Open
506000	Radiation doses to the public exceed annual dosage limits.	Mineralised material left on surface (gamma, dust and radon). Exposed tailings - see risk TD08-01. Solutes expressed to surface water and mobilised. Elevated levels of contaminants (metals) in bush tucker.	Non-compliance with ER 5. Increased dose to public.	Access restrictions to particular areas of the RPA may apply post closure to keep doses below dose constraint. [506004] Active water management strategy and inventory control. [506008] Data from trial landform studies has informed the landform design and LEM. [506007] Dust control during decommissioning. [506002] Final landform thickness reduces the likelihood of exposing tailings and radon emanation from tailings. [506003] Iterative landform design informed by LEM. [506006] Material movement planning and stockpile resource model to identify location of 1s and 2s rock. [506001] Storm water and erosion control, design and management structures. [506005]	Would require restrictions on use - these would be minimised.	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II		Air quality assessment to be completed. [506013] Complete bush tucker monitoring and assessment. [505999] Complete surface water model [506011] Identify options for restrictions on land use post-closure. [506014] Radiological dose assessment to model the predicted annual doses to be completed. [505996]	Open

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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.	Additional 6 months of BC operation available over and above current model (reduces size of HDS plant required). [504172] BC production currently higher than planned in model (Sept 2018). [504173] Contingency plan for higher-than-planned rainfall (large scale HDS plant) - note this contingency plan is only available up to 2023 (end of Phase 1 demolition). [504170] Industry established tool used (water model) with model assured. [504167] 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] FS scope - Develop contingency plan for extreme weather event later in Closure schedule. (Run alternative scenarios of rainfall). [504180] MTC approval for release of process water treated through OBS [676904] Develop contingency plans for higher rainfall events [593627] Complete OBS pre-filtration trial [672328] Conduct a 1G project workshop [678243]	Higher than planned rainfall (P70) early in the project schedule (prior to 2022-23 wet season) results in implementation of HDS contingency at approx. 2 Ml/d. Rationale includes effect of updated BC productivities (Sept 2018) and additional 6 months of BC operation at end of schedule.	Fortnightly meeting determined risk to be stable pending thorough review of actions.	Stable	8/12/2020	Good	IV		Assess the viability of using the Pit 3 bulk backfill waste rock void as a process water storage and include into decant well design (based on Pit 1 learnings) [693029] Complete 1G project desktop review [678240] Complete a concept level study to determine a suitable location and design for RP7, including in TSF options [693027] Complete engineering works for full OBS plant trial [673822] Review and update process water inventory reduction contingency plans for the P70 and P90 cases based on the latest forecast [693026] Staged OBS plant trial - pilot plant trail to treat process water using brine squeezer technology. [675333]	Open

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505207	Removal of remnant tailings takes longer than planned (this is on critical path).	TSF amphibious excavator doesn't meet planned production rates. Floor cleaning methodology flawed. TSF floor more uneven the expected. Stakeholder acceptance of "clean" different to ERA definition. Cannot achieve water drawdown rates in TSF. Foreign objects in TSF floor.	Additional Costs. Delay to dredging. Delay to Pit 3 works.	Additional land based excavators utilised [607323] Composite floor developed. [505208] High-level methodology developed. [505209] Magnetic survey of foreign objects. [505213] Procuring amphibious excavator for wall cleaning. [505212] FS Scope - complete QRA on TSF cleaning activities. [505216] FS Scope - Finalise engineering solution including integration with dredging and wall cleaning activities. [505215]	Additional 6 months required for removal of remnant tailings.	07/07/20 Annual workshop determined risk to be increasing due to compressed schedule / wicking approvals causing potential impact to overall schedule of over 6 months.	Increasing	20/07/2020	Satisfactory	III		Finalise detailed floor cleaning plan with input from ERA Operations. [682598] Finalise detailed wall cleaning plan with input from ERA Operations. [505218]	Open

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500614	Site condition at 8 Jan 2026 does not meet Stakeholder expectations	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] Application of BPT processes [602095] ARRTC process and key knowledge needs developed. [500616] BPT and approvals process. [500625] Closure Criteria Working Group was re-engaged in 2016 and produced set of draft closure criteria. [500618] Closure Plan updates to incorporate stakeholder recommendations [500630] Communication fora (e.g. ARRTC, ARRAC, MTC, stakeholder workshops). [602096] Contingency's for closure included in Closure Plan. [500631] Continued stakeholder engagement via ongoing presentations to stakeholders through MTC and RCCF. [504195] Early engagement with stakeholders [602094] External commitments register [602097] FS schedule is transparent to stakeholders and provides pressure to endorse closure criteria. [500624] GIS study undertaken to model the potential view lines which has been approved by stakeholders. [602100] GIS study undertaken to model the potential view lines. [693666] Landform design cultural closure criteria. [693663] Nominated resource for stakeholder engagement in place - Chief Advisor. [500620] Rehabilitation Animation [608175] Socio-economic impact assessment [602098] Stakeholder communication strategy and management e.g. traditional owners, MTC, ARRAC, ARRTC, technical working groups, community engagement. [693662] 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] Update Closure Plan with updated closure criteria and submit to Minister for approval annually. [500646] Update SSB & stakeholders engagement plan for closure activities. [500640] Continue ongoing stakeholder engagement via the RCCF [500652] Create simulation (e.g. VR) of final closure site condition for communication to stakeholders. [500658]	Threat of closure criteria not being agreed prior to works being approved is covered by other risks. For example possible reinstatement of Djalkmarra billabong.	07/07/20 Annual workshop determined that risk ID 693660 is merged with this risk. Work completed with TO early on remains valid, no indications that this has changed. Also working on ripping plan for Pit 1 to get feedback on surface preferences.	Decreasing	22/07/2020	Satisfactory	III		Complete negotiation on the specific measurable requirements to be incorporated into closure criteria - target inclusion in MCP [500647] Stakeholder site visit on pit 1 ripping to be arranged. [728625] Update Contingency section in Closure Plan [500654]	Open

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504602	Solute transport outcomes do not match modelled behaviour breaching closure criteria.	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 HLUs. Incorrect assumptions of source concentrations. Higher than estimated solute load from leaving Mill plume and other contaminants in situ. Mineralised material left out of Pit 3. Seepage rates from pit tailings/waste rock are higher than predicted. Active water treatment ceases too early. Volumes of process water and pit tailings flux are not recovered and treated, as predicted. 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.	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. 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.	Baseline groundwater concentrations determined. [504612] Calibrating all the bores over 35 years. [504610] Characterisation of LAA and billabong sediments (partially complete). [504627] Contingency Plan for excessive solute transfer developed (i.e. interception trenches). [504605] Existing solute management experience. [504604] Historic and ongoing studies into erosion. [504625] Landform flood study informs sedimentation controls design. [504613] Monitoring of bores and review and validation of Intera model. [504607] Peer review of Intera Study. [504606] Post-closure Management Plan. [504628] Ranger Conceptual Model (RCM) and solute transport modelling completed. [504623] Sensitivity analysis. [504608] Solute transport and balance study ongoing by stakeholder recognised experts (Intera). [504603] TSF solute transfer study completed by Intera. [504626] Update of conceptual model to include all geological knowledge. [504609] Updated geochemical model and drilling of stockpiles to improve understanding of source concentration. [504611] Surface Water Model. [504616] Landform Flood Study to inform sedimentation control design. [504615] Validation of ground water model through monitored real data. [504618]	Low probability due to inherent conservatism in the model. Water quality in Magela creek causes environmental harm and reputation impact on national level; recovery period 1 year plus.	07/07/20 Annual workshop determined Risk ID 504622 Class II Solutes and sediments from surface runoff from final rehabilitated site enters off-site water bodies at greater than closure criteria. (surface water) merged with this risk.	Increasing	20/07/2020	Satisfactory	III		Challenge ERISS diet assumptions and concentration factors for manganese and prompt expert opinion [707693] Complete Ground Water and Surface Water interaction study [504617] Complete update to surface water model [715083] Consider reactive transport for Manganese, Ammonia, Uranium and Radium in Solute Transport Model [707692] Engage with stakeholders regarding water studies. [504620] Investigate potential hydrodynamic surface water modelling for Gulungul and other billabongs. [707695] Review source term for magnesium, manganese, ammonia, uranium and radium [707442] Undertake bathymetry and eye-sight scanning for Gulungul and other identified billabongs. [707694]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
504464	Subaqueously installed Geotextile fails to meet design requirements for geotechnical strength.	Uneven tailings surface. Subaqueous installation method in highly acidic water. Areas of large differential settlement, Inexperienced contractor. Poor material choice or quality. Lower density tailings than expected Utilization of inappropriate methodology/ contractor	Schedule (critical path) and cost overrun. Health and Safety impact (e.g. equipment sinking). Cannot install secondary capping. Heaving of tailings.	CPT testing at the end of tailings deposition to provide tailings properties. [504467] Engagement with vendors during FS. [504465] Similar works undertaken elsewhere (e.g. Port of Brisbane) Strength testing during construction of secondary cap. [504466]	Issues with surface of deposited tailings causes a delay in placement of the geotextile.	07/07/20 Annual workshop determined stable until EOI and further data validate methodologies.	Stable	20/07/2020	Satisfactory	III		Conduct field trial of geotextile chemical resistance. [504471] Conduct field trial of geotextile installation method at ERA. [504472] Engagement of a design consultant [608174] Peer review by geotechnical expert on geotechnical design [608173] Technical assurance of final geotech design. [504473]	Open
684886	Tailings exceeds MOL in Pit 3.	Additional tailings/material transferred from TSF to Pit 3. Additional tailings from mill. Notching of TSF reduces volume that can be stored in TSF. Sub-aerial deposition into water causes elevated tailings level (beach). Low density tailings result in elevated average tailings level.	Transport of solutes to Magela Creek through weathered zone. Requirement to store water in TSF stops dredging operations.	MOL proposed to stakeholders based on surrounding head data to ensure Pit 3 remains a sink. [504642] Ongoing survey of the TSF floor. [504645] Operations Maintenance Manual (OMM) Pit 3 [706862] Tailings quantities well understood - production data and Fugro survey. [504643]	Schedule delay. Cost to closure.	16/06/20 Fortnightly risk meeting determined risk was stable.	Stable	8/11/2020	Satisfactory	III	Extremely difficult to manage (M3)	Implement Operations Maintenance Manual (OMM) Pit 3 [706872] Presentation on risk detail; causes, consequences, controls and actions to be provide to management [616899]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
504385	Tailings Storage Facility wall breached during deconstruction works 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.	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 overseeing and approving all plans (Coffey). [504386] Downstream raise dam constructed with clay core [602113] Engineering supervision of construction works. [504388] 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]	Major compliance and reputation impact if was to occur.	07/07/20 Annual workshop determined new action and no change to risk.	Stable	20/07/2020	Satisfactory	III		Add information from the finalized draw down assessment and the monitoring to the TSF OMM [707378] Conduct an Independent Assurance Audit on TSF deconstruction methodology (post-FS). [504398] Develop a TSF draw down monitoring TARP (Trigger, Action, Response Plan) [728628] Update process safety hazard packages for the TSF wall cleaning works. [504400] FS Scope - Develop model for water transfers/draw down rates. [504401]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
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. [506002] Erosion structures are incorporated into landform design - e.g. ripping and armouring where required. [693677] Establishment of vegetative surfaces to reduce erosion. [693676] Alternative/adaptive landform design based on landform stability modelling. [693675] Material movement planning and stockpile resource model to identify location of 1s and 2s rock. [506001] Storm water and erosion control, design and management structures. [506005]	Unlikely probability as existing controls effective.	07/07/20 Annual workshop determined no change.	Stable	22/07/2020	Unrated	II	Easily managed by entity (M1)		Open
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. The use of cold process water to flush blocks the pipe from scale being detached. Floating Brine injection pipeline is kinked and stops/slows flow. 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 voice space as planned. Lack of operating data on brine injection due to underdrain not operational. Brine detected in underdrain. Insufficient brine void space	Brine recycling leads to increased 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 water treatment duration (with risk of additional process water from rainfall).	Ability to directional drill additional steel-cased wells with positive-displacement pumps. [504877] Assurance Plan with production metrics developed. Infrastructure built. [504878] Conductivity meter on the under-drain water flow. [602390] Data gathering plan for performance of brine injection. [504882] Full pump replacement held on-site as critical spare. [504881] Have additional pipe on-site to allow faster installation of replacement. [504880] HDS plant incorporated into water model, removes salt from circuit. [602389] 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. Pigging and flushing. [504879] Develop contingency plan for blocked well head. [504886]	Current Scope includes 3 new bores. Evaluation based on potential for additional injection bores. No impact on water treatment schedule as brine recirculated. Additional work for underdrain is lower risk. Rationale does not consider alternative salt disposal. Financial risk has been assessed and schedule risk are based on alternative option being required which is unidentified at this stage.	07/07/20 Annual Risk Workshop determined that process water quality still continues to degrade while brine injection is offline. Contingency has been considered but is not a preferred option.	Increasing	14/07/2020	Marginal	IV		Confirm current pigging strategy is correct (chemistry-cold water, cold water (pipe contraction and expansion), frequency). [504891] Contingency plan for brine injection system development [706768] Engage with design vendors regarding alternative methods to directional drilling [607335] Engage with directional drilling company for scope, price and schedule for new well. [504887] Establish a data gathering plan for performance of brine injection. [504890] Issue Expression of Interest for the development of an alternative brine disposal option [726641]	Open

Risk ID	Risk Title	Causes	Consequences	Controls	Evaluation Rationale	Recent Developments	Trend	Date	Control Effectiveness	Risk Management Class	Manageability	Actions	Risk Status
505847	Uncontrolled release of contaminated material into the onsite environment during tailings transfer to Pit 3.	Failure or damage is incurred to tailings transfer pipeline. Poorly managed transport of hazardous substances. Truck deviates from planned course. Changing environment during closure with respect to controlled areas. Inadequate identification of controlled areas.	Release of hazardous materials on to ground causes environmental incident. Onsite water is contaminated Non-compliance with Ranger Authorisation and ERs.	Closure implementation plan includes expanded controlled area for all hazardous materials handling activities. [505852] Existing ERA procedures for contaminated material management [505851] Pipeline actively managed through ERA's process safety management system. [604157] Tailings transfer pipeline design [604154]	Spillage is contained, no offsite environmental impact.	Risk discussed in a risk owner meeting held on the 06/05/20.	Stable	5/06/2020	Unrated	I		Incorporate management of controlled areas and transport of contaminated materials in the demolition and disposal work methodologies. [505855]	Open

APPENDIX 7.2 ERA CLOSURE RISK SUMMARY 2020

ERA Energy Resources of Australia Ltd

8 Post-mining land use, closure objectives & closure criteria

Issued date: October 2020

Revision number: 1.20.0

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Cover photograph: Wasp nest (*Polistes* sp.) on Scarlet Gum (*Eucalyptus phoenicea*) on Trial Landform

FIGURES

TABLES

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 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.
Closure criteria	performance criteria and will be used to measure the achievement of the rehabilitation closure objectives
Constituents of potential concern	Chemical elements identified by the Supervising Scientist Division as being of potential concern to the receiving environment
Environmental Requirement	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
AALL	Annual Additional Load Limits
ALARA	As Low As Reasonably Achievable
ANZEEC	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
BACIP	Before-After-Control-Impact Paired sampling
BPT	Best Practicable Technology
CCWG	Closure Criteria Working Group
COPC/COPCs	Constituent of Potential Concern / Constituents of Potential Concern

Abbreviation/ Acronym	Description
DEM	Digital Elevation Model
EIL	Environment Investigation Levels
ER	Environmental Requirements
ERA	Energy Resources of Australia
ERM	Environmental Resources Management
ERISS	Environmental Research Institute of the Supervising Scientist
GAC	Gundjeihmi Aboriginal Corporation
GV	Guideline Values
HIL	Health Investigation Level
IAEA	International Atomic Energy Agency
ICRP	International Commission of Radiological Protection
IMAP	Inventory Multi-tiered Assessment and Prioritisation
KKN	Key Knowledge Needs
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
LAA	Land Application Area
LEM	Landform Evolution Model
NEPM	National Environment Protection Measure
NLC	Northern Land Council
NOHSC	National Occupational Health and Safety Commission
NP	National Park
RPA	Ranger Project Area
SSB	Supervising Scientist Branch
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WoNS	Weeds of National Significance
WQMF	Water Quality Management Framework
W/SQO	Water or Sediment Quality Objectives

8 POST-MINING LAND USE, CLOSURE OBJECTIVES AND CLOSURE CRITERIA

8.1 Post-mining land use

The post-mining land use needs to be clearly articulated to allow 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 should be:

- relevant to the wider regional environment.
- achievable in the context of post-mining land capability.
- acceptable to Energy Resources of Australia (ERA) stakeholders.
- ecologically sustainable in the context of the local and regional environment.

The Environmental Requirements (ERs) (refer MCP Section 3) 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 should be noted that any decision on the actual incorporation of the RPA to 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 stakeholder engagement with the Mirarr people through consultation with the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC). In 2014, ERA formalised this engagement regarding post-mining land use and closure criteria development with extensive consultation with Traditional Owners, through the consulting linguist and anthropologist Murray Garde (Garde, 2015). This report was summarised and refined for habitation, use of traditional plants and animals and the assumed post closure bush food diet (Paulka, 2016).

8.1.1 Future occupancy intentions

Consultation with Bininj, Aboriginal people of the West Arnhem region, including the Mirrar, has established that 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 organised into the following purposes:

- hunting, fishing, bush food gathering
- recreation
- land management activities
- 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 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 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 extend 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 an ecosystem, drainage lines will reform and fauna will reinhabit the landform. It is at these locations that it is estimated that occupancy, mainly in the form of hunting and food gathering, will occur (refer Figure 8-1). It is likely that shorter, infrequent hunting will occur on the remainder of the landform, however this has been estimated to be minimal. The fauna detailed by Garde 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 & 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 & 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 & 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 & 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)

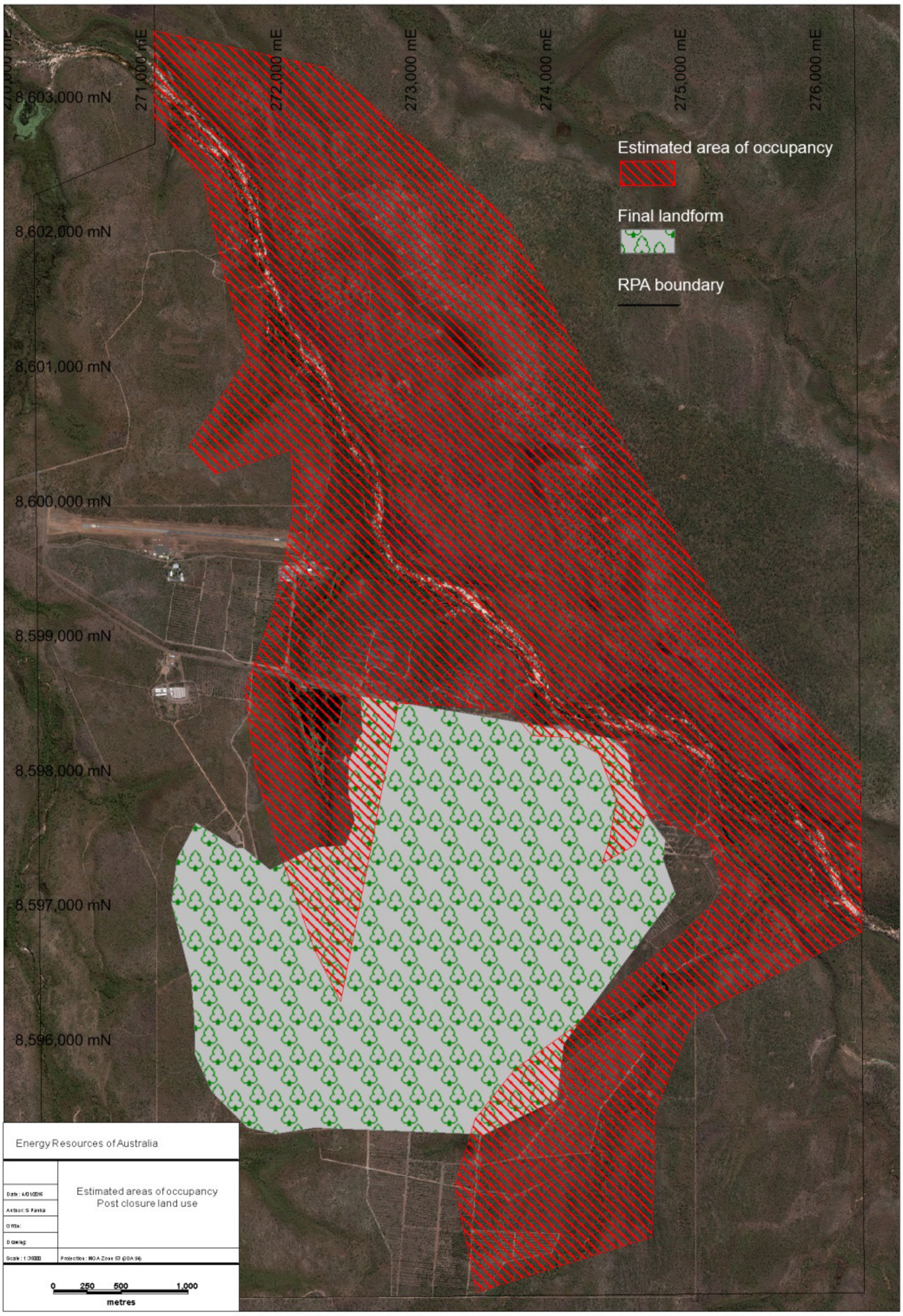

Figure 8-1: Estimated location for occupancy post closure

8.1.1.1 Hunting and gathering

Customary harvesting by local people of terrestrial bush foods from former mine impacted areas is ultimately likely to become more prevalent following the rehabilitation of the RPA.

Garde (2015) notes that the most popular of excursions usually involve fishing in Magela Creek but he is also aware that Bininj regularly hunt macropods, pigs, buffalo, water fowl (mostly magpie geese) and emus, mostly with guns. His 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.
- Seasonal camping or extended occupation for seasonal resource exploitation is also highly likely.

Extended seasonal camps are common in the region and the concentration of food resources at various times, such as the late dry/early wet season, for water fowl 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 and the rehabilitated RP1 area and Magela Creek mainly from MAG009 and upstream as far as the Magela Falls region.

<u>Estimate of time spent on hunting and gathering, day trips:</u>

Average of three times a month (less lack of access in wet season) = 30 days per year.

<u>Estimate of time spent on hunting and gathering, extended seasonal camping:</u>

= 20 days

<u>Notional estimate of number of people accessing the rehabilitated RPA:</u>

50 people— mostly from local resident areas.

8.1.1.2 Recreation

Bininj consulted in relation to intended recreational activities listed a number of possibilities. These include the following:

- intergenerational knowledge transfer visits
- residential college and school trips
- camping trips along Magela Creek

- bushwalking trips along traditional walking routes
- weekend swimming, ‘get out of town picnics’

Some Bininj consulted 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 a 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 documented traditional walking routes on the RPA and Magela Creek area in his report of 1981. Whilst they have a recreational aspect to them, bushwalking programs by indigenous ranger groups are also considered as important activities. This is discussed in the next section; land management and monitoring.

<u>Estimate of time spent on or transit through rehabilitated RPA for recreation:</u>

10 days average per person per year.

<u>Locations:</u>

Gulungul Creek road crossing, Georgetown Billabong, Coonjimba Billabong and 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; in the midst of 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 1 day per person each year. Locations would be 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 can 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 know how frequently site visits for this purpose may be planned. 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 is important as part of the post rehabilitation radiological dose assessment. Sources for bush meat fall largely into three categories - that hunted by Bininj themselves in Kakadu; that delivered as a community service by other agencies or non-indigenous individuals; and that 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 still are a significant element of the diet would require a large number of teams to record everything harvested over an annual cycle. This would require an unacceptable intrusion into the lives of bush food consumers and be beyond the resources of any research agency. This impracticality was confirmed by economic anthropologists discussing this issue at an Australian National University conference (September 2014) and based on the work of the anthropologist Jon Altman.

Altman’s work (1987) is one of only two studies in Australia that have focused on the quantitative collection of nutrition data for Aboriginal people living in remote areas on their own estates, the other being Betty Meehan’s work with the coastal Burarra people near the mouth of the Blyth River near Milingimbi (Meehan, 1982). As part of his doctoral research in the late 1970s, Altman resided for about 18 months at Mumeka outstation on the Mann River south of Maningrida. During a ten month period of that time, he collected daily data on returns for this outstation community from hunting and gathering (as well as market goods delivered by the store) and employed Bininj assistants to do the same if there was more than one production team away from the camp on any one day. Altman’s data is represented in kilocalories and protein rather than pure weight of food resources collected. However, in 1980 he calculated that per capita forty-six per cent of total kilocalorie, and eighty-one percent of total proteins came from bush foods for this remote western Arnhem Land community (Altman, 1987, p.37). Comparisons with contemporary northern Kakadu 35 years later would be difficult. Bininj in the Kakadu region have greater access to market foods (and higher cash incomes to spend on such foods) throughout the seasonal cycle, but bush foods still represent a significant economic, nutritional and cultural element of diets.

As an absolute quantitative measurement of bush food consumption cannot be undertaken, an estimate has been made based on long term and extensive data collection by survey and interview. This is the methodology undertaken by the Supervising Scientist Branch (SSB) (Ryan *et al.*., 2011) and has been used for the proposed post closure diet.

The estimated annual intake of bushfood by local Aboriginal people, living in northern Kakadu NP has been provided in Table 8-2. This diet has been adapted from that compiled by Ryan *et al.* (2011). The Gundjeihmi names for these foods have been added and there have been some additions of missing items. Anecdotal evidence based on recent interviews with residents from Bininj communities in northern Kakadu and long term participant observation of food collection trips by Murray Garde since 2003, indicate that there is a high probability that the Supervising Scientist data is still accurate. Specific differences from that diet to today are described below.

- Emu (they are periodically hunted in the area south of the RPA)
- Flying fox (consumed regularly in some communities, occasionally or never in others) Those communities that consume flying fox suggested they did so about every one to two months and an average take would be about a dozen animals (by shotgun). Sometimes flying fox have been supplied to Bininj by other agencies/individuals, for example Dave Lindner.
- Various water fowl including plumed whistle ducks, wandering whistle duck, Radjah shelduck, white ibis and straw-necked ibis and less frequently brolga and the black-necked stork. Consumption of other birds such as sulphur-crested cockatoos and corellas is rare.
- In relation to crocodiles, typical consumption is approximately 5 or 6 crocodiles (combined fresh and salt water). This suggests that the ERISS 2 kg per person figure is low and has been slightly adjusted up to 3 kg.
- The figure for goanna consumption should include consumption of frilled neck lizards. Their consumption is not infrequent as they are now more commonly eaten than goanna. Their populations have not been affected by cane toads to the same extent as have those of goannas. The figure of 2kg/year per person still seems reasonable.

Although there is no direct quantifiable evidence, except comparison in the general Australian population, the figure for buffalo consumption in the SSB diet seems possibly over-estimated at 146 kg per person per year. Agricultural commodity statistics (2013, Australian Bureau of Agricultural and Resource Economics and Sciences) indicate per capita consumption of meats in the general Australian population total approximately 100 kg per year, with beef/veal being only 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 per year 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 2 days, being shared among the community (i.e. 1kg 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/yr 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
Filesnake	X		3
Crocodile flesh	X		3
Goanna	X	X	2
Yams	X		20
Fruit	X		3
Water Lilly	X		3
Flying fox	X		5
Emu	X	X	2
Food total			*330.5*

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 5 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); if this is the case a justification will be provided for exclusion. The plants listed are those found across the three relevant ecological zones of the RPA - watercourses and billabongs, riparian margins and savannah woodland.

8.2 Closure objectives

Closure objectives set out the long-term goals for closure and should be based on the post-mining land form 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 environmental obligations, termed Environmental Requirements (ERs), of the section 41 Authority, issued under the *Atomic Energy Act,* and now annexed to the Ranger Authorisation issued under the *Mining Management Act*, 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.

The guidelines for preparing mine closure plans (DMIRS 2020) provides a planning framework for mine closure. The framework is similarly reflected in other industry guidance documents (AusIMM 2018) and details the process for collating project details, stakeholder input, baseline environmental information, risk and uncertainties to determine appropriate post-mining land use(s) and closure objectives. Closure objectives require the development of relevant and measurable criteria, to demonstrate and determine when the objectives and successful rehabilitation have been achieved. 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)

<table>
<tr><th>Closure objective</th><th>ER reference</th></tr>
<tr><td>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.</td><td>3.1, 1.2(d) and 11.3 (ii)</td></tr>
<tr><td>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.</td><td>3.1 and 1.2(e)</td></tr>
<tr><td>Flora and fauna</td><td></td></tr>
<tr><td>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.</td><td>2.2 (a)</td></tr>
<tr><td>Soil</td><td></td></tr>
<tr><td>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.</td><td>1.2 (e)</td></tr>
<tr><td>Cultural</td><td></td></tr>
<tr><td>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.</td><td>1.1 (a)</td></tr>
<tr><td>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.</td><td>2.1</td></tr>
</table>

*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

A key component of closure planning for the Ranger Mine is the development of closure criteria, which form the performance criteria and will be used to measure the achievement of the rehabilitation closure objectives. These criteria are to 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 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) and shown in Figure 8-3. The closure criteria address the broader objectives described in the ERs and Ranger Authorisation. Figure 8-3 has been updated to reflect the current status of closure criteria planning and shows the five-stage pathway for the development, refinement and approval of these criteria.

As described in Section 8.2, the Ranger ERs contain a number of objectives for the rehabilitation and closure of Ranger Mine. The overall objective for rehabilitation and closure has been based on the rehabilitation goals outlined in the Ranger Authorisation and the ERs (ERA 2014). It is recognised in the wording of Primary Environmental Objectives that the environment established on the rehabilitated Ranger Project Area must be similar to the adjacent Kakadu National Park and any impacts within the RPA must be as low as reasonably achievable (ALARA). These objectives are reflected within the closure criteria. The assessment of what is ALARA is discussed in Section 6.

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) over the life of the mine.

The closure criteria presented in this MCP have been divided into two categories; proposed criteria for minister approval, and draft criteria for further review. These have been divided into separate tables in order to clearly identify those that have been agreed between stakeholder groups and are ready for finalisation with ministerial approval and those that require further review and consultation.

The draft closure criteria will continue to undergo review and refinement, based on studies and consultation with MTC members with a plan to finalise all criteria for the 2021 MCP.

Each closure theme is presented in a separate section below with the following information:

- summary of relevant objectives and outcomes
- closure criteria summary table
- justification for outcome, parameter, criteria and method to assess achievement

Figure 8-2: Fungi on Trial Landform

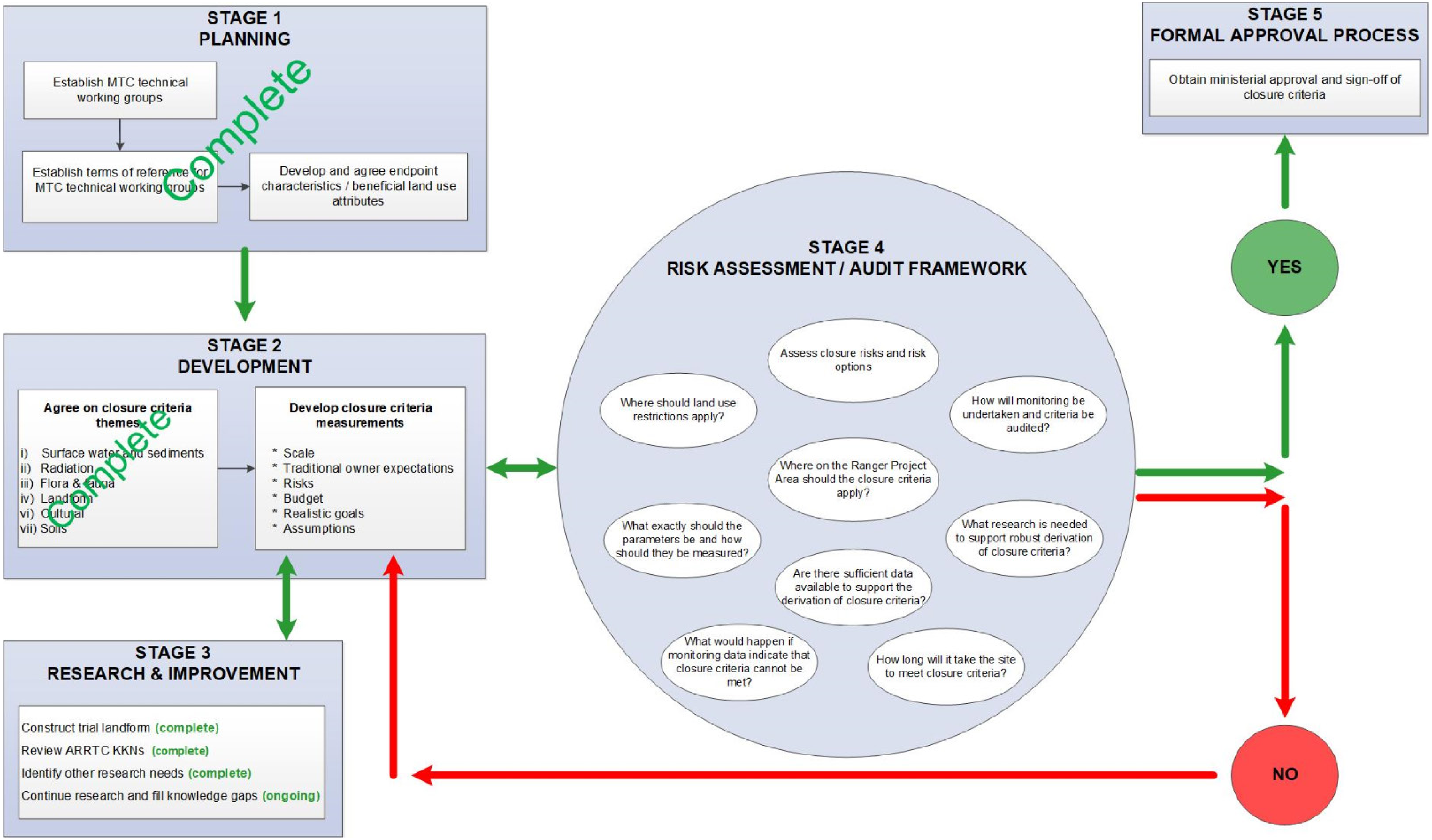

Figure 8-3: Framework for the closure criteria working group, and subsequent closure criteria development and approvals pathway

8.3.1 Landform

There are two objectives derived from the ERs relating to the landform theme (Table 8-3). Each objective, the outcome derived from that objective and explanation are summarised below.

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 towards the natural rates. As these timeframes are expected to be quite long best available modelling will be used to demonstrate that the erosion characteristics of the final landform will eventually be comparable to natural landscapes.

Second outcome - to ensure sediments created through erosion of the landform do not cause sand to infill Magela and Gulungul creeks and associated billabongs. Whilst this outcome does not directly relate to the objective for erosion characteristics, it was considered an important environmental protection outcome that relates to erosion.

Third outcome - applies the concept that turbidity can be used as an indicator of site-scale erosion characteristics. Moliere *et al.*. (2004) have shown that turbidity measures are highly correlated to total suspended sediment loads taken as a cumulative total over the wet season. The total suspended sediment can be captured at sites upstream and downstream in a paired before-after-control-impact design (BACIP) to demonstrate landscape stability and the trajectory of sediment fluxes on the rehabilitated landscape towards those of analogue landscapes. This method is further described in Moliere & Evans (2010).`

The proposed landform closure objectives, outcomes and parameters are set out in Table 8-4 and Table 8-5 with the former providing a summary of the proposed closure criteria for ministerial approval and the latter those that remain in draft for further review. Some criteria also have linkages to cultural criteria. Where this occurs, reference has been made to the cultural criteria section for more details.

Section 8.3.1.1 provides justification the outcomes, parameters and closure criteria that were derived for each of the key elements of the landform theme: infrastructure, isolation of tailings, and erosion characteristics.

Figure 8-4: Typical rocky surface of the Trial Landform (2019)

Table 8-4: Final Closure criteria – Landform

ER	Objective	Outcome	Parameter	Summary of criteria[2] for Minister Approval	ID	Cultural link
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.	L1	
			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.	L2	
			Gully erosion	Gully formation will not expose buried tailings.	L3	C2
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	Best available modelling demonstrates that erosion rates return to that of comparable natural landscapes	LEM model predictions of denudation rate	Modelling of erosion on the constructed landform predicts that the denudation rate will be on a trajectory towards 0.04 mm/year.	L4	C2 C3
		Sediments from erosion of the landform do not cause sand to infill in Magela and Gulungul creeks and associated billabongs	Bedload	Bedload is not being carried away from the constructed landform, in the absence of active management.	L5	C6

Table 8-5: Draft closure criteria - Landform

ER	Objective	Outcome	Parameter	Draft criteria for review 2	ID	Cultural link
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	Sediments from erosion of the landform do not cause sand to infill in Magela and Gulungul creeks and associated billabongs	Sedimentation	Accumulation of erosion products in Coonjimba and Georgetown Billabong will be ALARA.	L7	C6
		Suspended sediment loads in Magela and Gulungul creeks will be approaching background	Suspended Sediment	Event-based fine suspended sediment loads, evaluated across the wet season, to Magela and Gulungul creeks, are on a trajectory towards background loads.	L6	C7

[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 justify 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). Confidential

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 CEASER-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 boundaries and +/- 1 m elsewhere (Section 9.4.5.).

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 no gully erosion, beyond that would ordinarily occur in the region, could 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 rates (reported by the SSB in their rehabilitation standard to be 0.04 mm per year).

Sediments from erosion of the landform should cause sand to infill in Magela and Gulungul creeks and associated billabongs. This will be measured through both course sediment (bedload) and finer sediment (sedimentation). The criteria will be to make sure that Bedload is not being carried away from the constructed landform, in the absence of active management, and over time accumulation of erosion products in Coonjimba and Georgetown Billabong will be ALARA.

Event based suspended sediment loads, evaluated across an entire wet season, is considered the most suitable parameter for measurement of site-scale erosion characteristics. Suspended sediment loads from the rehabilitated landform to Magela and Gulungul creeks are expected to be high initially, and then trend progressively towards background (analogue) suspended sediment loads. Work completed by the SSB has demonstrated that turbidity can be used as an indicator for suspended sediment (Moliere & Evans 2010).

The suspended sediment load leaving the landform and entering Magela or Gulungul Creek will be measured through turbidity monitoring up and downstream of the RPA. Event-based sediment loads leaving the site will be tracked across a wet season and compared to background (analogue) loads, based on the method described in Moliere and Evans (2010). It is expected that it will take some time for these loads to return to background levels; therefore, achievement of this criterion will be based on the trajectory towards the analogue, which is expected to be between five and ten years.

8.3.2 Water and sediment

8.3.2.1 Water quality management framework

The recently revised *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018) provide a stepwise Water Quality Management Framework (WQMF) for developing agreed water and sediment quality objectives.

The language of the WQMF differs from that used by ERA and stakeholders in closure criteria discussions (reflected throughout this section). In this section both sets of terms are used in places. Where this occurs, terms from the WQMF are italicised in brackets.

An important distinction is the term “objective”. Throughout the MCP “objective” is used to imply a management goal whereas the WQMF refers to water or sediment quality objectives (W/SQO). As explained in Section 8.3.2.2 water/sediment quality guideline values (GVs) are identified for each management goal. The most stringent of these GVs is then chosen as the draft W/SQO.

The setting of the water quality objectives is currently at Step 5 of the process “Define draft water/sediment quality objectives” (Section 8.3.2.3). For this reason, ERA will be requesting minister approval of Draft Water Quality Objectives not final criteria as in the other themes. The proposed water and sediment management objectives and outcomes (*management goals*) and parameters (*indicators*) are set out in Table 8-6 and Table 8-7 with the former providing a summary of the stakeholder agreed draft Water Quality Objectives for ministerial approval, and the latter being those proposed, that are undergoing further review with stakeholders.

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 draft W/SQO. This is indicated in Table 8-6 by underlined italicised type. 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 final W/SQO. This process is important to derive and agree on final W/SQO for waterbodies on the RPA where impacts are to be as low as reasonably achievable (ALARA).

8.3.2.2 Management objectives and outcomes

There are three management objectives derived from the ERs that relate to the water and sediment theme (Table 8-3). These objectives 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.

The ER 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 closure management objectives for this closure criteria theme.

Water and sediment management objective (*management goal*) 1:

The first management 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):

- Pathway 1: through ingestion of water and bush food that has bio-accumulated mine derived analytes. The management outcome is that diet consumption limits are not exceeded as a result of mine derived contamination.

- Pathway 2: through recreational activities. The management outcome is that recreational water resources remain safe for their designated use.

Water and sediment management objective (*management goal*) 2:

The second management 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 and 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 outcomes have been derived from this management objective:

First outcome - mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health of the Alligators River Region, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.

Second outcome - mine sourced solutes do not increase contaminants in sediments off the RPA to levels that would be detrimental to ecosystem health of the region.

These two outcomes cover the three pathways for contaminant transport for this theme, groundwater, surface water and sediments.

Water and sediment management objective (*management goal*) 3:

The third management 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 outcome for this objective is that impacts on the RPA (water and sediment quality) will be as low as reasonably achievable (ALARA).

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) Water Quality Management Framework (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 8-5) to setting management goals through to assessing, refining and deriving water and sediment quality objectives (W/SQO).

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 and consultative forums.

The following sections describe the ten-step framework, and a high-level description of information available, for developing a water management plan. These same steps can be applied to assessing a remediation strategy. Both are relevant to deriving closure criteria.

Table 8-6: Agreed draft water and sediment quality objectives for minister approval – water and sediment

ER	Objective	Outcome (Management Goal - WQMF)	Parameter (Indicator – WQMF)	Guideline Values & Draft Water Quality Objectives for Minister Approval[3] [4]	ID	Cultural link
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 times when they would be met in non-mine effected local creeks) • 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 & NRMMC, 2011; v3.5 updated 2018).	W1	-
		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 times when they would be met in non-mine effected local creeks) • 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 NHMRC, 2008).	W2	C7
			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.	W6	C7
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 of the Alligators River Region, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Turbidity, ammonia, manganese, uranium, magnesium, (magnesium: calcium mass ratio) & sulfate.	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-hour moving average)* *Dissolved manganese; 75 µg/L (72-hour moving average)* *Turbidity: no statistically significant increase over natural turbidity*	W3	C7

[3] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.2.

[4] Most stringent GV are taken as the draft W/SQO. These have been underlined.

Table 8-7: Draft water and sediment quality objectives under review

ER	Objective	Outcome	Parameter	Draft criteria for review [5]	ID	Cultural link[6]
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.	W7	-
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 of the Alligators River Region, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	copper and zinc	SSB Rehabilitation Standards are met in Magela and Gulungul creeks at the boundary of the Ranger Project Area, downstream of the Ranger Mine: Values TBC following development of local site specific guideline value	W3	C7
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 sourced solutes do not increase U in sediments off the RPA to levels that would be detrimental to ecosystem health of the region.	Uranium in sediments	Uranium in sediments does not exceed 100 mg/kg dry weight (whole sediment; weak acid extactable digestion method)	W4	-

[5] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.2.

[6] All cultural criteria will be considered as part of the ALARA process

ER	Objective	Outcome	Parameter	Draft criteria for review [5]	ID	Cultural link[6]
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.	Impacts on the RPA are ALARA	W5	-

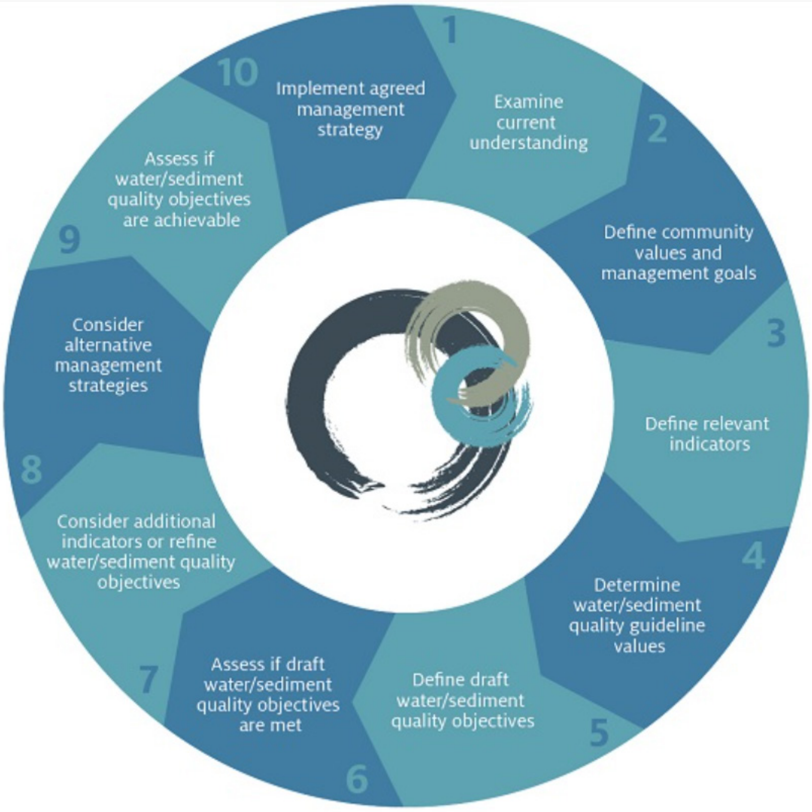

Figure 8-5: The Water Quality Management Framework (ANZG 2018)

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[7] and throughout this document).

Several key risk assessments and conceptual models relevant to the closure phase for water and sediment were considered. For example:

- revised Key Knowledge Needs (KKN) for closure (Supervising Scientist 2017a) have been based on 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)

[7] https://www.environment.gov.au/science/supervising-scientist/publications#bibliography

- peer reviewed groundwater and surface water conceptual models (INTERA 2019 and Water Solutions 2018)
- linkages between hydrological processes and ecosystem dynamics (BMT 2018)
- discussions of Indigenous worldviews on the environment, including water (Garde 2015).

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 as low as reasonably achievable (ALARA) (ER 1.2e)
- all aspects of the Ranger Environmental Requirements and those environmental matters not covered by the Environmental Requirements must use Best Practicable Technology (BPT) (ER 12)
- the RPA must be rehabilitated to a state to allow incorporation into Kakadu NP (ER 2.1).

These Environmental Requirements provide high-level management goals for rehabilitation of the minesite. 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:

- 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 principle of 'as low as reasonably achievable' 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 Northern Land Council (NLC) and Gunjeihmi Aboriginal Coroporation (GAC) reiterated this and provided additional (draft) information on their position on ALARA for onsite water bodies (email from Chris Brady 8/4/2020).

  - 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 principle of "as low as reasonably achievable" 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.
  - The final NLC/GAC position paper is discussed in Section 6.
- 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).
- The Traditional Owners and the SSB have indicated that a goal of no change to biodiversity on the RPA is preferred.

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 ANZEEC and 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. After further review, the

SSB developed rehabilitation standards[8] in the water and sediment theme for key chemical contaminants (ammonia, manganese, uranium, magnesium, (magnesium:calcium ratio), sulfate, aluminium, cadmium, chromium, copper, iron, lead, vanadium and zinc, turbidity and sedimentation[9]. Several metals were later removed from this list based on a hazard assessment undertaken by the SSB and reported to several stakeholder fora (eg; the Water and Sediment Working Group, ARRTC, Ranger MTC). The scientific basis for the SSB standards is described in each standard.

Other work relevant to selecting indicators for closure water quality management are as follows:

- the development of endpoints and indicators for the protection of biodiversity (Supervising Scientist 2002) and that reflect the environmental values of water bodies both on and off the Ranger Project Area. These include indicators for health and cultural uses and the Ramsar and Kakadu NP World Heritage values (BMT WBM 2017).
- 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 Ranger Project Area 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)
- the identification of uranium as the COPC in reports on accumulation of metals in contaminated sediments on the minesite. Other metals showed limited enrichment even in the sediments of the waste water treatment wetlands (Iles et al.. 2010, Parry 2016, Esslemont and Iles 2017)
- the selection of indicators for drinking water and recreation from NHMRC & NRMMC (2011; v3.5 updated 2018) and NHMRC (2008) based on the surface water COPCs identified by Frostick et al.. (2012)
- a review of current load limits for nutrients and a risk assessment of eutrophication that indicated a low risk from nutrients following closure. Nutrients have therefore been removed from the closure criteria list. Nutrients will be monitored during and following

[8] https://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards

[9] Management goals and criteria for sedimentation are captured in the Landform and Cultural themes

closure and the risk reviewed with updated predictions of post closure contaminant discharges (Section 5.5.2.1.5)

- 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.

Ecosystem protection

Guideline values (GV) for high-level ecosystem protection have been derived by the SSB and reported in their Rehabilitation Standard Series[10]. 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 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 an uranium GV for sediment (SSB 2019). A narrative guideline was used for sediments referring to meeting the GV for U in water in the 2019 MCP. Due to ongoing discussions with the Alligator Rivers Region Technical Committee (ARRTC) this criteria remains in the draft table with the value being the rounded up value of the interim sediment quality criteria derived by the SSB. The SSB are finalising their advice on the guideline value for uranium in sediment

GVs based on ecotoxicity studies of the SSB are available for species protection levels of 99, 95, 90 and 85 %. The closure objective for water quality in the Ranger Project Area (ERA 2018), reflecting ER 1.2e was stated as *'Surface water quality on the RPA [Ranger Project Area] meets the highest ecosystem protection level that is demonstrated to be reasonably achievable.'* Stakeholder feedback indicated that a process was needed to determine what water quality was ALARA and recommended that quantifiable numeric values are derived to reflect ALARA values. This is addressed in Step 8.

[10] https://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards

Management goals differ for on and off the RPA, and therefore GVs would also be expected to differ. However, the same GVs can be used for on and off the RPA at this step. Subsequent steps will enable refinement of GVs and W/SQO for on and off the RPA.

Diet and recreation

Guideline values for drinking water are from the Australian drinking water guidelines NHMRC & 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 by a specialist. This assessment will be based on the water quality predictions from the surface water model.

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 & ARMCANZ (2000) do. The GV for sulfate was therefore taken from ANZECC & ARMCANZ (2000).

The same parameters identified for drinking water are used as suggested above. I should be noted that the irritant 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 *et al.* (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.

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 8-6. 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 underlined. These are the GVs that are adopted as draft W/SQO at this step.
- ANZG (2018) supports narrative statements (as opposed to numeric values) as GVs and W/SQO. Several examples of narrative draft W/SQO are used in Tables 8-6 and 8-7, e.g. demonstrating what water quality is ALARA and for aesthetic water values.

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 5.5.2.11). Initial predictions have been provided and are being compared to the draft W/SQOs. Improvements are being made to the suite of models used with updated outputs to be available in late 2020. The predicted concentrations of these COPC will be compared to the draft W/SQO and the following steps of the WQMF implemented as appropriate. The outcomes will form part of the Pit 3 closure application process.

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).

It is likely that concentrations higher than the draft W/SQO will be predicted for some locations/times on the disturbed mine footprint in the RPA. 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.

If concentrations do exceed the draft W/SQO, this does not necessarily imply that impacts will occur. Further assessment is required to understand the implications; this type of tiered assessment is common to many guideline frameworks (eg EnHealth 2012, NHMRC 2008, NHMRC & NRMMC 2011).

Assessing the need to revise the GVs 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.

The draft W/SQO is for high-level ecosystem protection. On the RPA the goal is for impacts that are ALARA so the need to revise the GV for application to the RPA is not unexpected. Step six will indicate which COPC GVs need to be revised.

Some progress on alternative GVs and additional indicators and lines of evidence has been made.

- GVs are available from the ecotoxicity studies of the SSB and ANZG (2018) for alternative levels of species protection for most COPC.
- 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 to magnesium concentrations and indirect sensitivity via other factors affecting vulnerability, such as habitat, diet, reproduction and dispersion. (Section 5.5.2.16 provides a description of the project).

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.

Consideration of alternative management options, community, environmental and cost aspects are common to both ALARA and BPT assessments. Impacts on the RPA must be ALARA and closure options must undergo a BPT assessment.

The BPT assessment 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 deemed the best practicable technology.

ERA has identified a process that combines options assessments with a risk management framework to demonstrate that the chosen closure strategy is based on BPT and ALARA. ERA proposes that the analyte concentration associated with the option that is considered BPT-ALARA will be the water quality that is adopted as W/SQO for on the RPA. This aligns with the ALARA approach for radiation protection described by Oudiz *et al*. (1986), shown in Figure 8-6. Refer to Appendix 6.2 for further details.

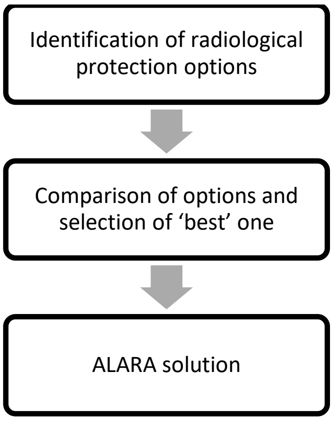

Figure 8-6: The main features of the ALARA procedure (Oudiz *et al*. 1986)

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.

Step 10. Implement agreed management strategies

Document and implement agreed management strategies, including, in some cases, a suitable and agreed adaptive management framework.

Management strategies will be documented in applications to stakeholders and regulators for approval for key activities. Applications will include the results of BPT assessments and the descriptions of mitigations and management actions.

Stakeholder feedback will occur again at this stage. Future Ranger Mine Closure Plans will be updated with a record of progress.

8.3.3 Radiation

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 2018c, SSB 2018d)

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 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. A summary of the radiological impact assessment is provided in Section 7.9.1.

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 8-8: Closure criteria – radiation

ER	Objective	Outcome	Parameter	Summary of criteria for Minister Approval[11]	ID	Cultural link
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 doses 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 per year	R1	-
		Radiation doses 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 per year	R2	--
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	R3	--
		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	R4	--

[11] 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 Commission.

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 several pieces of 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 one milli-Sievert in a year, 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 micro-Sieverts in a year 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 milli-Sieverts (500 micro-Sieverts) would be in keeping with the principles for setting dose constraints; however, ERA has elected to keep the recommended 300 micro-Sieverts per year default from the IAEA.

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 8-8 and forms the basis for setting of the radiation criteria for protection of human health outlined previously in Table 8-7.

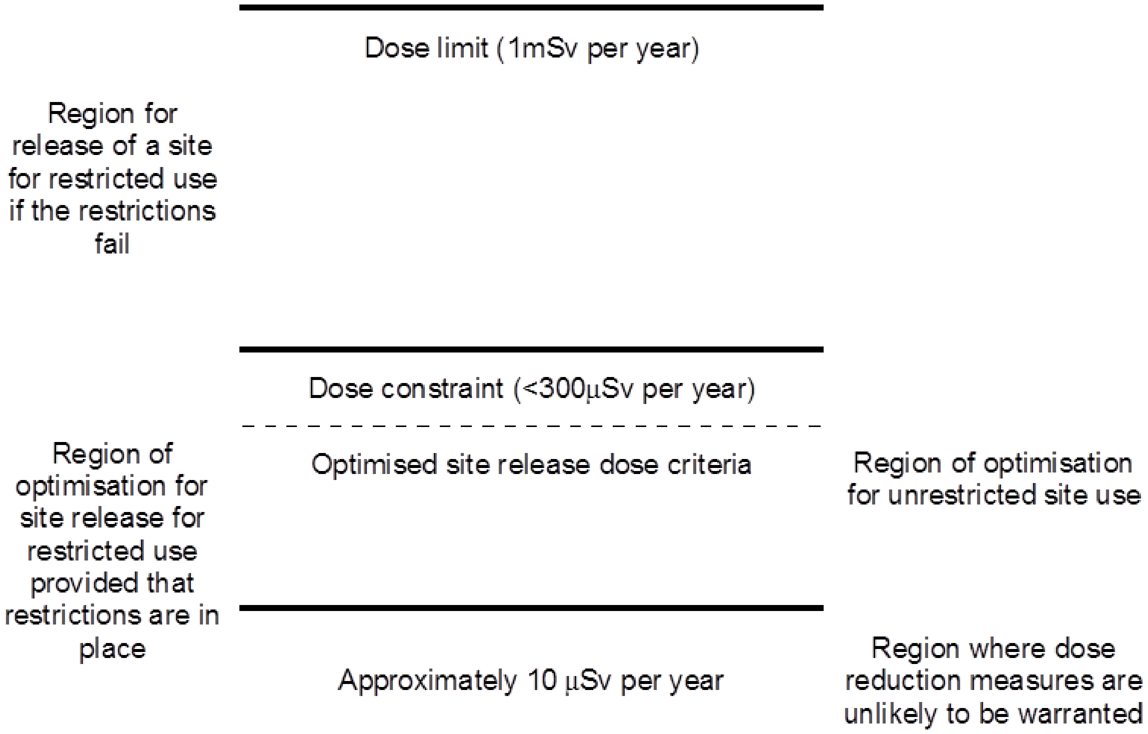

Figure 8-7: Constrained optimisation and regions of effective dose for members of the critical group in the release of sites (IAEA 2006)

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 possible 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 has been 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)
- 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.

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.

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.

This has been the basis for selection of the outcomes, one related to the terrestrial biota and one for aquatic biota. This division is based on the guidance for assessment provided within the ICRP document (ICRP 2014).

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 recent 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). Recent 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
- 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 (Supervising Scientist, 2018c). 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

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 for minister approval. For the case of soils, no link to cultural criteria has been identified. 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

An objective for closure is that, where needed, soils will be remediated to a level where their environmental impact is as low as reasonably achievable. The preferred option identified during the best practicable technology assessment will be progressed whilst the other options then form the contingency plan, prioritised by rank. Outcomes of contaminated sites assessments will be included in future versions of the MCP.

Achievement of these criterion 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 (refer Section 6.3 and Appendix 6.2).

Table 8-9: Closure criteria – soils

ER	Objective	Outcome	Parameter	Summary of criteria for Minister Approval[12]	ID	Cultural link
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	S1	-
			Contaminated assessment of identified COPCs for other soils identified as not being part of the larger decommissioning works	Demonstrate risk is ALARA	S2	-

[12] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.4.

8.3.5 Ecosystem

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.*

Three outcomes have been derived from this objective:

First outcome - relates to the use of local native plant species

Second outcome - relates to the flora and fauna species composition and community structure being similar to Kakadu NP

Third outcome - relates to the long-term viability of the ecosystem and the associated maintenance regime

Closure criteria have been developed for both revegetation and fauna recolonisation. Table 8-9 and Table 8-10 provide a summary of the closure objectives, the outcomes derived from these objectives and parameters used to measure the outcome with the former providing a summary of the proposed Revegetation closure criteria for minister approval and the latter proposed fauna recolonization criteria that remain in draft for further review. Some criteria also have linkages to cultural criteria. Where this occurs, reference has been made to the cultural criteria section for more details.

Section 8.3.5.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of flora and fauna.

Table 8-10: Closure criteria – Ecosystem (Revegetation)

ER	Objective	Outcome	Parameter	Summary of criteria for Minister Approval[13]	ID	Cultural link
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	Revegetate the disturbed sites of the RPA using local native plant species	Provenance	Revegetation has used (100%) local native species from Kakadu NP.	E1	C10
		Species composition and community structure is similar to adjacent areas of Kakadu NP	Species composition and relative abundance	Species composition for all overstorey and midstorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E2	C10 C12
				Species composition for all understorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E3	
				Stems per hectare of overstorey and midstorey framework species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E4	
				Total species richness of framework species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E5	
				Total species richness of all overstorey and midstorey similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E6	
				Total species richness of understorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E7	
			Community structure	Vegetation structure similar to, or on a trajectory towards that of the agreed reference ecosystem(s).	E8	C9, C10
				% Cover of overstorey and midstorey is similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E9	C9
				% Cover of understorey vegetation is similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E10	
				Overstorey and midstorey species distribution ('naturalness') is similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E11	-
		Long term, viable ecosystem which would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	Reproduction (flowering and seeding)	Flowering and fruiting of framework species (based on species present), similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E12	C10
			Recruitment / regeneration	Recruitment and regeneration of framework species (based on species present), similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E13	C9 C11
			Nutrient cycling	Chemical and biological indicators provide evidence that nutrient cycling will sustain ecological processes, similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).	E14	-
			Resilience	Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.	E15	-
				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.	E16	C8
			Weed composition and abundance	No Class A weeds or Weeds of National Significance (WoNS).	E17	C11
				Abundance of Class B weeds no greater than agreed reference ecosystem(s).	E18	
				Abundance of other introduced flora species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	E19	
			Exotic fauna	Density of buffalo, horses and pigs on the RPA no greater than adjacent areas of Kakadu NP.	E20	C12

[13] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.5.

Table 8-11: Draft Closure criteria – Ecosystem (Fauna recolonisation)

ER	Objective	Outcome	Parameter	Draft criteria for review	ID	Cultural link
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	Long term, viable ecosystem requiring maintenance similar to adjacent areas of Kakadu NP	Habitat connectivity	Lack of physical barriers (e.g. fences) provides the potential for external exchanges similar to, or on a secure trajectory towards, that of the agreed reference ecosystem(s).	E21	
			Native fauna species richness and diversity	Number of vertebrate species is on a trajectory towards that of agreed reference sites.	E23	
				Evenness of birds species across sites (Pielou's evenness) is on a trajectory towards that of agreed reference sites.	E24	
			Functional diversity of native fauna	Species richness for each of four Key Functional Groups of ants is on a trajectory towards that of agreed reference sites.	E25	
				Species richness of nectivorous and frugivorous species is on a trajectory towards that of agreed reference sites.	E26	
			Target native fauna species	Appropriate criteria for culturally significant fauna when identified.	E28	
				Activity, diversity, and functional diversity of subterranean active termites is on a trajectory towards that of agreed reference sites.	E29	
				Number of threatened species are on trajectory towards that which occurs in the agreed reference sites.	E30	

8.3.5.1 Justification for outcome, parameter and criteria

Derivation of the ecosystem (flora and fauna) criteria is underpinned by an understanding of both general ecological restoration principles (SRG 2017), ecosystem dynamics in northern Australia, and the knowledge gained through 30 years of flora and fauna studies, revegetation trials and research on RPA and surrounding areas. Background information on the various aspects of appropriate reference site selection and the research underpinning the trial landform; plant available water; flora and fauna baseline monitoring; landform design, performance and properties; and, ecosystem establishment is provided in Section 5.3.3 and Appendix 5.1.

Revegetation

The closure criteria for revegetation (Table 8-9) 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. 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, which means that one (or more) local indigenous ecosystem/s more ecologically appropriate to the changed conditions may be suited as a guide for revegetation of the site (SRG 2017). Therefore, 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 (e.g. modifications for predicted climate change or substrate limitations, Prober *et al.* 2015).

Whilst work is ongoing to obtain and consider additional information from reference sites, development of the Ranger Mine conceptual ecological model for the revegetation objective continues. This model is key to defining the target ecosystem/s and will determine the quantitative, semi-quantitative and/or qualitative 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 conceptual model is further developed and/or finalised.

Further information on the justification for each component of the ecosystem theme is provided in below including: locally native species; species composition and community structure; and long-term viability of the ecosystem.

The ERA revegetation strategy is based on harnessing and manipulating natural ecological processes such as reproductive phenology and the structural and functional importance of framework species. A key principle is to actively facilitate establishment of framework overstorey species along with a subset of important and predictable midstorey and understorey species (Appendix 5.1). Once these species have established, they will control much of a site’s nutrient and water resources, confer resilience to weeds and other threats, and will provide many of the core habitat values for other plants and animals to colonise.

Despite the functional importance of framework species for the long-term sustainability and stability of the plant communities, they are not necessarily 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, density, cover etc). However, these components can be very ephemeral in their nature, resulting in considerable year-to-year variation in both species diversity and composition, even at a single natural woodland site (eg Fenshaw 1990, 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 total species diversity and composition can be quite dynamic and variable in a manner that is largely unrelated to the overall functional performance of the plant community (which is controlled by the framework species). This has implications for revegetation in that standard measures of diversity which focus on total species numbers are not necessarily an appropriate indicator of the functional performance, sustainability or habitat values of the plant community at a site.

Reflecting this situation, some closure criteria have been specified for overstorey and midstorey framework species, such as species composition, density, species richness, and reproductive or recruitment measures. This approach ensures that framework species are given the appropriate priority in any assessment. In most cases, the combined vegetation community (all overstorey, midstorey and understorey species) are also considered for the same parameters, although with a degree of similarity reflective of the variability and dynamism of the holistic ecosystem.

Local native plant species

The first outcome for flora and fauna is that the disturbed site must be revegetated using local native plant species. In order to determine what would be considered as "local" a number of provenance studies have been conducted and consultations have occurred with GAC and many national and local experts (Section 5.3.3 and Appendix 5.1).

The resultant criterion is that: "*Revegetation has used (100%) local native species from Kakadu NP*".

In order to achieve this, any plants introduced to the rehabilitation landform as part of the revegetation implementation program will be identified from an agreed revegetation species list which shall only include appropriate species found within the Kakadu NP, as derived from:

- Surveys of suitable reference sites from the RPA and adjacent areas selected to account for the changed conditions of the rehabilitated landform. For example earlier studies jointly by ERA and the SSB, the ERA long-term monitoring program and more recent studies by the SSB (Appendix 5.1);
- A list of culturally important plant species, identified by the Mirarr Traditional Owners in Garde (2015).

The species list is included in the revegetation implementation plan (Section 9.4.6.1) and shall undergo further refinement considering outcomes from ongoing reference site survey and analysis, revegetation trials, risk assessments, expert advice (including CDU researchers and local native seed experts from Kakadu Native Plants Pty Ltd) and further stakeholder consultation (including appropriate formal review by stakeholders).

Seed collection and revegetation establishment records will be maintained as evidence that the agreed species list was used and this criterion achieved.

Species composition and community structure

The second outcome is that species composition and community structure is similar to adjacent areas of Kakadu NP. Ten parameters are being proposed to measure the achievement of this outcome, which are described in the following sections.

Species composition and relative abundance

Plant species composition and relative abundance in the RPA and surrounding landscape have been studied extensively and have been summarised in Appendix 5.1. An assessment of species composition and relative abundance will ensure that the range of species present and their densities in the revegetation are similar to the agreed conceptual reference ecosystem/s.

Species composition is the array and relative proportion of organisms, in this case vascular plants, within an ecosystem (SRG 2017). This measure is important to understand 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 conceptual reference ecosystem) have been established and/or that there is improved potential for colonisation of more species over time (SRG 2017). Species composition is generally expressed as a per cent (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.). The degree of compositional similarity between two ecosystems (e.g. a reference ecosystem and a revegetated ecosystem) can be assessed using a range of indices, for example the Bray-Curtis similarity (or dissimilarity) index (Bray and Curtis 1957).

The relevant criteria are:

- Species composition for all overstorey and midstorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).
- Species composition for all understorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Density

"Density" in plant ecology is defined as the number of individuals of a group (e.g. species, genera, or overstorey / dominant trees and shrubs) that occur within a given area, for example stems per hectare. Density of overstorey and midstorey framework species (as a group) is a basic metric used to ensure that sufficient representatives of that important cohort are present to confer the requisite ecological functions (site capture / dominance; long-term resilience to disturbance; amelioration of lcoalised environmental conditions).

The relevant criterion is:

- Stems per hectare of overstorey and midstorey framework species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Species Richness

Species richness is simply a count of the number of different species represented in an ecological community, landscape or region. It does not take into account the abundances of the species or their relative abundance distributions.

As described above in the discussion on local species, the target diversity and abundance of species for Ranger revegetation is derived from suitable reference ecosystems, culturally important species and outcomes of revegetation trials. The current revegetation R&D list includes 119 species, dominated by overstorey and midstorey framework species but including other trees, shrubs, palms, lianes and understorey species (Appendix 5.1). This is comparable to the total number of species (127) detected in earlier surveys of Eucalypt-dominated savannah woodlands in the Georgetown reference area (Hollingsworth & Meek 2003).

As discussed in the introduction above, closure criteria for the species richness of the different cohorts (framework, overstorey and midstorey, and understorey) are considered separately to enable differentiation of their relative importance to the revegetated ecosystem at Ranger Mine.

The relevant criteria are:

- Total species richness of framework species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).
- Total species richness of all overstorey and midstorey similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).
- Total species richness of understorey species similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Community Structure

The forests and woodlands of the Kakadu NP are multi-strata systems, typically with distinct canopy, midstorey and ground layer (Russell-Smith 1995b) (Appendix 5.1). At a given site, the structural characteristics of the vegetation are determined primarily by the availability of water and, to a lesser extent, nutrients within that part of the regolith accessible to plant roots. As a consequence, the accessible depth and hydrological storage characteristics of the regolith under the final landform will be important controls on the potential for structural development in the revegetation.

Structural characteristics may be assessed as vegetation height, the depth and total leaf area of each stratum, and/or the density, diameter and size class distribution of stems.

The relevant criteria are:

- Vegetation structure similar to, or on a trajectory towards that of the agreed reference ecosystem(s).
- Percentage cover of overstorey and midstorey similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).
- Percentage cover of understorey vegetation similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Tree distribution or 'naturalness'

The composition and distribution of vegetation across the revegetated landscape may be impacted by physical and chemical constraints, which is why it is important that these measures are considered within the different domains, and based on comparison with suitable, agreed conceptual reference ecosystems.

Following early revegetation activities, the revegetated ecosystem/s will develop and mature with time and appropriate management, with increasing diversity and structural complexity, internal recruitment as well as external colonisation of new species and/or additional plants into new locations on the landform. In the long term (and following some generational turnover of framework overstorey species), the initial planting layout is likely to be barely discernible and the natural occurrence of vegetation community preferences and therefore distribution is more likely to be a result of localised site conditions, fire regimes, and proximity to different recruitment sources. By 25 years, the mature, overstorey and midstorey trees and long-lived shrubs may still largely reflect the initial planting layout (although cohorts of recruits will likely be present), and so a closure criterion relating to the distribution of these is reasonable.

The relevant criterion is:

- Overstorey and midstorey species distribution ('naturalness') similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

A suitable assessment approach will ensure that other criteria (such as composition, density, structural stratification and cover) combine to ensure that a reasonably 'natural' distribution of the important overstorey and midstorey species within the different revegetated domains is achieved. Assessment of achievement of these criteria will be based on surveys conducted according to the Northern Territory vegetation survey guidelines (Brocklehurst *et al.* 2007).

Long-term viability of the ecosystem

The third outcome is to achieve a long-term, viable ecosystem 'which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park'. There are eight parameters proposed to measure the achievement of this outcome, which are described in the following sections.

Reproduction (flowering and fruiting)

Under normal conditions reproductive (sexual) propagation is the key to the survival of the vegetation population. Flowering and fruiting (or seeding) also provides other vital ecological functions such as pollen, nectar and seeds for various insects, birds and other animals, and cultural function such as bush foods and traditional produce (such as bush soaps).

The relevant criterion is:

- Flowering and fruiting of framework species (based on species present) similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Recruitment and regeneration

Under current land management practices in the Kakadu NP area, particularly fire management regimes, the majority of the successful natural regeneration of terrestrial plants is via vegetative propagation (e.g. root suckers). Therefore, recruitment and regeneration of vegetation will include regeneration from both seedlings and root suckering.

The relevant criterion is:

- Recruitment and regeneration of framework species (based on species present), similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Nutrient cycling

The process of nutrient cycling will be important for the ongoing sustainability of revegetation, and can be assessed through a range of biological attributes including litter cover, depth and and degree of decomposition (Ludwig *et al.* 2003), the presence of soil organisms including soil fauna and saprophytic fungi (including wood decomposers for woody stems and logs), and plant health. Direct chemical analysis of the nutritional status of soils (and plants) may also prove useful to assessing this parameter.

The relevant criterion is:

- Chemical and biological indicators provide evidence that nutrient cycling will sustain ecological processes, similar to, or on a trajectory towards, that of the agreed reference ecosystem(s).

Resilience

The current landscapes found across Australia's tropical savannah are largely a product of the various fire regimes and climatic dynamics in these regions i.e. distinct wet and dry seasons.

Local native woodland species in the surrounding Kakadu NP are mostly fire resilient. The fire resilience of these plants is by inherent characteristics, although the development stages will also influence resilience. ERA revegetation will use only locally native species in similar proportions to surrounding communities, and therefore it is considered that the fire resilience should be similar. Based on the ERA trial landform studies (Wright 2019) and studies on the RPA (e.g. Gardener *et al.* 2007), it is expected that the majority of the framework tree and shrub species planted as tubestock would achieve resilience to fire within five to seven years. The proposed revegetation strategy therefore requires fire exclusion of the revegetation area for five to seven years.

Following this initial exclusion timeframe, fire will be introduced in a controlled manner prior to allowing uncontrolled fire entry. Following introduction of a fire regime typical for that of Kakadu NP, the mature revegetation will demonstrate resilience through key composition and density metrics being sustained following fire. Assessment of achievement will be through a post-fire vegetation survey of an area determined in consultation with the Supervising Authority.

The relevant criterion is:

- Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.

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).

Resilience of the revegetated Ranger ecosystem to wind and drought will be largely dependent upon appropriate species composition and, particularly for overstorey and midstorey trees and shrubs, the development of a good root system. Early watering of the revegetation post planting can decrease the risk of mortality. However, long-term watering can lead to shallow root development and decrease resilience to wind and drought. The current revegetation strategy involves initial watering (3-6 months), then reliance on only wet season rainfall to ensure appropriate root development.

The relevant criterion is:

- 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.

Weed composition and abundance

In order to have a maintenance regime that is not significantly different from that of the surrounding Kakadu NP, weed populations will need to be comparable. The closure criteria are based on the applicable national and Northern Territory legislation. In addition to the prescribed weeds, there are also some introduced species that have the potential to increase the maintenance programs above that of the surrounding Kakadu NP, for example Annual *Pennisetum*. Any weed that is assessed as presenting this risk will be monitored and demonstrated to not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.

Demonstration of achievement will be through weed survey conducted according to the Northern Territory Weed Management Branch Guidelines (2015a, b).

The relevant criteria are:

- No Class A weeds or Weeds of National Significance (WoNS).

- Abundance of Class B weeds no greater than agreed reference ecosystem(s).
- Abundance of other introduced flora species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.

Exotic fauna

In accordance with the ERs, feral animal numbers on the RPA (specifically buffalo, horses and pigs) may be at similar densities to those in adjacent areas of Kakadu NP. 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.

The relevant criterion is:

- Density of buffalo, horses and pigs on the RPA no greater than adjacent areas of Kakadu NP.

Fauna recolonisation

Historically, mine closure globally and in Australia and has focused on the restoration of vegetation communities, while fauna communities have been assumed to passively recolonise restored vegetation (e.g., Palmer *et al.* 1997, Cristescu *et al.* 2012, Cristescu *et al.* 2013, Cross *et al.* 2019a, Cross *et al.* 2019b). This approach is reflected in previously proposed draft closure criteria for Ranger, including the ERs which do not specifically address fauna. The closure criteria for native fauna identified in the 2018 Ranger MCP (Energy Resources of Australia Ltd and Eco Logical Australia 2018) included 'presence of major functional groups (vertebrate and invertebrate)' and 'feral animals … are similar in density on the RPA compared to the adjacent areas of KNP'. In the same MCP, 17 criteria for vegetation were presented. Fauna recolonisation closure criteria were expanded in the 2019 MCP (Energy Resources of Australia Ltd and Eco Logical Australia 2019) to include:

- Development of habitat suitable for native fauna species that utilise appropriate reference sites: The following habitat features must be present: multi-strata layers; coarse woody debris (10 cm in diameter), trending towards development of hollows, rock features.
- Local native mammals, birds, reptiles and invertebrates using the site (or likely to). An effective termite decomposer fauna has developed: Recent termite constructs (mounds, arboreal nests, earthen workings in litter, on wood and on tree stems) are present, and there is evidence of termite-mediated decomposition of woody and other plant materials.
- Feral animals (specifically buffalo, horses and pigs) are similar in density on the RPA compared to the adjacent areas of Kakadu NP.

The feral animals criteria has now been finalised for minister approval, see exotic fauna section above. The remainder of the fauna recolonisation criteria are in draft and require further studies and stakeholder consultation. Table 8-10 presents the current draft criteria, these will be reviewed with stakeholders and updated ready for minister approval in the 2021 MCP. Details of each of the draft criteria are provided in the following sections.

Fauna habitat

Tree hollows provide important habitat for amphibian, bird, mammal and reptile species, including many species which are hollow-dependent (Taylor *et al.* 2003, Goldingay 2009, Goldingay 2011, Lindenmayer *et al.* 2014). Individuals of hollow-using and dependent species 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 attrititon of exisiting 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. The development of tree hollows will be assessed based on the density of potentially hollow bearing tree species.

Fauna habitat including the provision of hollow bearing tree species and edible fruit species, is addressed in the flora closure criteria.

Habitat connectivity

Habit connectivity criteria for physical barriers have been included and is based on the SSB standards with minor word changes. Criteria for pollinators and frugivores is discussed under functional diversity of native fauna.

Native fauna species richness and diversity

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 and Grant 2007, Brady and Noske 2010, Gould 2011, Frick *et al.* 2014, Triska *et al.* 2016, Houston *et al.* 2018).

Criteria are being proposed for both vertebrate species overall and for birds (for which a sufficient number of species for assessment of evenness are likely to be detected (Anderson 2019) including:

- Number of vertebrate species is on a trajectory towards that of agreed reference sites.

- Evenness of birds species across sites (Pielou's evenness) is on a trajectory towards that of agreed reference sites.

Functional diversity of native fauna

Ants have been widely used as ecological indicators of habitat disturbance in the Australian tropics (King *et al.* 1998, Andersen *et al.* 2002, Hoffmann and 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).

A widely used classification of ants into nine functional groups, based on their responses to stress and disturbance, is provided by Andersen (1995). This list was refined based on the outcomes of surveys at the Ranger Trial Landform and reference sites, and four functional groups are were identified as the Key Functional Groups for the site (Andersen and Oberprieler 2019):

- dominant Dolichoderinae
- hot-climate specialists
- specialist predators
- subordinate Camponotini

The draft criteria for functional diversity of ants is:

- Species richness for each of four Key Functional Groups of ants is on a trajectory towards that of agreed reference sites.

The SSB Rehabilitation Standards include reference to vertebrate pollinators/frugivores, but does not give further details; this has been further refined. In contrast to invertebrates, there is no widely accepted classification of Australian vertebrates to functional groups. Within the Alligator Rivers Region a number of studies have inconsistently classified the same species as belonging to different functional groups (including inconsistent classifications by the same authors). We thus recommend a simplified approach to vertebrate functional groups, whereby species that use specific resources, which are among the later to develop in the rehabilitated landscape, and species that perform key ecological functions are targeted. These species include nectivorous and frugivorous bird species (which both indicate that suitable habitat resources are available, and facilitate dispersal and pollination of plant species), and species that use hollows[14] (assessment of frugivorous and hollow using species is also supported by Andersen 2019 and Einoder *et al.* 2019).

[14] Acknowledging that until the rehabilitation has developed self-sustaining array of tree hollows, it is likely to comprise only part of the home range of any hollow using fauna

Frugivorous and nectivorous vertebrate species that will potentially occur within the rehabilitated Ranger mine site identified by John Woinarski are listed in Table 8-11.

Table 8-12: 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
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 Honeyeater	*Lichenostomus unicolor*	2	1
White-Throated Honeyeater	*Melithreptus albogularis*		1
Yellow Oriole	*Oriolus flavocinctus*	1	
Yellow-Throated Miner	*Manorina flavigula*		2

The proposed vertebrate functional diversity closure criteria is:

- Species richness of nectivorous and frugivorous species is on a trajectory towards that of agreed reference sites.

Target native fauna species

Culturally significant species - ERA is conducting ongoing regular stakeholder consultation with the Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC). However, fauna of importance within woodland ecosystems have not been addressed to date. This criteria is yet to be developed.

Environmentally significant species - The key fauna groups of environmental significance include groups that indicate key ecosystem functions are occurring (i.e. decomposer fauna) and groups whose recolonisation is considered relatively challenging and dependent on the provision of specific resources. Species dependant on fruit and/or nectar and hollows, which could also be considered environmental key target species, are addressed as key functional fauna groups.

The SSB Rehabilitation Standards refer to the abundance and diversity of key invertebrate species (including ants and termites) in their consideration of nutrient cycling (Supervising Scientist Branch 2018). Ant abundance and diversity is addressed in other criteria.

Using 'termite activity' as an indicator can be problematic, as 'termites' as a whole are diverse and difficult to systematically survey. An alternative approach that provides a measurable outcome of termite activity is the method for sampling subterranean termite species diversity and activity in tropical savannas described by Dawes-Gromadzki (2003). This approach uses multiple bait types (including paper rolls, cardboard, and wooden stakes) from which the activity and diversity of subterranean termites can be assessed. The assessment of subterranean termite fauna will be to compare to their activity in reference sites.

- Activity, diversity, and functional diversity of subterranean active termites is on a trajectory towards that of agreed reference sites.

The Black-footed Tree-rat, Fawn Antechinus and Partridge Pigeon, which are listed as threatened under the TPWC Act or the EPBC Act, have been identified in the assessment of vertebrate species in the Ranger Mine site surrounds. The Black-footed Tree-rat and Partridge Pigeon are considered 'detectable' (Einoder *et al.* 2019). The presence/absence of these species will be assessed.

- Number of threatened species are on trajectory towards that which occurs in the agreed reference sites.

8.3.6 Cultural

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). This work built upon a large body of previous consultation work and studies into cultural closure criteria completed by ERA, NLC and GAC. There is regular and ongoing stakeholder consultation with the GAC and NLC to finalise the cultural criteria that will be provided in the 2021 MCP.

The cultural closure criteria are closely linked to other criteria, with the linkages shown in each of the criteria tables.

A summary of the closure objectives, the outcomes derived from the objectives, parameters used to measure the outcome and the proposed closure criteria as at 2020 is provided in Table 8-12. Each cultural criterion has been numbered to show links to the various other closure criteria listed in the previous sections. Section 8.3.6.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of the cultural theme.

Table 8-13: Closure criteria – cultural

ER	Objective	Outcome	Parameter	Summary of criteria for Minister Approval[15]	ID #	Other criteria link
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, savannah 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	C1	
			Presence / absence of erosion	≥7 Erosion verified by Bininj monitoring – limited to very minor concerns and only small areas	C2	L3, L4
			Accessibility, traversability[16]	≥7 Traversibility verified by Bininj monitoring – limited to minor difficulties only and few in number	C3	L4
			General aesthetics (does it look 'natural')	≥7 Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory	C4	-
		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	C8	E16
			Vegetation diversity	≥7 Diversity verified by Bininj – all of the expected species are present in a natural combination in nearly all of the area	C9	E8, E13, F7
			Correct species for ecological zone	≥7 Species verified by Bininj – all of the species are correct for nearly all ecological zones	C10	E1, E2, E3, E4, E5, E6, E7, E8, E12,
			Presence of weeds	≥7 Weeds verified by Bininj – weeds are present in only a minor portion of the area, low level of concern	C11	E13, E17
		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	C5	L1
		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	C7	L6, W2, W3, W6,
		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	C6	L5
		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	C12	E20
		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	C14	-

[15] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.6.

[16] 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

In determining the success of the rehabilitation over time, significant emphasis will be placed on ensuring that culturally important flora and fauna are present on the final landform. 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 8-13. 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 8-13.

In addition to the cultural health indices, one additional criterion has been included into the table being that traditional burning practices have resumed, which was included at the request of GAC.

Table 8-14: Suggested indicators of cultural health of rehabilitated site (Garde 2015)

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

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.

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 and their relevant kin.

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 has required 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 water course margins will obviously not apply to assessment of areas away from water courses. An example of what the scalar measurement tool has been provided in Table 8-14.

Table 8-15: 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 has proposed a series of workshops and meetings with Mirarr participation to progress this work.

Cultural criteria for closure monitoring 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 10.8.

8.4 Status of closure criteria

The closure criteria presented in this MCP include both those proposed for ministerial approval and draft for further review. The following sections describe the status of criteria for each theme. The draft closure criteria will continue to undergo review and refinement, based on studies and consultation with MTC members with a plan to finalise all criteria for the 2021 MCP.

8.4.1 Landform

Five of the seven landform criteria have now been finalised and are proposed for ministerial approval. The remaining two criteria will be finalised for minister approval in the 2021 MCP.

8.4.2 Water and sediment

Agreement with stakeholders has been achieved for 50% of the draft water and sediment quality objectives. These include drinking water, recreational use and ecosystem protection off the RPA for all parameters except copper and zinc in water and uranium in sediment.

Further studies and/or stakeholder consultation require to finalise the remaining draft criteria includes:

- SSB water quality standard for copper
- SSB water quality standard for zinc
- Determination of the diet parameters to be included in the diet model and assessment
- SSB standard for uranium in sediment
- Stakeholder agreement of processes for assessment of water quality as ALARA

8.4.3 Radiation

All radiation criteria have now been finalised and are proposed for ministerial approval.

8.4.4 Soils

All soil criteria have now been finalised and are proposed for ministerial approval.

8.4.5 Ecosystem

Ecosystem criteria have been developed for both revegetation and fauna. All criteria for revegetation and that of exotic fauna are being proposed for ministerial approval.

There are a number of studies currently underway to inform the development of fauna recolonisation criteria. The current status of draft fauna recolonisation criteria is presented for review. These will be finalised and proposed to the minister for approval in the 2021 MCP

8.4.6 Cultural

The cultural criteria presented in this MCP have been developed in consultation with the GAC and NLC. Ministerial approval is not being sought for cultural criteria.

Figure 8-8: Georgetown Creek

8.3 References

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Energy Resources of Australia Ltd

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	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.
Closure domain	Areas with similar features, decommissioning and/or rehabilitation requirements for closure.
Conceptual Reference Ecosystem	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	The statutory surface water monitoring point for Georgetown Billaboing, 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.
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.
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.
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.*

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 tailings dam, 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).
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	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
Underfill	Initial fill of waste rock placed in the base of 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.
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.
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 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	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
XPAC	A mine scheduling software.

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
BoM	Bureau of Meteorology
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
DISER	Commonwealth Department of Industry, Science, Energy and Resources (formally DIIS)
DITT	Department of Infrastructure, Tourism and Trade
DPIR	Northern Territory Department of Primary Industry and Resources (now DITT)
ERs	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
GIS	Geographic Information System
GPS	Global Positioning System
GTB	Georgetown Billabong
H2	Second Half
HDPE	High Density Polyethylene

Abbreviation/ Acronym	Description
HDS	High Density Sludge
LAA	Land Application Area(s)
MCP	Mine Closure Plan
MOL	Maximum Operating Level
mRL	Metres Reference Level
MTC	Minesite Technical Committee
NLC	Northern Land Council
NP	National Park
O&M	Operations and Maintenance
OPSIM	Operation Simulation Modelling
PAW	Plant Available Water
PMP	Probable Maximum Precipitation
PSD	Particle Size Distribution
PTF	Pit Tailings Flux (or expressed process water)
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
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
SSB	Supervising Scientist Branch; formally the Supervising Scientist Division (SSD)
SSD	Supervising Scientist Division
SX	Solvent Extraction
TARP	Trigger, Action, Response Plan
TDS	Total Dissolved Solids
TLF	Trial Landform
TSF	Tailings Storage Facility or tailings dam
UF/MFRO	Ultrafiltration/Microfiltration and Reverse Osmosis
WLF	Wetland Filter
WTP	Water Treatment Plant

9 CLOSURE IMPLEMENTATION

9.1 Introduction

The following section presents:

- a summary of closure implementation strategies for the Ranger Mine
- a description of the closure work program for each key closure domain
- an overview 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 section 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.

9.2 Closure planning

Closure planning aims to meet the closure objectives and achieve the post-mining landuse goals set out in Section 8. The principle closure objective is to rehabilitate the disturbed areas of the Ranger Project Area (RPA) to establish an environment similar to the adjacent areas of Kakadu National Park (NP). The total area of disturbance within the RPA (including Land Application Areas (LAAs) and the airport) is approximately 1062 ha.

ERA has undertaken significant progressive rehabilitation works since 2012, with more than AUD$600 Million spent on rehabilitation activities including tailings transfer, process water treatment and the backfill of Pit 1. Opportunities for final revegetation of disturbed areas have so far been limited, in part due to efforts to maintain a minimum footprint and concentrate operational activities within the existing disturbed area. Despite this, over 12 ha of successful native revegetation has been completed (Table 9-2).

A detailed risk assessment has been completed for the closure of the Ranger Mine, and this is discussed in Section 7. The closure implementation plan for Ranger Mine has been designed to mitigate these identified risks. The following sections provide an outline of how this closure plan will be implemented and includes the current stages of closure across the RPA and staged closure timing. The closure plan for each domain or activity has been developed through a review of all options with the preferred option selected through a Best Practicable Technology (BPT) assessment, where appropriate (Section 6).

Closure planning is subject to continual revision as results of closure studies[1] become available, and from continual assessment of implementation activities to ensure feasibility and a best practice approach to all closure activities.

A schedule of all closure tasks is presented for each domain/activity. The schedule is indicative and subject to ongoing revision to reflect the status of closure activities. A full schedule for all closure activities is provided in Appendix 9.1. ERA is committed to completing rehabilitation by the regulated closure date of 8 January 2026 and achieving all closure obligations and environmental requirements (Section 3). The current closure schedule indicates that this can be achieved.

The Ranger Mine closure plan factors in a number of contingency options for implementation in the event that the preferred option cannot be implemented or fails to achieve the desired outcome. The majority of these options are discussed in Section 6 as part of the best practical technology assessment with some specific contingencies further outlined in this section.

9.3 Closure domains

Closure domains are areas with similar features, decommissioning and/or rehabilitation requirements for closure (DMIRS 2020). The closure domains for the Ranger Mine are provided in Figure 9-1. The name and size of each associated area of land disturbance is provided in Table 9-1.

The purpose of the implementation section is to outline all closure tasks for each closure domain or closure activity. This includes tasks already completed, currently underway or planned. The main categories discussed within each domain, where appropriate, are:

- decommissioning, including decontamination and hazardous material management
- remediation
- final landform preparation, including erosion and sediment control
- revegetation
- monitoring
- maintenance
- contingency plans

[1] ERA completed a feasibility study in 2018 to review and refine the proposed closure strategy to obtain a better level of confidence in the execution plan. The outcomes of this study have formed the basis for the closure implementation plan outlined in this section.

The 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 9.4.

Table 9-1: Land disturbance by domains

Reference No.	Domain	Disturbance (ha)	
1	Pit 1	41.40	41.40
2	Pit 3	107.12	107.12
3	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 LAA	43.0	158.00
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	Gagadju 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	55.02

Reference No.	Domain	Disturbance (ha)	
9I	Trial Landform	10.60	
10 A & B	Airport & ERISS	44.08	44.08
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
RMV revegetation track	3.34
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
Total	*12.34ha*

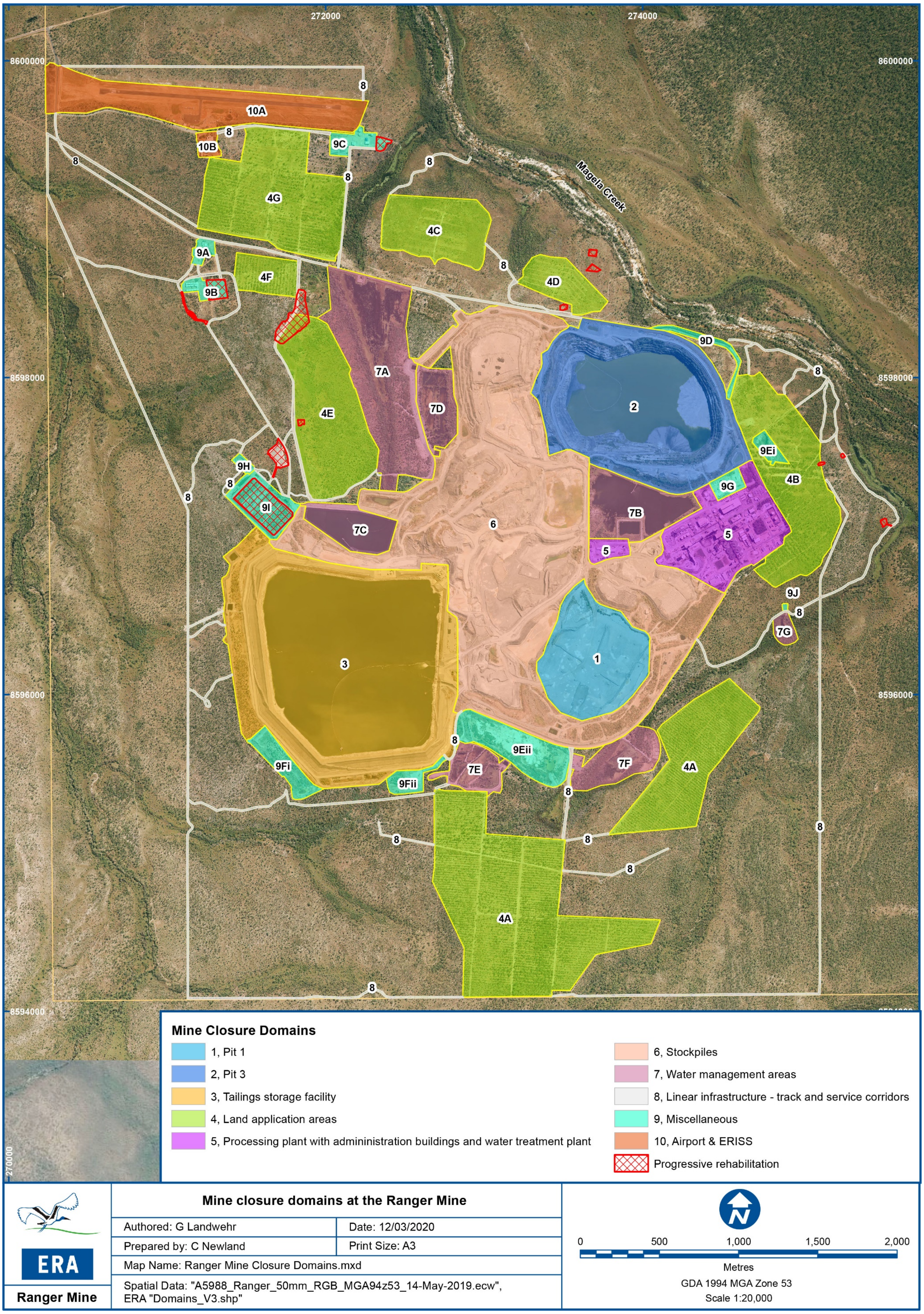


Figure 9-1: Ranger Mine closure domains (aerial 2019)

9.3.1 Pit 1

Figure 9-2: Pit 1 (August 2020)

With due consideration given to the outcomes of the relevant risk assessments, in particular the range of existing and proposed controls required to eliminate or mitigate the identified risks, a robust plan was developed for the execution of Pit 1 closure and the construction of the final landform. This is now in the final stages.

Key elements of Pit 1 closure are:

- construction of an underdrain across the floor of the pit
- deposition of 25.6 M tonnes (unconsolidated) tailings in the base of the pit between 1996 and 2008
- 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 (refer to Section 9.3)

- construction of a surface layer of non-mineralised Grade 1 (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
- construction of drainage channels within the surface layer to manage erosion for the Pit 1 catchment and reduce the risk of mobilised sediments or other contaminants impacting RPA or offsite aquatic ecosystems (to be discussed under Section 9.4.5)
- revegetation to initiate the establishment of a self-sustaining ecosystem
- 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. This is discussed further within Section 5 and Section 10 of the MCP

9.3.1.1 Completed rehabilitation

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 backfill and rehabilitation activities that have taken place in Pit 1 from 1995 to present are provided in Table 9-4.

Figure 9-3: A view of some of the 7,554 vertical wick drains installed in Pit 1 in 2012

Backfill

The two types of waste rock used in rehabilitation are termed 1s and 2s (Table 9-3). Waste characterisation is further discussed in Section 9.4.2.

Table 9-3: Type of waste rock used in rehabilitation

Type	Term	Uranium oxide grade (U_3O_8) %wt
Non-mineralised waste rock	1s (Grade 1)	Less than 0.02
Mineralised waste rock	2s (Grade 2)	0.02 – 0.05

The key to the backfill design of Pit 1 is 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. However, it was also desirable to maximise the volume of 2s material placed under the 1s layer (Fitton 2015).

The bulk backfill design also aims 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 2015) (Section 5.4.1.5). The settlement standpipes continue to provide this data.

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 2018). The conservatism built into the design allows for additional tailings settlement induced by the weight of the final waste rock cover.

Table 9-4: 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 Q4. 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 wick drains occurred to assist with dewatering the pit prior of capping and rehabilitation (Figure 9-3). 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.

Year	Closure activity
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 209,116 m2 (70%) of the pit. The rock placement was designed to activate the vertical wick drains and porewater expression. A 0.5 m – 1.0 m cover of laterite was placed over the northern half the pit to form the pond water interception layer as part of the Ranger Mine operational water management (to prevent rainwater adding to the process water inventory). 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 (30% of total surface).
2016	Jan - A 2.5 m thick rock initial capping layer and placement of 0.5-1 m laterite across the entire pit surface was completed. Two decant towers were installed to remove the expressed process water from the pit. A subsequent decant well was installed in 2017. May - Bulk backfill of Pit 1 commenced following regulatory approval of the final average tailings level of 7 mRL mRL (Pugh et al. 2016).
2018	July – Bulk backfill was halted pending regulatory approval for further works.
2019	May – Final backfill commenced following regulatory approval of the final landform design.
2020	August – Final backfill and landform contouring completed.

Note: the initial capping layer was previously termed 'preload'.

9.3.1.2 Current rehabilitation

Tailings consolidation and removal of pit tailings flux

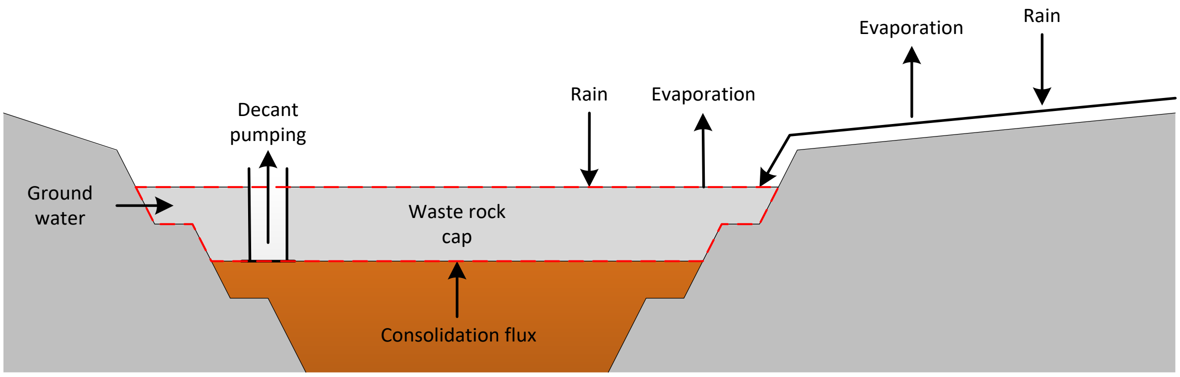


Figure 9-4: Pit 1 water balance schematic

Water from various sources contributes to the water balance of Pit 1. 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 undergoing consolidation. The pore spaces between the tailings solids contain process water and, as the tailings consolidate, that process water is squeezed up as a consolidation flux (pit tailings flux). Groundwater from surrounding rock formations may also enter the pit. Phreatic surfaces in the pit are currently lower than surfaces in the surrounding rock formations, meaning that flow from the pit to its surrounds is not possible whilst this head difference remains. 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.

Decant wells have been installed and extend from the surface of the waste rock backfill down to near to the top of the tailings. Tailings consolidation during the backfilling of Pit 1 steadily drives contained process water both towards the vertical drains (wicks) installed in the tailings and up into the waste rock. At any given time, it is planned that one of the decant towers is fitted with a pump that can extract solution accumulated within the waste rock, and direct it to the process water storages.

The purpose of the decant wells is thus to allow for the removal of process water derived from:

- water expressed during consolidation
- rainfall infiltration through waste rock
- groundwater ingress from the surrounding formation whilst the pit remains as a hydrologic sink

Through to late July 2019, the expressed water pumped from the southern decant used to feed the High Density Sludge (HDS) plant during its trial phase. From late July through to mid-November 2019, the decant system was offline due to low water level and to permit bulk backfill activities in the area of the decants. During this time pump and pipeline infrastructure were removed, additional concrete rings were installed on top of each of the two towers, waste rock was then placed around the decants up to the planned backfill level and the pump and pipeline infrastructure was re-installed. Once the backfil in the area of the decants was completed, pumps were installed into the northern decant (as it was the deeper of the two decants) and the system restarted in November 2019 and operated through to the end of capping activities. The decants, though currently offline, have been retained as a contingency for managing future tailings consolidation flux (Section 5.4.1.5).

Landform

The backfill of Pit 1 and contouring of the final landform was completed in August 2020 (Figure 9-6). The pit surface will now be ripped in preparation for revegetation and further trials (Section 9.3.1.3) and the interim water management works completed in preparation for the 2020/21 wet season. These works include the installation of a drain around the edges of Pit 1 to capture rainfall runoff (Figure 9-5), the extension of the existing sump (called CRS) to a sufficient capacity to collect this rainfall runoff and the installation of pumping and piping infrastructure.

These interim water management structures will remain in place until the remainder of the corridor creek catchment has been rehabilitated, 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 9-5: Construction of the drain at the southeast edge of Pit 1 (July 2020)

Figure 9-6: Backfill progress at Pit 1 (view northwest) (July 2020)

9.3.1.3 Planned rehabilitation

Surface preparation & revegetation

Pit 1 is available for revegetation two years before other sections of the final landform, therefore it provides an opportunity to further ERA's understanding of the behaviour and attributes of water, radiation exposure and ecosystem establishment as the landform matures. Pit 1 will be divided into four areas to trial different methods of ripping, irrigation and revegetation. The revegetation activities at Pit 1 will include 'conceptual reference ecosystem' (CRE) trial planting based on reference ecosystem surveys, and targeted revegetation trials.

Initial plant establishment and early development is essential for successful revegetation. Although adaptive management can be used to progress an ecosystem towards a desirable state, it is the initial ecosystem establishment phase that sets the trajectory for subsequent ecosystem development. The initial establishment stage has the highest rate of 'change', which means a relatively high risk of deviation but also a greater opportunity for corrective actions. Lessons learned from a series of re-establishment activities in different aspects of the ecosystem re-establishment will inform subsequent activity in other sectors of Ranger Mine.

Initial revegetation of waste rock landforms can be difficult due to harsh field conditions, including high temperatures, irradiance and surface reflectance. The substrate can have relatively low water holding capacity, and low or no organic matter, nutrients or microbial activity. Ranger Mine waste rock has proven to be highly variable in quality and texture, and it is likely that different substrate types will yield different plant responses.

Pit 1 provides the opportunity to test and evaluate a range of aspects related to early revegetation activities. Opportunistic, small-scale tubestock trials were conducted at Stage 13.1, adjacent to Pit 1 as a precursor for the Pit 1 revegetation. These pilot trials allowed ERA to explore a range of methodologies and techniques, and has highlighted treatments that warrant further, large-scale investigation at Pit 1.

The total surface area of Pit 1 will be close to 40 hectares; the shape will be roughly circular and have a radius of approximately 300 – 400 metres (Figure 9-7). Some sections of Pit 1 will not be available for immediate revegetation due to future works such as access and the removal of decant wells and water management features (e.g. drains, sumps).

Pit 1 will be divided into four areas to trial different methods of ripping, irrigation and revegetation (Figure 9-7). The naming convention for the areas across the pit have been based on the catchment names provided by the board of the Gundjeihmi Aboriginal Corporation (GAC). The corridor creek catchment that drains south to Georgetown Billabong is known as Walem Madjawulu. Based on this the locations have been named WM-1 though WM-4. The revegetation activities at Pit 1 will include "Research revegetation trials" and "Operational revegetation trials". The research revegetation trials will be targeted, manipulative trials investigating different potting, propagation and/or sowing methods with the aim of improving initial plant survival and establishment. Operational research trials will investigate different approaches for the operational aspects of revegetation, including irrigation and land preparation.

Table 9-5: Revegetation trial areas of Pit 1

Area	Size (Ha)	Revegetation trial type	Surface preparation
WM-1	5.3	Operational	Reefinator surface roughness
WM-2	9.9	Operational	Single shank on back of grader (up to 300mm) along contours, up to 4 m apart
WM-3	14.5	Research	Shallow scarification (200-300 mm) along contours, small distances between lines
WM-4	6.2	Operational	No ripping

The following sections describe the final landform and ecosystem establishment plans in more details.

Figure 9-7: Area of planned revegetation for Pit 1 showing trial areas

Surface preparation trial

The different ripping/scarification methods to be applied in the four areas of Pit 1 are intended to create a natural appearance on the Pit 1 surface topography while providing an opportunity to trial their impact on revegetation outcomes. Ripping methods are also in line with the principle of reducing erosion in final landform by creating roughness at the surface which slows the rate of rainwater run-off.

The objective of the Pit 1 landform configuration is to, firstly, trial multiple surface preparation methods for Pit 1 revegetation activity, in this case establishment of key species from potential conceptual reference ecosystems. Secondly, the shallow-scarified area will provide an area for a series of revegetation trials for improved revegetation methods for subsequent site-wide implementation.

A plan of the surface landform is proposed as four trials in the Pit 1 as shown in Figure 9-7. Four different surface ripping options are proposed, each separated with interim windrows. Each area has a different topography and surface micro-topography conditions. The four different surface preparation options are listed against each trial area in Table 9-5. The assessment of each ripping trial will be completed in consultation with stakeholders and used to inform the final landform ripping plan.

Irrigation trials

Irrigation infrastructure will be installed and operational prior to planting. Different configurations of irrigation system may be trialled, however all will be capable of up to 8 mm delivered over the entire planting area during a 12-hour period. Irrigation will be applied at a rate that does not cause soil displacement, surface runoff, significant water pooling or damage to young plants. All irrigation treatments shall remain consistent within each of the four trial areas. Irrigation will be operated and maintained for up to six months following planting.

Revegetation trial

The standard revegetation implementation activities are described in Section 9.4.6 including herbicide application and the tubestock planting method. Only those aspects of revegetation being investigated as part of the Pit 1 trials shall be discussed here.

ERA has recently proposed a series of four ‘conceptual reference ecosystems’ that could form the basis of revegetation communities most likely to be suited to the challenges posed by the rehabilitated landform (Section 5.5.4.1). Pit 1 provides a good opportunity to plant out these different CREs so that their suitability for revegetating waste rock landforms can be assessed. The conceptual reference ecosystem trial plantings will also visually demonstrate the different ecosystem types to Traditional Owners and external stakeholders prior to finalising the revegetation plan for the Ranger final landform.

Three of the four conceptual reference ecosystems will be used to revegetate Pit 1 (Table 9-6). The full species lists and their exact planting densities are to be confirmed, as the conceptual reference ecosystems are part of ongoing discussions with the Supervising Scientist Branch.

However, overall planting densities will range between 800 – 1200 stems per hectare, with an average of 1000 stems per hectare.

Table 9-6: Example of overstorey and midstorey tree and shrubs species compositions for the different Conceptual Reference Ecosystems, listing the 18 highest density species listed in descending order of dominance

ICRE	ACREv1	ACREv2	ACREv3
Acacia mimula	*Acacia mimula*	*Acacia mimula*	*Acacia mimula*
Eucalyptus tetrodonta	*Eucalyptus tetrodonta*	*Eucalyptus miniata*	*Eucalyptus tetrodonta*
Eucalyptus miniata	*Corymbia porrecta*	*Eucalyptus tetrodonta*	*Corymbia foelscheana/ latifolia*
Corymbia bleeseri	*Livistona humilis*	*Xanthostemon paradoxus*	*Xanthostemon paradoxus*
Corymbia porrecta	*Eucalyptus miniata*	*Corymbia porrecta*	*Terminalia pterocarya*
Livistona humilis	*Xanthostemon paradoxus*	*Corymbia bleeseri*	*Corymbia porrecta*
Xanthostemon paradoxus	*Corymbia bleeseri*	*Terminalia ferdinandiana*	*Terminalia ferdinandiana*
Erythrophleum chlorostachys	*Erythrophleum chlorostachys*	*Livistona humilis*	*Corymbia disjuncta*
Terminalia ferdinandiana	*Terminalia ferdinandiana*	*Erythrophleum chlorostachys*	*Eucalyptus miniata*
Persoonia falcata	*Planchonia careya*	*Melaleuca viridiflora*	*Buchanania obovata*
Acacia lamprocarpa	*Buchanania obovata*	*Planchonia careya*	*Corymbia bleeseri*
Buchanania obovata	*Persoonia falcata*	*Corymbia foelscheana/ latifolia*	*Calytrix exstipulata*
Acacia oncinocarpa	*Acacia lamprocarpa*	*Corymbia dunlopiana*	*Cochlospermum fraseri*
Brachychiton megaphyllus	*Syzygium eucalyptoides bleeseri*	*Persoonia falcata*	*Eucalyptus tectifica*
Pandanus spiralis	*Brachychiton megaphyllus*	*Syzygium eucalyptoides bleeseri*	*Planchonella arnhemica*
Cochlospermum fraseri	*Acacia oncinocarpa*	*Calytrix exstipulata*	*Gardenia megasperma*
Planchonella arnhemica	*Jacksonia dilatata*	*Corymbia chartacea*	*Planchonia careya*
Stenocarpus acaciodes	*Planchonella arnhemica*	*Buchanania obovata*	*Grevillea mimosoides*

There will be transect monitoring of the CRE planting areas to assess tubestock survival as per the *Pit 1 Ecosystem Rehabilitation Monitoring Plan*, to be developed under the *Pit 1 Progressive Rehabilitation Monitoring Framework* and further discussed in Section 10.

Monitoring methods utilising the efficiencies of remote sensing, for example drone surveys for overall survival, will be explored.

Where high levels of mortality are observed, a remediation plan will be considered including review of potential causes, adjustment of species mix, and opportunities to infill plant.

Tubestock trials

ERA has considerable knowledge and experience regarding revegetation of waste rock using tubestock planting. The Ranger Trial Landform (TLF) has demonstrated many of the target overstorey and midstorey species can successfully establish on waste rock, despite relatively high levels of early mortality. Modifications to ERA's revegetation approach since the TLF, such as the assembly of reliable irrigation prior to planting, have already resulted in significant improvements to initial survival rates (e.g. Stage 13.1 early survival). Some propagation changes, as outlined in Table 9-8, may yield further improvements in early tubestock establishment.

The overall objective of the tubestock trials is to investigate different potting and propagation techniques with the aim of improving tubestock survival and health during the first two years after planting. This study will also provide an opportunity to:

- Gather species-specific data to fine-tune nursery propagation methods, such as germination rates, required growing times, irrigation requirements etc.;
- Obtain baseline performance data for species that have not been grown on FLF media previously; and
- Propagate and plant tubestock during different times of the year.

Species selected for tubestock trials are listed in Table 9-7. These were selected based on the following considerations:

- species which are most important to optimise establishment. e.g. Culturally significant species, species which occur at high densities etc.
- species which have historically been difficult to establish on waste rock
- species ERA has limited or no experience establishing on waste rock
- species not suitable for initial planting, either because the conditions are too harsh or because they may be too aggressive

Table 9-7: Tubestock trial species (may change slightly depending on seed collection / availability)

Species	Lifeform	Family	Seed Quantity Status
Overstorey and Midstorey			
Acacia lamprocarpa	Tree	Fabaceae	Sufficient
Acacia mimula	Shrub	Fabaceae	Sufficient
Brachychiton megaphyllus	Shrub	Malvaceae	Sufficient
Buchanania obovata	Shrub	Anacardiaceae	Collect Sep - Nov
Calytrix exstipulata	Shrub	Myrtaceae	Collect Aug - Oct
Corymbia bleeseri	Tree	Myrtaceae	Sufficient
Corymbia chartacea	Tree	Myrtaceae	Sufficient
Corymbia disjuncta	Tree	Myrtaceae	Sufficient
Corymbia dunlopiana	Tree	Myrtaceae	Sufficient
Corymbia foelscheana	Tree	Myrtaceae	Sufficient
Corymbia polysciada	Tree	Myrtaceae	Sufficient
Corymbia porrecta	Tree	Myrtaceae	Sufficient
Erythrophleum chlorostachys	Tree	Fabaceae	Sufficient
Eucalyptus miniata	Tree	Myrtaceae	Sufficient
Eucalyptus tectifica	Tree	Myrtaceae	Sufficient
Eucalyptus tetrodonta	Tree	Myrtaceae	Sufficient
Gardenia megasperma	Shrub	Rubiaceae	Sufficient
Grevillea mimosoides	Shrub	Rubiaceae	Collect Sep - Nov
Jacksonia dilatata	Shrub	Fabaceae	Collect Jul - Nov
Livistona humilis	Palm	Arecaceae	Collect Jul – Dec
Melaleuca viridiflora	Tree	Myrtaceae	Sufficient
Planchonella arnhemica	Shrub	Sapotaceae	Collect Jul – Aug
Planchonia careya	Shrub	Lecythidaceae	Collect Jul – Dec
Stenocarpus acacioides	Tree	Proteaceae	Collect Nov – Dec
Syzygium eucalyptoides ssp. bleeseri	Shrub	Myrtaceae	Collect Nov – Dec
Terminalia ferdinandiana	Shrub	Combretaceae	Sufficient
Terminalia pterocarya	Shrub	Combretaceae	Sufficient
Understorey			
Acacia gonocarpa	Shrub	Fabaceae	Sufficient
Alloteropsis semialata	Grass	Poaceae	Sufficient
Ampelocissus acetosa	Vine	Vitaceae	Sufficient
Aristida holathera	Grass	Poaceae	Collect Jul – Nov

Species	Lifeform	Family	Seed Quantity Status
Cartonema spicatum	Herb	Commelinaceae	Sufficient
Eriachne obtusa	Grass	Poaceae	Sufficient
Galactia tenuiflora	Vine	Fabaceae	Sufficient
Haemodorum coccineum	Herb	Haemodoraceae	Sufficient
Heteropogon triticeus	Grass	Poaceae	Sufficient
Indigofera saxicola	Shrub	Fabaceae	Sufficient
Larsenaikia suffruticosa	Subshrub	Rubiaceae	Collect Jun – Dec
Petalostigma quadriloculare	Shrub	Picrodendraceae	Sufficient
Tacca leontopetaloides	Herb	Taccaceae	Sufficient
Uraria lagopodioides	Vine	Fabaceae	Sufficient

Four tubestock treatments are to be trialled during three different planting times; these are described in Table 9-8, Table 9-9 and Table 9-10.

Table 9-8: Tubestock treatment factors and rationale

Factors to be investigated	Rationale
Pot types	Although plastic nursery tubes are the commercial standard for revegetation, past experience at Ranger Mine suggests biodegradable pots may be a preferable option as they eliminate the need to de-pot. The preliminary results from Stage 13.1 suggest that tubestock grown in nursery tubes generally have greater survival than tubestock grown and planted in biopots. However, these results may be because the plants in biopots were disproportionally impacted by the nursery irrigation failure incident (due to their slotted sides) and/or the delayed planting and additional bench time (due to their smaller volume). Further trials are needed to determine whether biopots or nursery tubes are optimal for plant establishment.
Plant Size/Age	Planting smaller tubestock may result in a higher root-shoot ratio, decreasing the initial water demand of the seedling. Planting smaller sized tubestock appeared to improve *Xanthostemon paradoxus* survival on the TLF. Nursery observations of the Stage 13.1 tubestock, and experience from previous revegetation trials that were also unexpectedly delayed, indicate that prolonged bench time can significantly impact plant health and presumably field performance. Although 'maximum holding times' are relatively clear, 'minimum holding times' were tubestock field performance is still optimal are relatively unknown.

Factors to be investigated	Rationale
Unseasonal planting	Tubestock planting traditionally takes place during the wet season. However when revegetation operations peak in 2024/2025, tubestock will need to be grown and planted all year round. It is believed that rates of (some) seed germination and tubestock growth may be reduced during the cooler dry season. Understanding this will be important to setting the correct propagation plan for areas requiring dry season planting in future. In contrast, there is a concern that the harsh conditions during the 'build up' period (very high temperatures and humidity) may stress plants in the nursery, and/or when newly planted out, resulting in unacceptably high rates of mortality. Depending on the findings of this trial, there may be options to modify the nursery and/or planting out methods, or look to reschedule works during particularly harsh periods. This treatment is included in the Stage 13.1 trial, however planting is not scheduled until October 2020.

Table 9-9: Tubestock Treatments

Treatments	Pot Type		Plant size	
	Plastic	*Bio*	*Smaller*	*Standard*
Control (C)	X			X
Smaller (S)	X		X	
Biopot (B)		X		X
Biopot + Smaller (B+S)		X	X	

Table 9-10: Tubestock Trial Planting Details

Planting Time	Revegetation Trials		
	Hectares (approx.)	Total Stems (approx.)	Total Species
March	~ 6.6	6,570	41
Dry	~ 3.4	3,420	19
Build-up	~ 3.4	3,420	19

All of the overstorey and midstorey species will be trialled with the four tubestock treatments (Table 9-9), excluding *Livistona humilis,* which will only be trialled with different pots (treatments C and B) due to its long propagation requirements (Table 9-8). The majority of the understorey species will only be grown in biopots with different sizes/ages (treatments B and B+S), except for species which will be the focus of a PhD (future work by Megan Parry).

All of the trial species will be planted in March and half of the species will be included in the dry and build-up trials (Table 9-11 and Table 9-12). The species chosen for the unseasonal planting trials generally occur at high densities, are a range of families and lifeforms, and a combination of deciduous, evergreen and/or fresh-seeded species.

Table 9-11: Experimental Design (subject to change depending on seed collection/availability and statistical method chosen)

Species	Treatments	Replicates	Planting Seasons	Total Stems
Acacia lamprocarpa	4	45	3	540
Acacia mimula	4	45	3	540
Brachychiton megaphyllus	4	45	3	540
Buchanania obovata	4	45	3	540
Calytrix exstipulata	4	45	1	180
Corymbia bleeseri	4	45	3	540
Corymbia chartacea	4	45	1	180
Corymbia disjuncta	4	45	1	180
Corymbia dunlopiana	4	45	1	180
Corymbia foelscheana	4	45	1	180
Corymbia polysciada	4	45	1	180
Corymbia porrecta	4	45	3	540
Erythrophleum chlorostachys	4	45	3	540
Eucalyptus miniata	4	45	3	540
Eucalyptus tectifica	4	45	1	180
Eucalyptus tetrodonta	4	45	3	540
Gardenia megasperma	4	45	1	180
Grevillea mimosoides	4	45	1	180
Jacksonia dilatata	4	45	1	180
Livistona humilis	2	45	1	90
Melaleuca viridiflora	4	45	1	180
Planchonella arnhemica	4	45	1	180
Planchonia careya	4	45	3	540
Stenocarpus acacioides	4	45	1	180
Syzygium eucalyptoides subsp. bleeseri	4	45	3	540
Terminalia ferdinandiana	4	45	3	540
Terminalia pterocarya	4	45	3	540
Acacia gonocarpa	4	45	3	540

Species	Treatments	Replicates	Planting Seasons	Total Stems
Alloteropsis semialata	4	45	3	540
Ampelocissus acetosa	2	45	1	90
Aristida holathera	2	45	1	90
Cartonema spicatum	2	45	1	90
Eriachne obtusa	4	45	1	90
Galactia tenuiflora	4	45	3	540
Larsenaikia suffruticosa	2	45	3	540
Grevillea goodii	2	45	1	90
Haemodorum coccineum	2	45	1	90
Heteropogon triticeus	4	45	3	540
Petalostigma quadriloculare	2	45	3	540
Tacca leontopetaloides	2	45	1	90
Uraria lagopodioides	4	45	1	90
TOTAL STEMS				13,410

Table 9-12: Example propagation, planting and irrigation schedule for 2020 – 2021

Season	Size	Size	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Wet	Normal	Normal	Nursery propagation					Planting event	Irrigation period												
		Small																			
	Small	Normal																			
		Small																			
Dry	Normal	Normal										Planting event	Irrigation period								
		Small																			
	Small	Normal																			
		Small																			
Build-up	Normal	Normal													Planting event	Irrigation period					
		Small																			
	Small	Normal																			
		Small																			

The first planting will commence in March 2021, and the third planting event is scheduled for the start of October 2021 (Table 9-12). The tubestock with the smaller/younger treatments (S and B+S) will be propagated approximately four weeks after the treatments with standard growing periods (C and B). The dry and build-up trials may require slightly longer propagation times (to be informed by the Stage 13.1 'unseasonal' trials that are currently underway).

The seedlings will be tagged to ensure individual species, treatment and replicate number are identifiable. Survival and health, growth, flowering, fruiting, and recruitment will be monitored throughout the trial.

Direct seeding trials

The ERA revegetation strategy primarily involves the use of tubestock. Due to the restricted provenance zones for seed collection it is not possible for ERA to gather the volume of seed that would be required for traditional broadcast seeding of all species. 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. Furthermore, there is still opportunity to direct seed species that have readily available and reliable volumes of seed, such as grasses.

The revegetation strategy for introducing midstorey and understorey species from seed would be different based on their life cycles/traits. Understorey species mature quickly and generally begin self-recruiting within one to two years. In theory, understorey species could be introduced in patches, which would then spread outward into the remaining revegetated area over time. This would minimise the risks of introducing understorey at the initial stages of revegetation (eg. increased competition and likelihood of fire as discussed in Appendix 9.4), and would reduce the amount of seed needed for the successful introduction of these species. Conversely, midstorey species are relatively slow to mature and would take decades to colonise through the revegetated area naturally, therefore these species need to be broadcast throughout the revegetated landform rather than in patches.

The overall objective of the direct seeding trails is to determine which species can successfully establish from seed on the final landform during the initial stages of revegetation. In addition, for some species:

- Does time of sowing impact plant establishment from seed?
- Does surface treatment impact establishment from seed?
- Does irrigation impact establishment from seed?

Midstorey and understorey species have been selected for the direct seeding trials (Table 9-13). Because the revegetation strategies/methods are different for midstorey and understorey species, each strata had different considerations when selecting trial species.

Midstorey species were selected for direct seeding trials based on the following key considerations:

- Availability of seed in sufficient quantities, and are easy to collect and process.

- Potential suitability of species for direct seeding: eg. they were amongst the better performing species in previous trials on Ranger Mine waste rock, they typically grow in harsh conditions somewhat similar to those found on the initial final landform etc.
- Species which occur at high densities in the surrounding bushland, therefore would provide significant savings if able to direct seed.

The understorey species were selected based on:

- Common species in the woodlands surrounding Ranger mine, based on ERA and ERISS reference surveys.
- Species which have colonised revegetated areas over time such as many annual species on the trial landform, and therefore may not require active re-introduction.
- Species not suitable for initial introduction because they are too competitive or pose a fire risk (eg. Sorghum intrans).

Most of the species will only be sown during the wet season with no additional treatments (Table 9-13). Four to six understorey species will have more treatments as they will be the focus of future studies. These treatments include:

- Different sowing times (wet, dry and build-up)
- Irrigated and non-irrigated, wet season only (still pending)
- With and without surface mulch. A thin layer of litter mulch has previously been found to improve seed germination and seedling survival in the harsh dry conditions of hard-rock mines in northern Australia (Parry 2018, Saragih 2017, Spain & Reddell 1995). However, litter may have a negligible effect on seed germination and establishment in plots that are receiving regular irrigation. The addition of litter also has the potential to add biological elements to the barren waste rock, including seeds, microbes, fungi etc. Ethical aspects of litter collection methods, volumes and sources need to be considered for this treatment.

Table 9-13: Direct seeding species and experimental design

Species	**Strata** **Understorey - US** **Midstorey - MS**	**Treatments**	**Replicates**	**Sowing Times**	**Total Plots**
Acacia gonocarpa	US	2	8	4	64
Alloteropsis semialata	US	2	8	4	64
Ampelocissus acetosa	US	1	8	1	8
Aristida holathera	US	1	8	1	8

Species	**Strata** **Understorey - US** **Midstorey - MS**	**Treatments**	**Replicates**	**Sowing Times**	**Total Plots**
Brackychiton megaphyllus	MS	1	8	1	8
Calytrix exstipulata	MS	1	8	1	8
Cartonema spicatum	US	1	8	1	8
Eriachne obtusa	US	2	8	4	64
Galactia tenuiflora	US	2	8	4	64
Grevillea goodii	US	1	8	1	8
Haemodorum coccineum	US	1	8	1	8
Heteropogon triticeus	US	2	8	4	64
Larsenaikia suffruticosa	US	1	8	1	8
Livistona humilis	MS	1	8	1	8
Petalostigma quadriloculare	US	1	8	1	8
Tacca leontopetaloides	US	1	8	1	8
Terminalia ferdinandiana	MS	1	8	1	8
Uraria lagopodioides	US	2	8	4	64
Total					488

All seeds will be viability tested to determine appropriate sowing rates. Plots/patches will be 2 m x 2 m (pers comm. Kingsley Dixon) and located in between trial tubestock, therefore will be irrigated at the same frequency and duration as the trial tubestock.

Seeds will be sown by hand, with one species sown per plot. Small and/or fluffy seeded species will be sown mixed with a portion of substrate to help evenly distribute seeds in the plot. Species such as *L. humilis* and *T. ferdinandiana* are large and heavy enough to easily broadcast evenly into plots without bulking agents.

A small amount of slow-release fertiliser will be applied to each plot, once immediately after sowing and potentially the first year after sowing.

9.3.1.4 Contingency planning

There is an ongoing monitoring program (Section 10) 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.

Table 9-14: Schedule for Pit 1 closure rehabilitation

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	26>
Pit 1	Wicks	Installation of prefabricated vertical drains (wicks) within previously transferred tailings	Complete							
	Geofabric etc.	Installation of geotextile and preload activities	Complete							
	Backfill	Pit 1 bulk backfill	Complete							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation activity commences on the perimeter of the pit	Scheduled							
	Monitoring	As per Pit 1 progressive monitoring framework and associated monitoring plans	Ongoing							
	Maintenance	Weed control, remedial works etc.	Scheduled							

9.3.2 Pit 3

Figure 9-5: Pit 3 (May 2019)

9.3.2.1 Completed rehabilitation

Open-cut mining in Pit 3 commenced in July 1997 and ended in November 2012 with a base (floor) elevation of -265 mRL. A timeline of the key mining, backfill and remediation activities that have taken place in Pit 3, from 1995 to present, is provided in Table 9-15.

Table 9-15: Completed Pit 3 rehabilitation

Year	Pit 3 activity
1995	ERA applied to the MTC to mine Ranger Pit 3, and was approved to do so in May 1996
1997	The excavation/mining of Ranger Pit 3 commenced in July 1997.
2008	Preliminary earthworks for the Shell 50 expansion/cutback commenced in the second half of 2008.
2012	Mining in Pit 3 ceased on 27 November 2012 and works to prepare the pit for closure commenced in December 2012.
2014	Completion of underfill. Construction of engineered underdrain for brine injection. Submission of assessment of potential environmental impacts from the interim final tailings level in Pit 3 (ERA 2014) to MTC in August.
2015	In February, disposal of approximately 15 Mt of mill tailings commenced, with tailings deposited from the east side of the pit. The transfer of mill tailings will continue until mill production ceases on/before January 2021. Pit 3 became a process water catchment. The brine injection system was commissioned in Q4.
2016	In January, transfer of approximately 27 Mt of dredged tailings from the Tailings Storage Facility (TSF) commenced. The brine injection system commenced full-scale operation in Q1.

Year	Pit 3 activity
2017	In March, ERA notified the MTC of a potential need to change the tailings deposition method in Pit 3 and the intention to undertake an assessment of the feasibility of changing to subaqueous discharge.
2018	ERA notified the MTC of the intention to trial subaqueous deposition of dredged TSF tailings in Pit 3. This trial commenced in 2018.
2018	ERA submitted an application seeking approval to modify the method of TSF tailings deposition from subaerial to subaqueous. Mill tailings continued to be deposited sub-aerially along the Eastern wall of Pit 3. Approval was granted in 2019.
2018	Sub-aqueous tailings deposition from TSF dredging commenced.
2019 – current	Installed and commissioned a second dredge. Sub-aqueous deposition of dredged tailings continues.

Underfill and brine injection

Prior to tailings being deposited into the mined out Pit 3, works were completed to prepare the pit to receive tailings and brine and to ensure backfill and closure of the pit can be achieved by January 2026. The overall backfill design for Pit 3 is provided in Figure 9-8. The underfill, comprised of waste rock, was constructed at the base of the mined out Pit 3 to raise the floor from -265 mRL to -100 mRL[2] (including the drainage layer) providing a broad, level surface area for tailings deposition. The intent of this underfill was, in part, to generate a low rate of tailings rise and to optimise consolidation rates allowing for minimal backfill consolidation over time. Early and rapid consolidation will provide for a stable rockfill cap design and improve the success of the revegetation and rehabilitation programs.

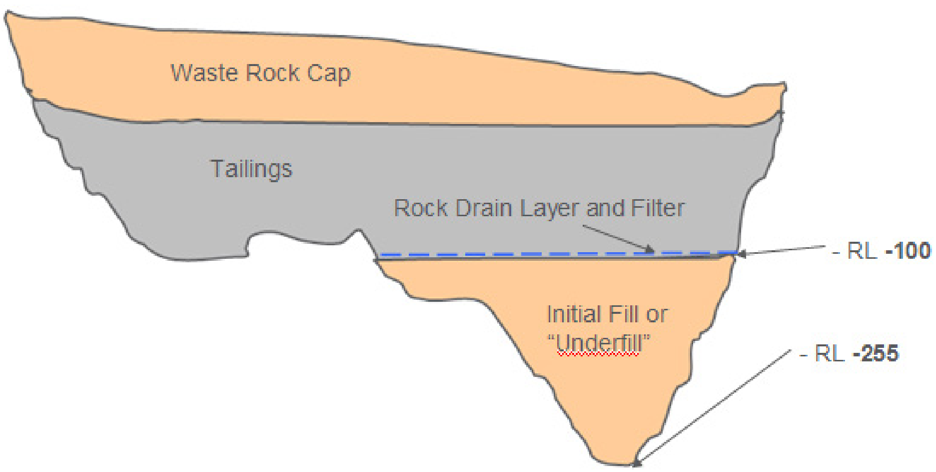
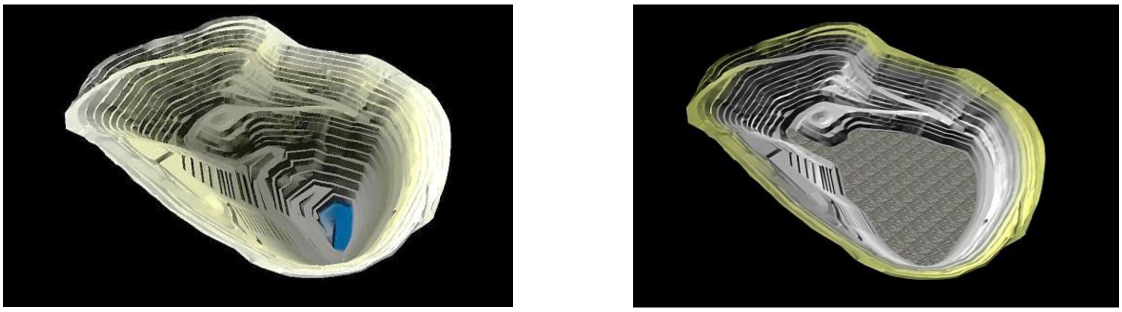


Figure 9-8: Pit 3 backfill conceptual design

[2] The final as built depth of Pit 3 was -265mRL and the underfill was constructed to -102mRL



(a) Empty pit shell: December 2012 (b) Pit base at end of underfill construction

Figure 9-9: Pit 3 before and after underfill construction

The underfill material was sourced from the nearby Low 2s stockpiles as this material was unable to be processed economically and as such is classed as waste. The underfill was deposited via a tall dump from -100 mRL in a fan pattern radiating outwards from a fixed point to maximise segregation of material. This ensured the larger size fraction filled the bottom and the fines content increased as the underfill approached its maximum elevation of -100 mRL (Figure 9-10).

In addition to providing a broad, level surface for tailings deposition, promoting a low rate of rise and improved consolidation rates, the underfill also serves as a repository for the brine produced by the brine concentrator. The brine concentrator produces a concentrated brine stream that requires management and final disposal as a hazardous waste, details of the process water treatment and the brine concentrator are provided in Section 9.4.3.

Figure 9-10: Pit 3 underfill during construction in 2014.

The volume of brine produced by the brine concentrator is currently forecast, using the site water balance model, to be 1.8 GL. The void volume available in the Pit 3 underfill has been estimated to be 2.48 GL (Coghill 2016). This void volume was determined from test work undertaken on the specific waste rock used in the underfill and the final survey volumes.

Following the completion of the underfill in August 2014, an engineered underdrain was constructed. The underdrain consists of a nominal 2 m thick waste rock layer to remove water, both expressed downwards by the overlying tailings during the consolidation process, and entrained pond water displaced upwards from within the underfill by the brine injection process. The drainage layer was graded slightly to the west to direct the collected water streams to an extraction sump. An underdrain bore was installed in order to extract water from this sump. This underdrain bore consists of a horizontal section that connects the sump and intersects a vertical bore installed on the south western wall of Pit 3. An underdrain pumping system was installed that consists of a submersible pump and associated power and piping infrastructure. In late 2016, the bore was shut down due to ingress of ground water. ERA has undertaken remediation work to repair the bore and is now in the process of recommissioning the underdrain pumping system.

Five brine injection bores have been installed into the underfill. Each bore has a dedicated pipeline connected to a valved manifold. A brine pumping system has been installed at the brine concentrator to manage the cooling of hot concentrated brine to below boiling point to:

- maintain a safe working environment
- reduce materials costs
- minimise salt precipitation.

The hot concentrated brine is cooled using indirect heat exchangers with process water as the cooling medium, and pumped to a storage (surge) tank. The brine is drawn from the surge tank and pumped to the brine injection system, refer Figure 9-11.

Due to the inherent scaling issues associated with concentrated brine, all lines and equipment within the brine injection area are regularly flushed with process water. In addition to this, a 'pigging' system has been installed to remove any residual scale.

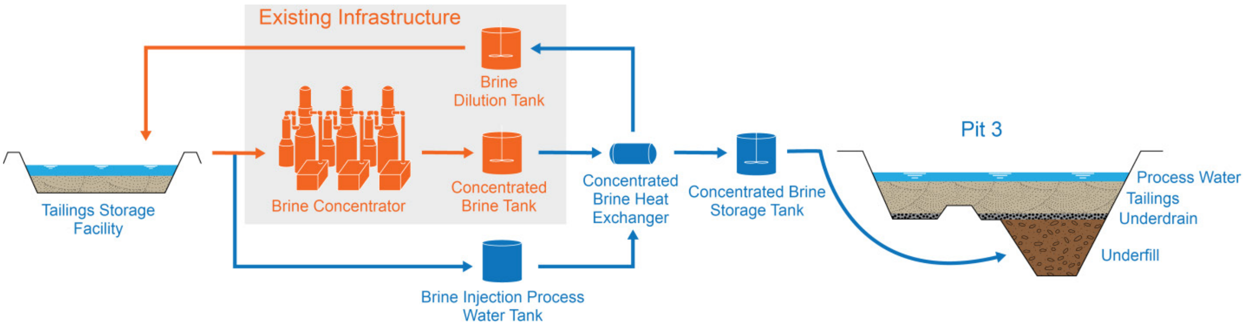


Figure 9-11: Flow Diagram of Brine Injection

A schematic cross-section of Pit 3, before tailings deposition commenced in 2015, is presented in Figure 9-12.

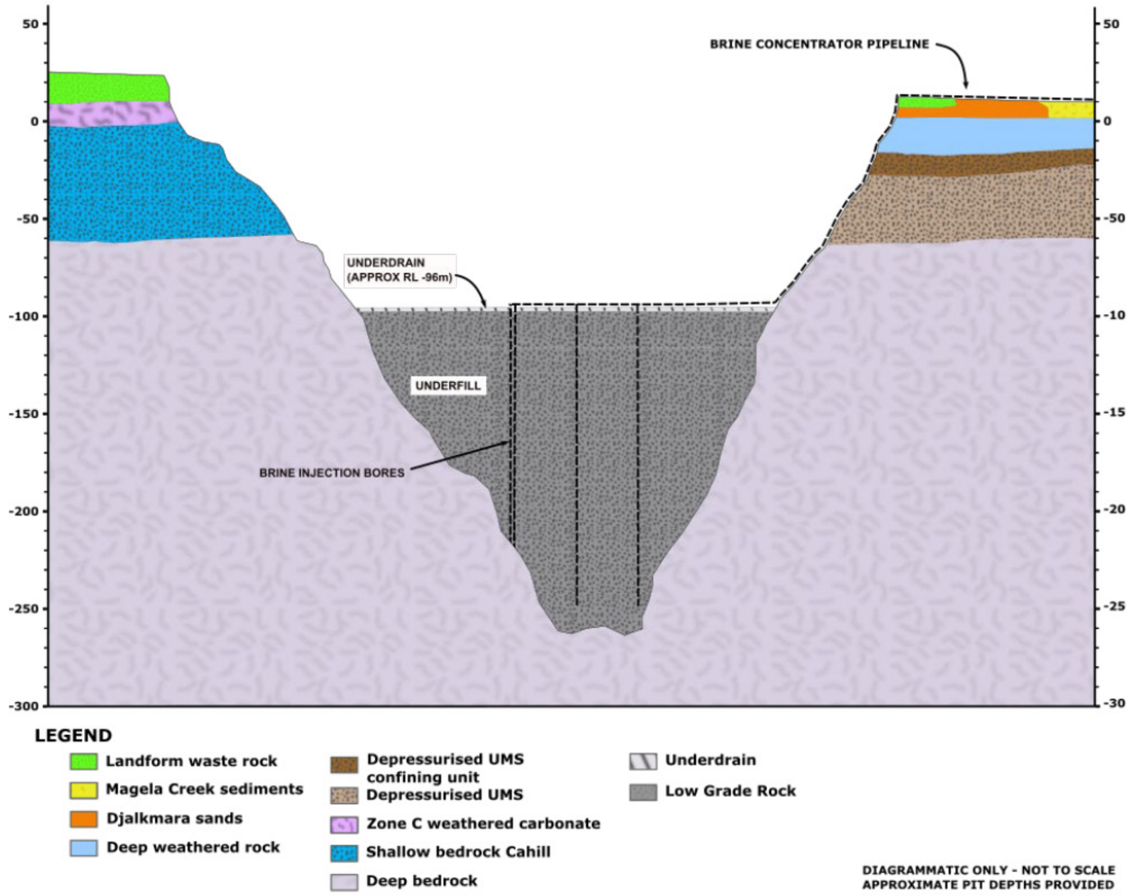


Figure 9-12: Schematic cross-section of Pit 3 before tailings deposition commenced

Tailings deposition

The direct deposition of processing plant (mill) tailings into Pit 3 commenced in 2015. The deposition of reclaimed tailings from TSF dredging operations into Pit 3 commenced in early 2016. Tailings deposition into Pit 3 is currently undertaken to meet Environmental Requirement 11.2, to ensure all tailings are placed in the mined out pits by the end of operations. The techniques employed to deposit tailings in Pit 3 must also meet the following objectives:

- tailings must be distributed in the pit so as to reduce the tailings differential to present a more uniform tailings surface with an ultimate slope from east to west.
- location and size of the supernatant pond must be controlled, including the maintenance of an adequate freeboard to prevent the risk of overtopping, particularly when the facility is nearing its full capacity.
- tailings must be deposited in such a manner as to reduce tailings segregation.
- tailings must be deposited cyclically to facilitate their consolidation and achieve the required dry density.

Mill tailings are 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 initially recovered from the TSF using a single diesel-powered cutter suction dredge. In 2019, ERA installed and commissioned a second dredge to increase the dredging capacity to meet the target date of January 2021 for the completion of tailings transfer. The slurry produced by the dredges varies between 18 and 28% by weight solids, depending on the type of tailings solid material (i.e. fine or coarse) and on the action of the dredge cutting head as it sweeps from side to side. Dredged tailings are transferred from the dredges via floating HDPE pipelines connected to an overland HDPE pipeline at the edge of the TSF for delivery to Pit 3. Residual tailings that cannot be dredged from the TSF will be transferred by truck to Pit 3 (Section 9.3.3).Plans for the deposition method into Pit 3 will be included within the Pit 3 closure application and the 2021 MCP.

Both mill and dredged tailings slurry were originally deposited into Pit 3 using a subaerial deposition method. This involved depositing tailings slurry via a number of spigots on the pit crest to form a sloping beach across the pit floor (Figure 9-13). Subaerial deposition of tailings was the preferred approach until an observation of coarse and fine tailings segregation led to a review of the subaerial deposition technique. It was observed that coarse tailings had formed an elevated beach in the eastern end of the pit whereas relatively finer tailings had migrated towards the western end of the pit and settled below the water surface.

Figure 9-13: Pit 3 showing the original location of mill and dredge tailings deposition points

The segregation was a result of the concentration of low discharge solids necessary for the TSF dredging and the ongoing fluctuation of process water volumes in Pit 3, a consequence of dredging operations. The combination of these processes created a differential in tailings elevation from east to west of about 10 m. This is demonstrated in the surface contours created from tailings surface surveys in April 2019 (Figure 9-14). The segregation of tailings and subsequent differential in tailings elevation indicated that the maximum approved tailings elevation of the time, -20 mRL, may be exceeded. The uneven tailings surface that would remain at the end of deposition and the associated segregated fine tailings and extended period of consolidation, presented a critical risk to the successful closure of Ranger Mine by 8 January 2026.

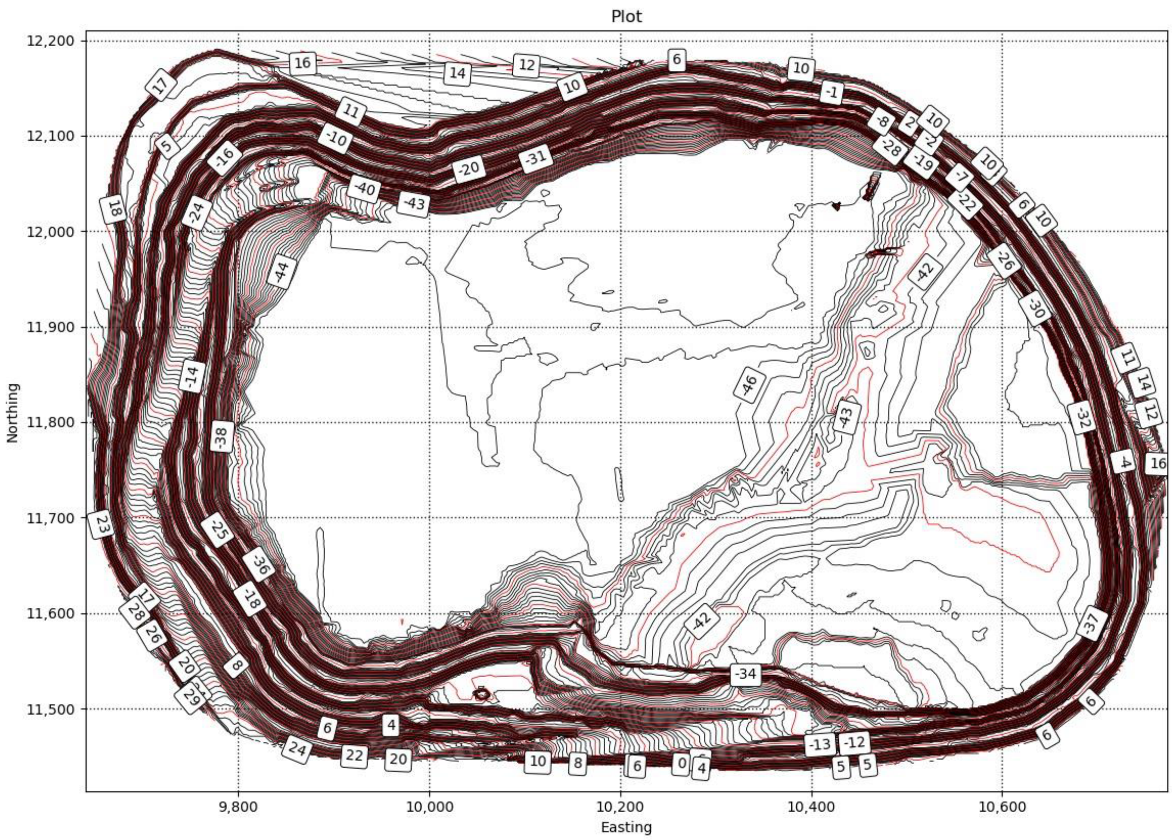


Figure 9-14: Tailings surface in April 2019 (Source: Fitton 2019)

Subaqueous tailings deposition was identified as a way to mitigate the risk of the deposition of segregated coarse tailings to a height that would exceed -20 mRL.

The benefits of subaqueous deposition in a fluctuating water level situation include:

- elimination of a coarse tailings beach deposited higher in the pit
- elimination of a steep uneven tailings surface

- promotion of the homogenous deposition of tailings by systematically moving the deposition point

On 15 and 16 January 2018, ERA hosted a stakeholder workshop to discuss current and proposed Pit 3 tailings deposition. Stakeholders agreed that the information presented by ERA at the workshop demonstrated that the "*[subaqueous] tailings deposition is unlikely to increase the risk of long-term environmental impact to ground and surface water from solute egress*." ERA was subsequently approved to deposit tailings subaqueously in the short-term pending the completion of tailings characterisation studies (Section 5.4.1), groundwater modelling (Section 5.4.3), a subaqueous deposition trial and the submission of a formal application to change tailings deposition method. The outcomes of these studies concluded that a change in tailings deposition method (and consequent maximum tailings level at the end of tailings deposition) would not result in any long-term environmental impacts to the surrounding Kakadu NP, nor any material impacts on the Pit 3 closure schedule.

In April 2019, ERA submitted an MTC application to seek approval to modify the dredged tailings deposition method from subaerial to subaqueous, and to increase the final maximum tailings level from -20 mRL to -15 mRL at the end of deposition. Approval was received in August 2019 to increase maximum tailings level to -15 mRL, applying specifically to the discharges from the fixed mill deposition spigots situated along the south and eastern pit perimeter. A tailings deposition level of -20 mRL was instated as the final average level of deposited tailings. This approved final deposition level was further increased in August 2020 to maximum height of -10mRL across the pit. This increase acknowledges the limitations on ERA that all remaining tailings must be deposited in Pit 3 and recognises that the risk to the offsite environmental during deposition is low provided process water levels in Pit 3 remain below 3.5 mRL.

The modified deposition system allows for the tailings dredged from the two operational TSF dredges to be deposited subaqueously into Pit 3. The existing subaerial discharge points will be maintained as a backup option to be employed during diffuser maintenance periods, planned pontoon movement operations, and monthly bathymetric surveys. Based on the periods of diffuser down time during the subaqueous trial and forecasts in deposition planning, the subaerial deposition system was predicted to be reinstated for the deposition of dredged tailings for approximately 5% of the remaining deposition schedule.

The current configuration of subaqueous deposition of dredged tailings is illustrated in Figure 9-15, whilst the location of the subaerial deposition points is provided in Figure 9-16, noting that the proposed points have since been implemented and the water level in Pit 3 as of the end of June 2020 was -22 mRL.

Figure 9-15: Subaqueous deposition of dredge tailings via floating pipelines and diffusers

Figure 9-16: Subaerial deposition of mill tailings from multiple spigot points

The key elements of the subaqueous deposition system are:

- Tailings is pumped via separate HDPE pipelines to Pit 3 (each pipeline sized to match flow from the dredge being served).
- Floating sections of pipeline allows for discharge over all parts of Pit 3.
- Each pipeline is fitted with a novel diffuser to reduce the velocity of slurry at the discharge point and reduce coarse and fine tailings segregation (Figure 9-17).
- Each diffuser is designed for the slurry flow from each dredge. The second diffuser is larger to accommodate the higher tailings transfer rate from the second dredge, but the configuration is essentially the same for both diffusers.
- Both diffusers are supported by a single pontoon.
- Diffusers are systematically moved across Pit 3 (using diesel-powered winches) following a deposition plan to ensure an even deposition across the pit. The location of the diffuser heads is shown in Figure 9-18.

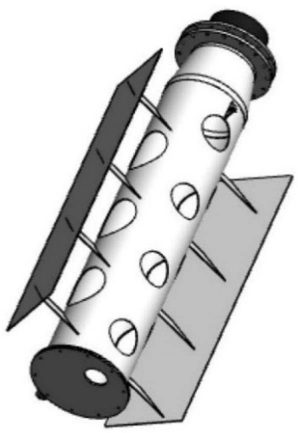


Figure 9-17: Novel subaqueous diffuser design

ERA engaged Fitton Tailings Consultants to develop a Pit 3 tailings deposition plan following a Fugro survey completed in Pit 3 on 17 March 2019. This survey allowed an assessment of the subaqueous deposition that had been completed up to that point and hence the development of an appropriate plan, in June 2019. The proposed plan, called “Pit 3 interim tailings deposition plan” comprised mill tailings discharge from spigots at the east and dredged tailings discharge from diffusers on the west. This interim deposition plan has now been finalised and is described in Section 9.3.2.2.

9.3.2.2 Current rehabilitation

Subaerial mill tailings deposition into Pit 3 is planned to end with the cessation of milling January 2021. Dredge tailings deposition is also currently scheduled to be completed in January 2021.

Mill tailings deposition

Subaerial deposition of mill tailings will continue until the end of milling operations. As described in Section 9.3.2.1, tailings are discharged from spigots on the east wall of Pit 3 to better distribute the tailings (Figure 9-16 and Figure 9-19). Discharge is through a single spigot at any one time.

Subaerial deposition of mill tailings will help maintain the westerly drainage of the tailings surface, but without excessively elevating the tailings beach as mill tailings constitute only a third of the total quantity of tailings to be disposed in Pit 3.

Subaqueous deposition

The subaqueous deposition of dredged tailings continues according to plan:

- both dredges discharge from the same location (approximately 148,000 tonnes per week)
- dredged tailings sink to the fine/coarse tailings interface and build up flat cones
- fine tailings are displaced upwards and form a near horizontal surface

Deposition plan

The basis of the deposition plan is to fill in the deep void at the western end of the pit. The "interim tailings deposition plan" could not be fully implemented due to the need to improve water recovery from Pit 3 to TSF to maintain dredge production. The dredged tailings deposition was, reverted to the subaerial method using spigots on the southern end of the pit from October 2019 to January 2020. The interim plan was then reviewed using the data obtained from the cone penetration test and geophysical survey completed in November and December 2019 respectively, along with monthly bathymetric surveys (Section 5.4.1.6). Subsequently, the interim deposition plan was revised in March 2020 and implemented in April 2020.

The mill tailings deposition method described within the interim deposition plan was considered appropriate and remains the same for the revised plan. The aim of the subaerial deposition is to achieve uniformity of the maximum level of the tailings at each spigot location, as much as possible. To achieve this tailings material is discharged from each spigot, in turn, for a duration of at least one week or until the maximum tailings elevation equals the level of the maximum elevation at the previous discharge location. The dredged tailings will be discharged initially from diffuser location 1 for three months and location 2 for two months (Figure 9-18). The deposition plan will be reviewed at the end of this period (October 2020).

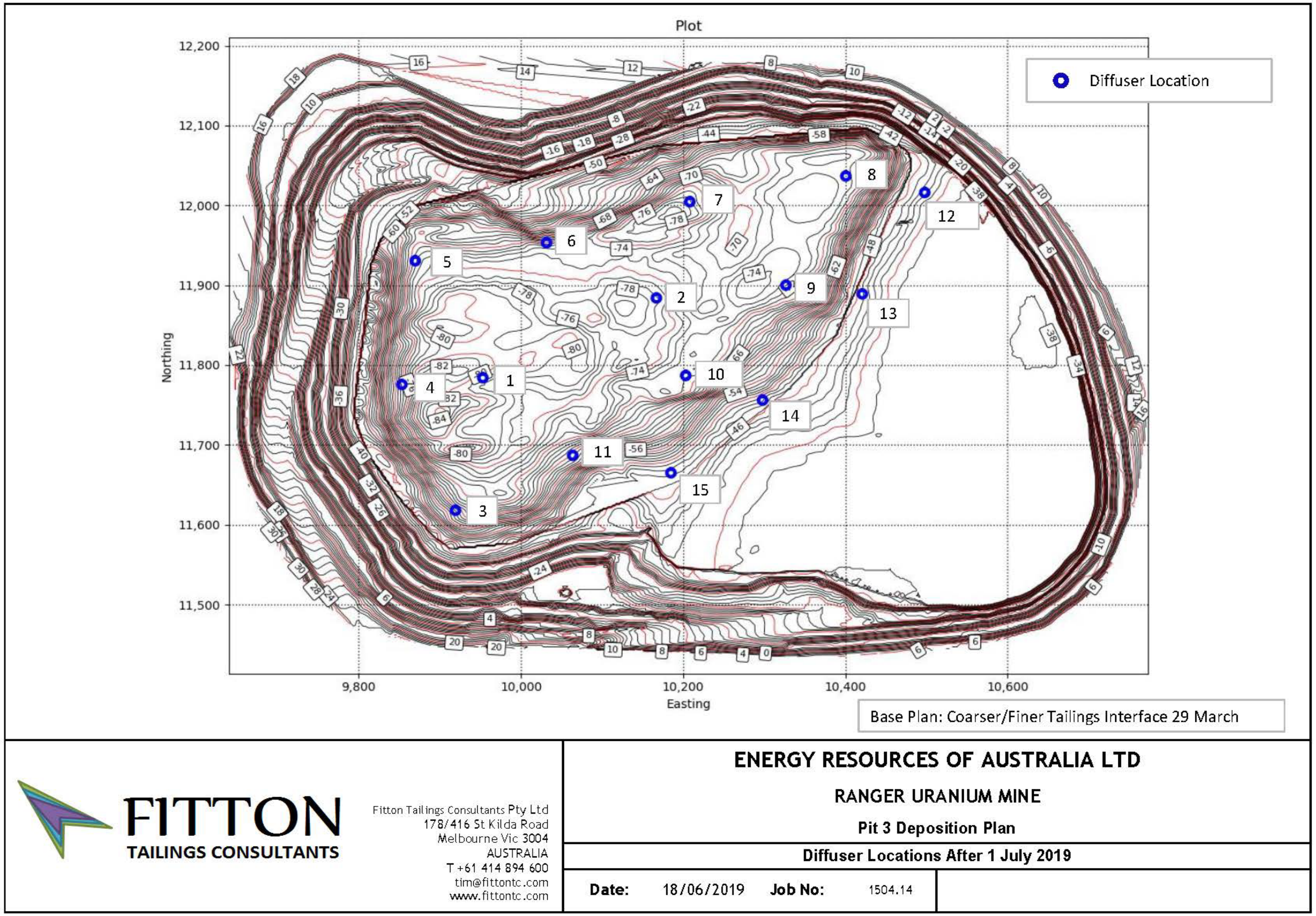


Figure 9-18: Pit 3 dredge tailings deposition plan

Figure 9-19: Southeast wall of Pit 3 – subaerial discharge point for mill tailings (Nov 2019)

9.3.2.3 Planned rehabilitation

The Pit 3 closure (wicking, capping, waste disposal and bulk backfill) will be subject to a standalone application to the MTC. This application will detail all the components of the closure of Pit 3, with associated supporting studies, and is scheduled to be submitted in Q4 2020. The final 6 m of the landform will be considered under a separate 'Final Landform' application, due for submission in Q2 2022.

After tailings deposition into Pit 3 has been completed (including mill, dredge and any residual tailings transfer), a series of activities will be carried out to facilitate the consolidation of deposited tailings. These activities will be undertaken in the following sequence:

- installation of wick drains within the tailings to promote consolidation
- installation of geofabric over the surface of the tailings to improve the bearing capacity
- placement of approximately 2 m layer of waste rock over the geotextile as a preloading material (initial capping)
- dewatering of the pit and installation of a decant system comprising a decant sump and extraction pipelines for continuous removal of expressed water from the wick drains
- construction of approximately 5 m layer of waste rock capping over the preloading layer

- placement of backfill material over the waste rock capping to a final stage ready for revegetation

Prior to the commencement of Pit 3 capping, geotechnical investigations will be required to determine the strength of the tailings and assess the geotechnical risk posed to construction. The geotechnical investigation will be conducted from September to November 2020, and will be comprised of cone penetration test with pore pressure measurement, vane shear test, recovery of tailings samples and laboratory testing. The strength of the tailings will inform the selection of geosynthetic material as the material must provide adequate bearing capacity. Tailings strength will also determine the size and weight of the construction equipment to be used in the placement of the secondary capping layer and bulk fill. The thickness of each capping layer is consequently influenced by equipment size.

Current scheduled milestones are provided in Table 9-16. Inherent in the sequence of Pit 3 closure activities is the continual water management to manage process water and, where possible, manage ‘clean’ surface runoff water separately (Section 9.3.7).

Table 9-16: Progressive tasks for closure of Pit 3

Key Milestone.	Date
Completion of all mill and dredged tailings deposition activities.	January 2021
Completion of the transfer activities from the TSF floor and wall cleaning.	August 2021
Injection of brines from the brine concentrator into Pit 3 underfill (ongoing until 2025).	Present to 2025
Installation of additional brine injection wells into Pit 3 underfill, if required.	As required
Installation of prefabricated vertical drains (wicks) within tailings.	September 2021 – January 2022
Commencement of the decommissioning and demolition of the processing plant infrastructure and stockpile for later disposal, potentially in Pit 3.	January 2021
Installation of geofabric and initial preload over pit.	February 2022
Commencement of bulk backfilling of Pit 3 and placement of waste material including site infrastructure.	October 2022
Backfilling of Pit 3 completed, surface contoured to Final Landform shape, and revegetation commences.	May 2025

Table 9-17: Schedule of closure for Pit 3

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	>26
Pit 3	Backfill	Initial backfill of Pit 3 with waste rock for underfill	Complete							
	Drainage	Underfill drainage layer & installation of extraction pumping system	Complete							
	Piping	Piping etc installation: from process plant to pit for delivery of tailings	Complete							
	Tailings	Tailings from process plant and from TSF delivered to Pit 3	Ongoing							
	Wicks	Installation of prefabricated vertical drains (wicks) within previously transferred tailings	Scheduled							
	Geotextile	Installation of geotextile	Scheduled							
	Backfill	Initial capping	Scheduled							
		Secondary capping	Scheduled							
		Final landform layer	Scheduled							
	Demolition	Potential placement of deconstructed mill and other infrastructure	Scheduled							
	Demolition	Decommission tailings transfer infrastructure	Scheduled							
	Landform	Surface contoured to Final Landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
	Monitoring	Closure & post-closure	Scheduled							

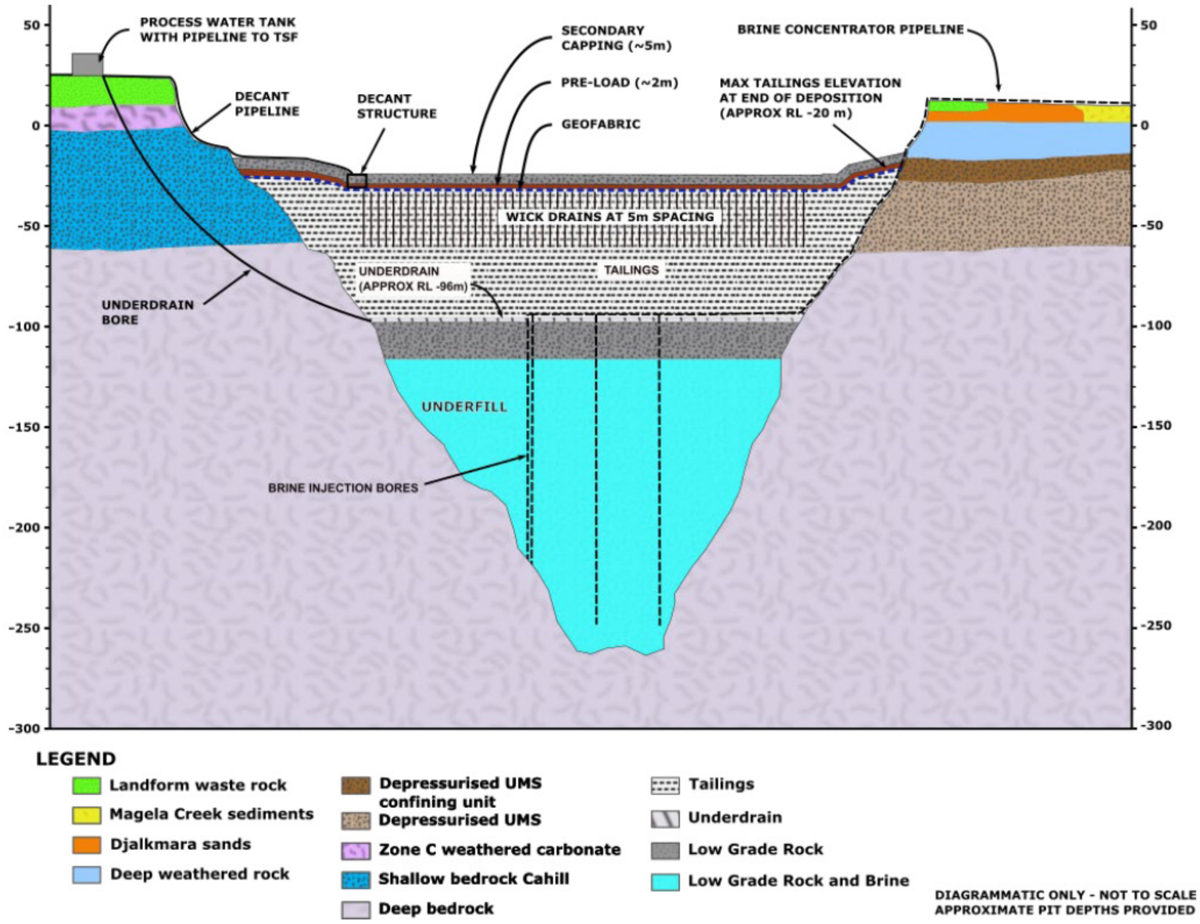


Figure 9-20: Cross-section of Pit 3 after tailings deposition

[Note: wick spacing may be altered and maximum tailings levels has been recently approved to be -10 mRL (DPIR, 2020)]

Underdrain bore and Brine injection

Brines were injected into the underfill during 2016; however, operational issues with the Pit 3 underdrain bore have required that brines be diverted back to process water. It is expected that brine injection will resume again in 2020. Once operational, the brine injection system is expected to be available for 80 percent of the time, with brines diverted back to process water when the system is offline.

The recirculation of brines to process water causes the process water salt content (measured through total dissolved solids) to increase. The brine concentrator is specifically designed to treat high salt content water. However, at total dissolved solids concentration over 120 g/L, the distillate production capacity of the brine concentrator is impacted. ERA regularly monitors for total dissolved solids concentration in process water and also forecasts future concentrations through its operational water balance modelling software. The most recent forecast (February 2020) uses the actual concentration in process water and assumes brine injection is operational for 80 percent of the time. This shows that the median forecast for total dissolved solids concentration in process water over time will remain below 120 g/L (Figure 9-21).

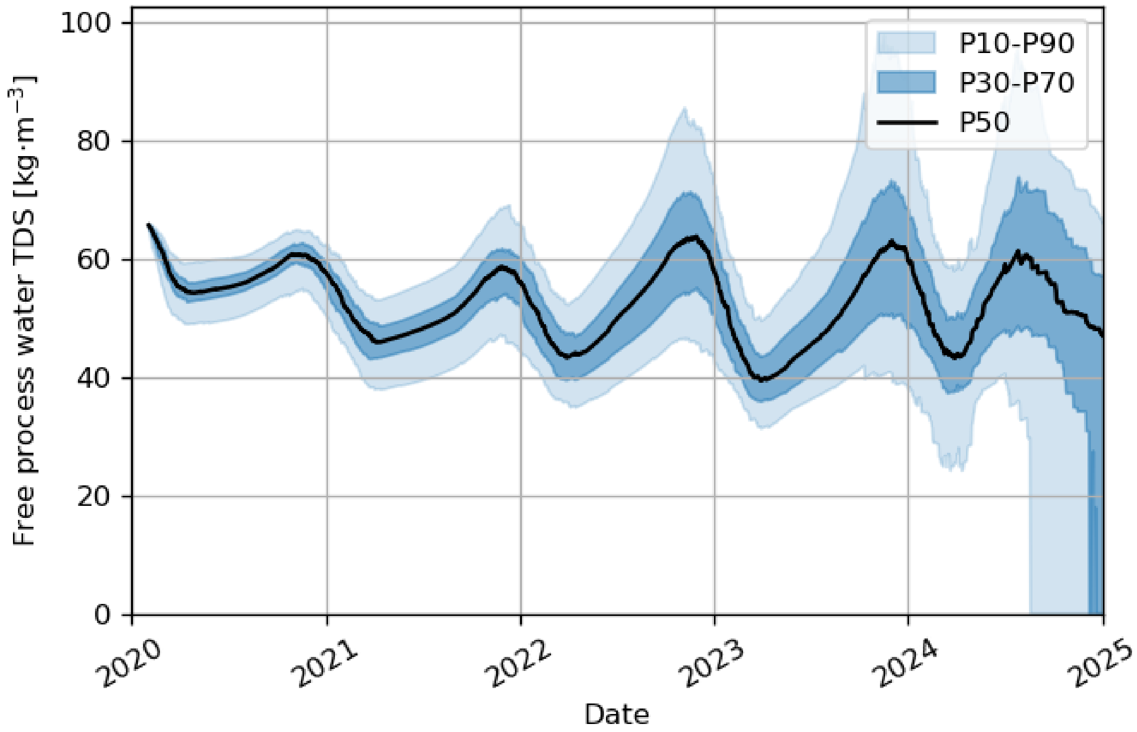


Figure 9-21: Site water model forecast of total dissolved solids concentration in process water

Tailings deposition

Deposition of dredged and mill tailings into Pit 3 is planned to continue until January 2021.

A tailings beach scan was completed in May 2020 and indicated that the beach height was at -24 mRL (Figure 9-22). Current modelling indicates that the final beach level will be -15 mRL, as predicted in 2019. The final beach level is highly dependent on the process water level in the pit which, in turn, is influenced by factors such as dredging performance and rainfall. Therefore, the final deposited tailings level cannot be predicted with a high level of confidence. ERA has approval to deposit tailings to a maximum height of -10 mRL.

Minor quantities of tailings will remain in the TSF following the completion of bulk dredging. The remnant tailings will be cleaned from the walls and floor of the TSF for transfer to Pit 3. The cleaning process is described below in Section 9.3.3. The final volume of this material cannot be known until the completion of dredging, as it is dependent upon the ability of the dredges to access the material and the volume of 'spill' during the dredging process. However, it is of a relatively minor volume compared to the main body of tailings in Pit 3.

It is currently planned to transfer the majority of these remnant tailings as a pumped liquid slurry, using the existing tailings deposition method. Some material may also need to be transferred to Pit 3 using heavy mobile equipment. Tailings and contaminated material will be transferred from the heavy mobile equipment to Pit 3 from one or more tip heads in Pit 3 prior to the placement of the geotextile layer. The final tipping location will be determined in early 2021. The management of contamination and dust from the transfer of this material will be according to the approved ERA Radiation Management Plan. The specific hazards identified and controls to be implemented during this phase of the project are detailed in Table 9-18.

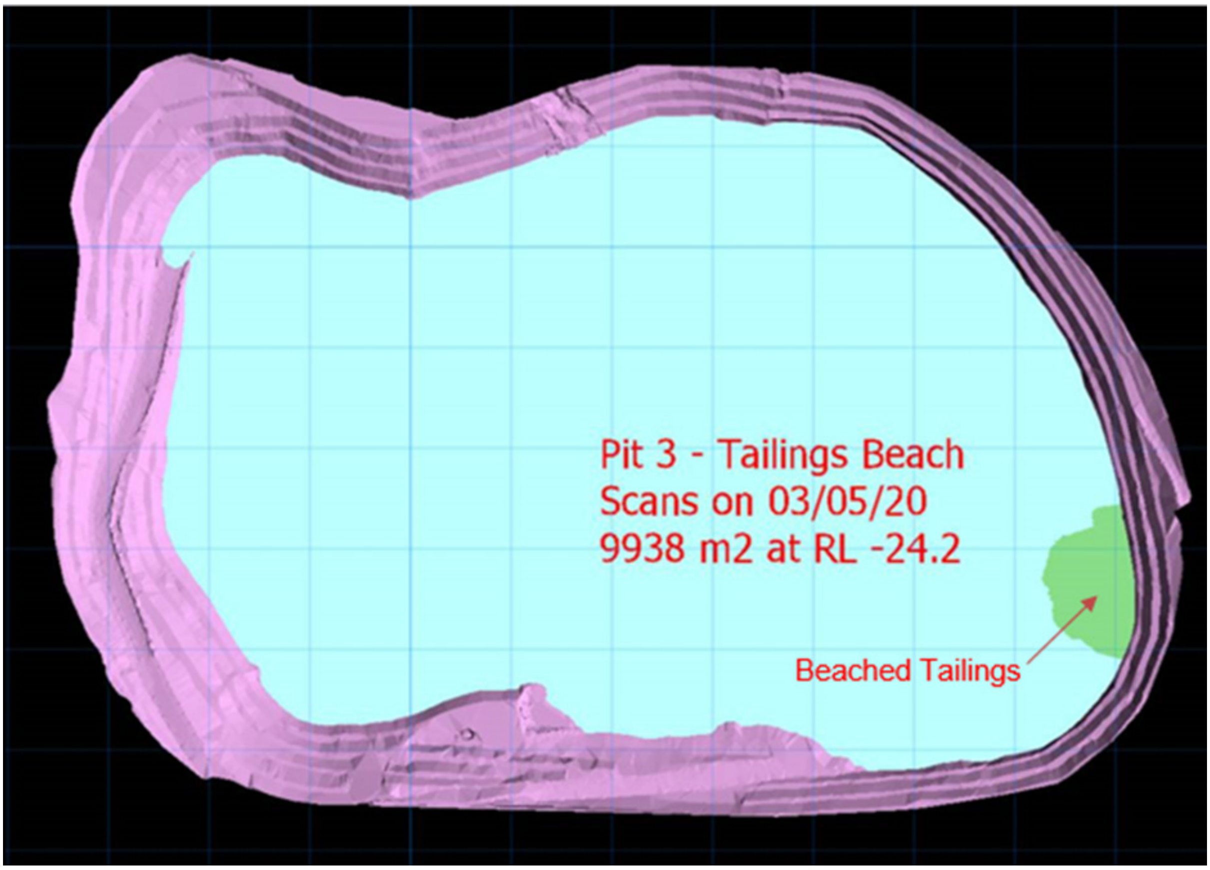


Figure 9-22: Pit 3 tailings beach scan in May 2020

Table 9-18: Risks and controls identified for transport and re-deposition of contaminated material from the TSF to Pit 3

Hazard	Impacts	Controls
Spillage during transport	Contamination of haul road	Transport of the less competent tailings and tailings contaminated material will utilise a range of controls that will minimise risk of material to spill from the equipment used. At this time the type, size and configuration of this equipment has not been finalised. Partial filling of heavy mobile equipment to minimise the risk of spillage. Grading / cleaning of road of any spilt material at end of transfer activities. Collected material will be deposited in Pit 3. Limit speed of trucks to minimise potential for spillage.
Spread of contamination	Contaminated equipment Movement of contaminated material into supervised area and/or off site	All equipment used to be radiation cleared before leaving site Transport route is designated a controlled area Visual inspection of the road for spillage by supervisor and equipment available for immediate clean up where necessary. Wash down facilities available by water truck if heavy mobile equipment is observed to have visible contamination that may fall from the equipment during transport operations Excavators and loaders to clean up any spillage after each load to prevent contamination of next truck wheels.
Dust emissions during loading, transport and dumping	Inhalation by project workers	Water cart to keep material damp during excavation and prior to transport. Project workers in air conditioned cabins. Water cart to keep material dust on roads to a minimum

Wick drains

Wick drains, or prefabricated vertical drains (PVD), will be required to increase the rate of tailings consolidation and reduce the time for the closure landform to reach its final profile. Wick drains have been installed and used successfully to consolidate the tailings deposited in Pit 1 (Section 9.3.1.1.1). By increasing the rate of consolidation, wick drains also increase the rate of tailings strength with time. In addition to strength gains, this will increase the rate of removal of consolidation flux (water trapped within the tailings) as process water. The drains consist of a geotextile filter - wrapped plastic strip with extruded channels that allow water to drain upwards from the tailings as it consolidates. The geotextile filter prevents soil particles from entering the channels and clogging the drain.

Wick installation will be undertaken from either a tracked amphibious vehicle or a barge, depending on the preferred option of the contractor selected. Wick drains will be installed at 2-3 m spacing in the western portion of the pit to an approximate depth of 38 m.

By the completion of dredged tailings transfer, process water levels will be managed in Pit 3 to facilitate subaqueous wicking, subaqueous geofabric placement and subaqueous initial capping. During this time, the remaining tailings from the TSF floor will be transferred to Pit 3. Process water will be returned to the TSF when the TSF wall and floor cleaning is complete, utilising the return water system that currently services the TSF dredges.

Geotextile

The most conventional approach to improve the bearing capacity and constructability of a capping layer on very soft tailings is to provide a geosynthetic layer between the two materials. Key performance requirements include:

- separation – preventing loss of cover material into the tailings layer and preventing tailings from extruding into the cover layer (the “opening size” of the geotextile needs to be sufficiently small to retain the fine particles)
- drainage – allow consolidation bleed liquor to express from the tailings into the permeable capping system (the permeability of the geotextile needs to be sufficiently high to meet the required flow rate), and
- reinforcement – provide tensile strength to the underside of the capping layer to improve the bearing capacity and stability and/or reduce capping layer thicknesses.

The geosynthetic material needs to provide the required tensile strength at relatively low strain, which typically precludes the use of a non-woven geotextile.

Either a woven geotextile or a geocomposite (geogrid in combination with a separation geofabric, often thermally bonded together) could meet all three of these requirements, dependent upon the specific criteria. Reduction factors are included in the material selection process to account for issues such as clogging, long-term creep, environmental and installation damage. The specific product to be utilised is still to be determined.

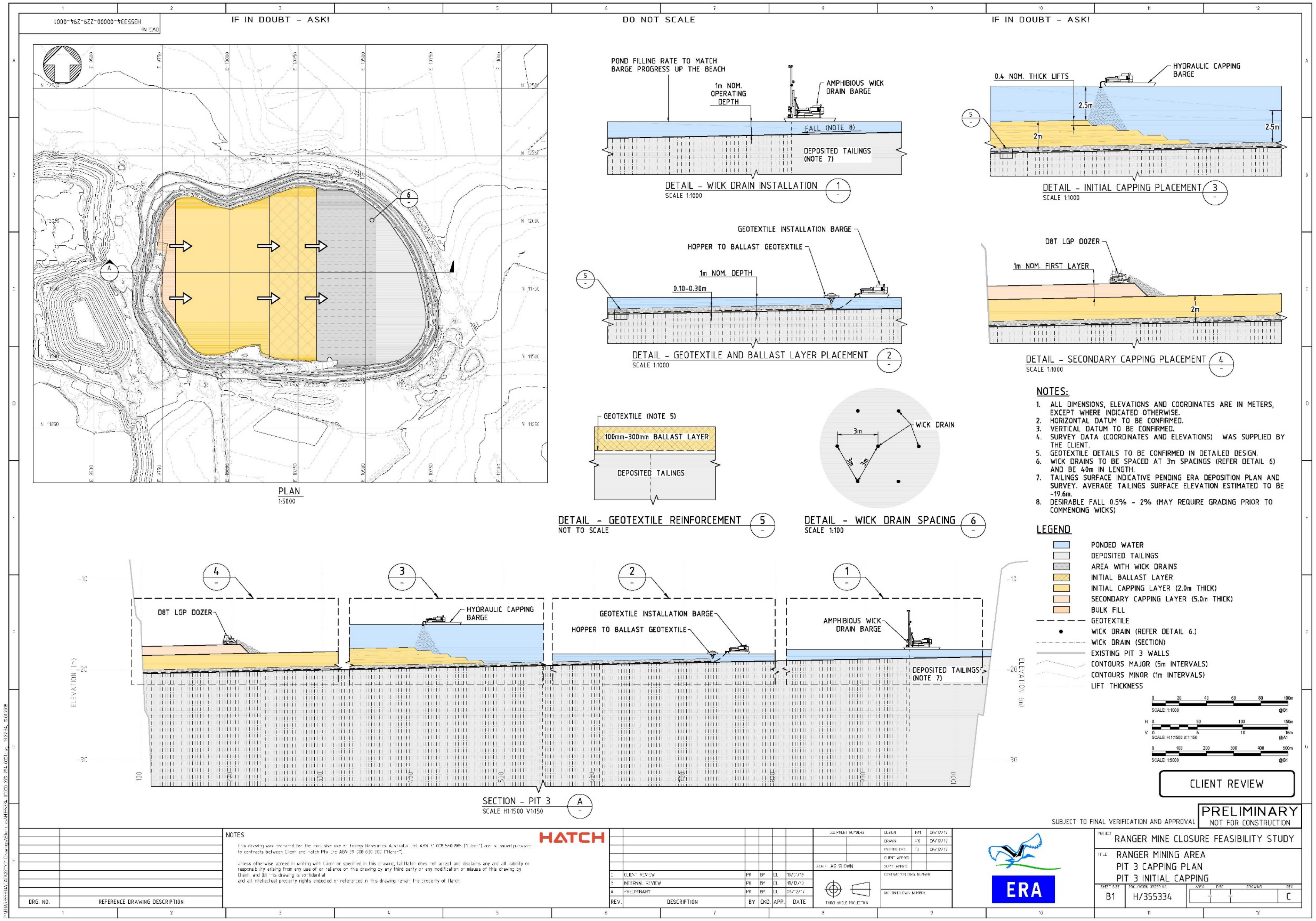


Figure 9-23: Indicative Pit 3 wicking, geofabric and initial capping plan.

Access to the pit will be from the western and, potentially, the southern ramp. Key challenges for the installation of geotextiles over the tailings include:

- sinking the geosynthetic material into the correct position
- minimising slack during deployment

Whilst subaqueous capping is a relatively uncommon approach, the unique conditions for Pit 3 provide significant drivers for its adoption. The constraints are:

- timing to complete closure implementation
- subaqueous deposition
- the rapid rate of rise of tailings

Various methods of placing the geosynthetic material were reviewed during the Feasibility Study. The baseline approach taken forward includes for the rolls of geosynthetic to be joined on the shore to the maximum size panels that could be efficiently and safely handled by the installation crew. The approach includes the installation of weights (prefabricated sleeves using heavy chain of reinforcing steel bars or similar to promote sinking) into the fabric which will subsequently be loaded, typically from a crane on the base level of the ramp, into the barge and deployed/placed by barge. It is planned to join the fabric by stitching rolls to achieve a nominal width of approximately 20 m and the trials planned will confirm the ability to join the overlapping layers. The plan provides for a wire rope or similar to support one edge of the fabric to allow joining the subsequent layers. That ballasting will need to be sufficient to flatten the wicks and to provide a level of anchoring for the geosynthetic material. Geosynthetic material will be laid over the wick drains but will not inhibit their performance.

During the placement of the geosynthetic material, the water level in Pit 3 will be maintained at a nominal depth. Trials will be conducted prior to finalising the design, these will focus on methods to control the direction of the barge, anchoring methods, stitching versus overlap and safety. These trials are expected to occur during 2020.

Initial capping

Following placement of the geotextile, the initial capping layer (waste rock) will be placed subaqueously up to an initial thickness of 2m.

The objectives of the initial capping layer are to:

- provide a drainage layer to allow the dissipation of excess pore pressures generated in the consolidating tailings
- act to dissipate the bearing pressure of the construction equipment acting on the surface during construction of the secondary capping layer. Thus allowing for safe access of heavy equipment

The initial capping material will continue to be placed until the second objective is achieved, to enable the secondary capping works to be completed. Depending upon tailings strength, the thickness may be up to or more than 5m.

The initial capping material will be sourced from the existing stockpiled waste rock. The subaqueous placement of the initial capping will be achieved by either hydraulically pumping to a barge or conveyer. This waste rock material will be specifically graded with screening and/or crushing to generate the correct sized for the placement method chosen. The initial capping layer is to be placed in a number of passes to minimise disturbance to the underlying geotextile and tailings.

During this phase of the work, process water will need to be transferred between the TSF and Pit 3 to control the water level above the geotextile/rock as the initial capping layer is constructed. A 'sump' arrangement will be required, typically in the western side of the pit, to allow for this continual water management.

Following the completion of the initial capping, Pit 3 will be dewatered to allow the surface to dry sufficiently for access to heavy equipment for secondary capping.

Secondary capping

The backfill requirements for the Pit 3 secondary capping and bulk fill are included in Table 9-19. Full details of the bulk material movement plan for Ranger closure are provided in the activities section 9.4.5 as it relates to multiple domains.

Table 9-19: Backfill specifications for Pit 3

Backfill layer	**Layer thickness (m)**	**Lift height (m)**	**Maximum slope (%)**	**Minimum bench offset (m)**
Secondary capping	5	1	10	10
Bulk fill – 1st layer	5	5	Nil	Nil
Bulk fill – successive layers	10	10	Nil	Nil

The placement of the secondary capping layer in Pit 3 will commence once there is sufficient strength in the tailings surface to allow access for heavy equipment. The secondary capping layer includes all works required to place and compact about 5 m of material onto the initial capping layer. The secondary capping is anticipated to be placed in 1 m lifts with mid-sized construction equipment such as a D8T dozer initially pushing from pit edge and ultimately using CAT D740 dump truck and a dozer combination (Figure 9-24). To minimise the risk of slumping at the face of the advancing cover, fill materials will need to be dumped away from the free face and pushed into place with dozers.

The maximum slope and bench offset for the secondary capping layer (Table 9-19) is in place for geotechnical stability. The first lift/layer does not need to be completed prior to commencing following lifts. There can be several work fronts open, each with a number of lifts in progress (Figure 9-24). If the secondary capping layer is completed using 1 m lifts, the minimum bench offset is 10 m for successive lifts. This method also specifies the equipment shall not exceed the equivalent bearing pressure of a CAT740 dump truck or D8T dozer for secondary capping works.

Once the full secondary cap thickness has been placed, mine fleet vehicles can be used to place the bulk fill materials. The proposed construction method is indicated below in Figure 9-24.

Water management during wet season works will involve the installation of sumps and pumps, as per previous operational water management. Currently it is planned to install this infrastructure in the western side of the pit with secondary capping commencing at the southern ramp. Once the capping layer at the western ramp has developed some competency, the secondary capping can continue over two work fronts.

Due to the limited competence of the deposited tailings, the construction of the secondary capping layers will be carefully controlled. Where very soft subgrade zones are encountered during placement, the area will be stabilised by using long reach excavators or mobile conveyors to reach the area.

Decant installation

Decant towers are required to remove the expressed tailings pore water (process water) as the tailings consolidate during placement of capping material. This water is termed Pit Tailings Flux.

Two decant wells located in the lower slope end of Pit 3 will be constructed with the base sitting in the initial capping layer to allow for removal of process water expressed from the wick drains as part of the consolidation process. Tailings consolidation will steadily drive contained process water towards the wick drains installed in the tailings and up into the waste rock, this will flow to the decant towers where it will be extracted. Pumps and pipes will be installed in the decent wells to extract and transfer flux to the TSF and subsequently to RP6.

Decant towers will be required to be operational until such time as the consolidation has reached a point where the remaining expressed process water, or pit tailings flux, will not case detrimental environmental impact (Environmental Requirement 11.3 (ii)). Based on the experience in Pit 1, ERA is currently assuming this will be 95% consolidation. Modelling for consolidation, groundwater solute transport and surface water quality are all currently underway as part of this assessment with results to be provided in the Pit 3 capping application and the 2021 MCP. Further details on these studies are provided in Section 5.4.1.6. This level of consolidation is expected 6 months after completion of backfilling activities. Decanting of Pit 3 is expected to commence during secondary capping installation in 2022 and continue until end May 2025.

A schematic of the proposed decant towers design has been provided in Figure 9-24.

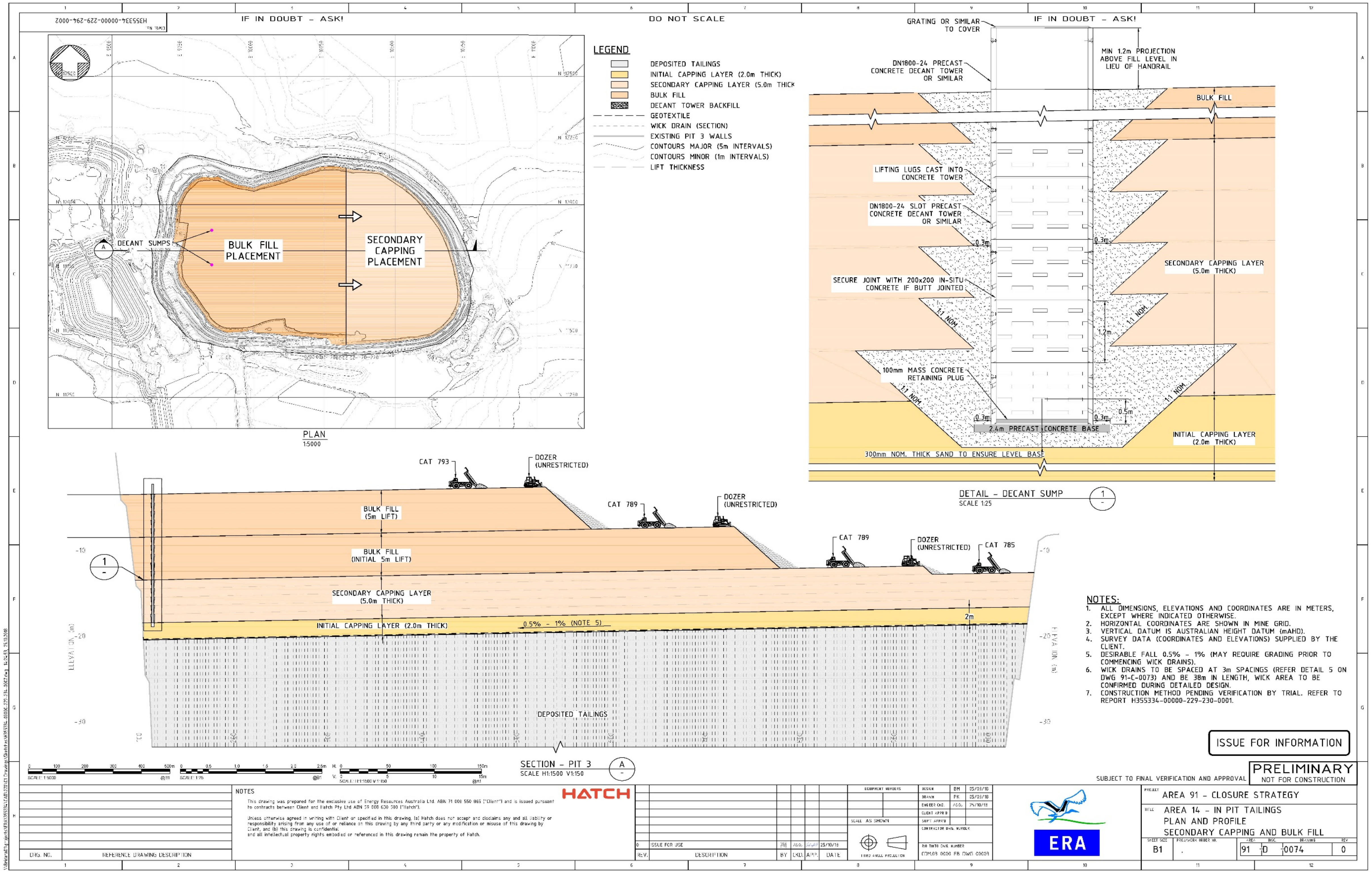


Figure 9-24: Pit 3 Secondary capping, decant wells and bulk fill plan

Bulk backfill

Following the placement of the secondary capping layer and the decant wells installation, the backfilling operation for Pit 3 can commence. The total waste rock fill to be placed into Pit 3 is approximately 67 M tonnes. The bulk backfill requirements for the Pit 3 are included in Table 9-20 with full details of the bulk material movement plan for Ranger closure provided in the Section 9.4.4 as it relates to multiple domains. Pit 3 can be accessed via two ramps; one on the western side and one on the proposed upgraded southern side. The western ramp is currently accessible by a CAT 785 dump truck. The southern ramp will be upgraded to allow access for at least this size of equipment; however, ramps may need to be widened if larger mine trucks are required. Vehicle movement and traffic control will form a critical part of the works.

Solute transport source term modelling has identified a better environmental outcome will be achieved if all mineralised material is placed below the vadose zone, refer Section 5.4.3.3. This surface has been determined as between 8 to 14 mRL across the Pit 3 surface and is termed the 2s cap. Approximately 50 M tonnes of material must be placed below the surface of the 2s cap. It is noted that an allowance may be required for keeping a void open in Pit 3 below the 2s cap to allow for late placement of demolition and/or contaminated material. This decision is subject to the completion of the finalisation of the detailed demolition execution plan and schedule. Once completed details of any void will be included in the MCP.

The backfilling of Pit 3 must also potentially accommodate the dumping of demolished process plant, administration offices, workshops/warehouses, and other materials and mobile equipment during operations. The demolition materials will be transferred to Pit 3 via the southern ramp.

Table 9-20: Bulk material movements 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*	

Final landform

The last phase of Pit 3 backfill consists of 20 M tonnes of non-mineralised material to the final landform surface. Details of the methods to be used to confirm material in the final landform are non-mineralised are provided with the bulk material movement plan in Section 9.4.4.

The final landform revegetation layer will be 6m thick. Details on the materials and methods of construction of the revegetation layer are provided in Section 9.4.5.

Following construction of the revegetation layer, the final surface will be contoured to form the approved final landform surface, this is currently final landform version 6.2 (FLv6.2), refer Sections 9.4.5 and 5.5.1.1. The surface will be ripped and the other erosion and sediment control structure installed, details of these have been provided in Section 9.4.5.

Revegetation

Revegetation will commence upon completion of the final landform surface. Revegetation works include:

- pre-emergent herbicide spray
- installation of irrigation
- initial planting
- infill planting

Details of these activities along with contingency plans are provided in the overall revegetation implementation plan provided in Section 9.4.6.

9.3.2.4 Contingency planning

Brine injection

During the construction of the Pit 3 underfill five brine injection bores well were installed to allow for injection of waste brine from the brine concentrator to be disposed of in the waste rock void spaces. During the operation of the brine injection system it is expected that wells will become scaled over time and eventually become unusable. The exact timing of this is dependent upon a number of factors so cannot be determined; therefore, ERA has allowed for the installation of additional directionally drilled wells to be installed from the edge of Pit 3 into the underfill. To provide confidence in this option, ERA completed a pilot directionally drilled hole 2012. Currently ERA have included the installation of three additional wells into the closure plan schedule.

In addition to the provision for additional wells, ERA is currently investigating injection of brine at a higher pressure and various system maintenance options such as chemical or other flushing. These are in the early phases of development; if they should form a contingency option or part of the plan then they will be included the MCP.

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, then additional contingencies are required. Currently ERA are progressing with the development of contingency options for two scenarios:

- The brine injection system fails to operate early in the closure project
- The brine injection system fails and/or void spaces are exhausted late in the closure project.

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.

Tailings deposition

At this stage of the life of Pit 3, it is not possible to plan and commission an alternative deposition strategy as a contingency. ERA, however, does have a number of potential contingencies available should modelling and/or monitoring indicate that the tailings level in Pit 3 will rise above -10 mRL. These include:

- apply for an increase in the final tailings level (supported by sufficient information to demonstrate there will be no detrimental environmental impact)
- apply for an interim increase in tailings deposition level with a requirement to move tailings to below -10 mRL prior to the commencement of backfilling
- increase the volume of water in the TSF and therefore reduce the rate of rise of the mill deposited beached tailings (this would not be implemented until a favourable assessment on impact of dredging performance was achieved)
- installation of a mill subaqueous deposition system (only relevant if implemented before the ceasing of milling on 8 January 2021), and
- cease milling and therefore cease subaerially deposition of tailings into Pit 3.

Wicking, geofabric and Initial capping

The wicking, geofabric placement and initial capping activities and standard construction activities that do not have outcomes related to environmental risk. The risks associated with these activities are all project related around cost and schedule. Standard project management practices will be used to manage these elements. The influence these elements have on the consolidation are discussed in the subsequent section.

Secondary capping and Bulk backfill

The secondary capping and bulk backfill activities are standard mining activities of which ERA has over 40 years experience, including the bulk backfill of Pit 1. Standard mine planning and survey techniques will be used to manage the bulk fleet and material movement. These techniques are flexible enough to all for daily modification based on monitoring and observations. No specific contingency plans are required.

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 for the capping layer. Both of these are well understood by ERA, refer to Section 5.4.2 for the tailings properties data. The consolidation model will inform the safe design of the capping layer and provide an estimation of the timing for expressed water. The 2019[3] consolidation model predicts that the 95% consolidation target will be achieved by June 2025, leaving ERA sufficient time to deconstruct the water treatment infrastructure by January 2026. ERA has a number of contingency options should either the consolidation target of 95% 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 are all related to the timing of achievement of the closure project and will not impact on the environmental outcome.

ERA has identified two contingency options to reduce the timing for consolidation:

- modification to the wick design to speed up the removal of water, including spacing, length and area wicked
- bringing forward the Pit 3 capping works to have the wicks installed earlier and the capping material placed earlier

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. In this case, an application would be submitted to the MTC requesting that water treatment infrastructure be allowed to remain on site for a period to allow for completion of this treatment. Refer to Section 9.4.3.6.

Final Landform and Revegetation

Contingency plans for the final landform construction, sediment and erosion control installation and revegetation have been provided in Sections 9.4.6.

[3] An update to the consolidation model is currently in progress and will be included in the 2021 MCP

9.3.3 Tailings Storage Facility

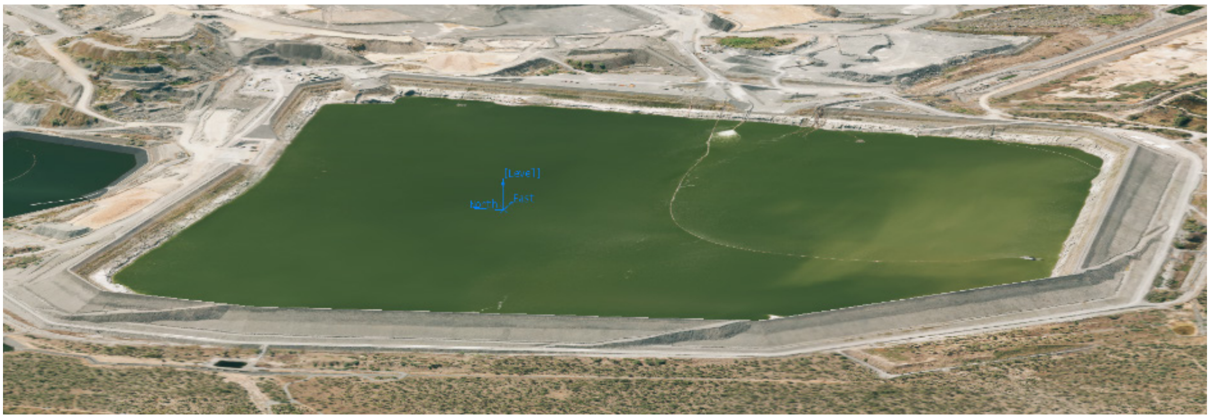


Figure 9-25: TSF (May 2019)

The Ranger Mine has three tailings storage facilities, Pit 1, Pit 3 and the Tailings Dam (referred to as the TSF). This section discusses the closure of the TSF only.

After completion of tailings reclamation and transfer, the TSF will be cleaned of all remnant tailings, infrastructure and foreign objects prior to use as a process water storage. On completion of process water storage, the TSF will be deconstructed.

9.3.3.1 Completed rehabilitation

Deposition of mill tailings into the TSF ceased in 2016 following the conversion of Pit 3 into a tailings storage facility. Progressive rehabilitation then commenced with the dredging of all tailings from the TSF to Pit 3. A summary of completed rehabilitation works in the TSF is provided in Table 9-21.

Table 9-21: Completed TSF rehabilitation

Year	TSF closure activity
1996	Tailings deposition from the TSF into Pit 1 commenced in August
2008	Tailings deposition into Pit 1 ceased
2015	The tailings dredge 'Jabiru' was launched and commissioned in the TSF
2016	In January, transfer of approximately 27 Mt of dredged tailings from the TSF to Pit 3 commenced
2019	Cleaning remnant tailings from the walls of the TSF commenced
2019	The second tailings dredge 'Brolga I' was fully commissioned in Q3
2019	Tailings transfer upgraded to new flow rates to meet the requirements of the two dredges

9.3.3.2 Current rehabilitation

Current rehabilitation works in the TSF include:

- dredging of tailings from the TSF and transfer to Pit 3, scheduled for completion in January 2021
- cleaning of remnant tailings from the walls and floor and transfer to Pit 3
- deconstruction of small sections of the wall to facilitate dredging, wall and floor cleaning

Details of these activities are provided in the following sections.

Tailings reclamation

The tailings reclamation system recovers tailings material from the TSF via use of two dredges, “Jabiru” and the “Brolga I” and their supporting maintenance crafts “Mudskipper” and “Ginga” respectively.

The Jabiru (Figure 9-26) is a stainless steel dredge, weighing approximately 170 t. The Jabiru uses a five-wire three-anchor system to manoeuvre whilst dredging.

Figure 9-26: The Jabiru dredge

The Brolga I (Figure 9-27) is a Damen CSD500S cutter suction dredge, using two spuds and two side wire anchors.

Figure 9-27: The Brolga 1 dredge

Maintenance craft (or workboats) set the anchors and assist dredge moves under tow. They also mobilise crew and equipment and support in servicing the vessels.

The Mudskipper (Figure 9-28) is a 13 m maintenance craft that services the Jabiru. The Ginga services the Brolga I.

Figure 9-28: The Mudskipper

A dredge plan has been developed by ERA and is currently based on HYPACK DredgePack dredging software. This provides for controlled dredging practices with accurate positioning and monitoring of progress per shift. Current run lines allow for a 40 m swing cut currently used by the Jabiru and 50 m wide run lines for the Brolga I.

The TSF rock walls are protected from contact with the dredge cutter head by the inclusion of a 0.5 m standoff zone. This standoff is programmed into the dredge computer.

Each dredge will operate in its own working area in order not to impede each other's operation. The south side will be dredged by the Jabiru. The remainder will be dredged by the Brolga I. The result is a 60 /40 volume split between the Brolga I and Jabiru. The north side of the TSF has been allocated to the Brolga I because the TSF the floor is considerably deeper there. This provides more scope for the water level to drop consistently over the course of the project. The maximum dredging depths for the Jabiru and Brolga are 10 m and 14 m, respectively. When a run line is completed, the dredge will shift in a clockwise direction to the adjacent run line. To manage free process water inventory the dredges will use an alternate run line method, dredging every second run. The resulting 'fingers' of tailings are evident in Figure 9-29. This means that if the TSF water level needs to be lowered the remaining 'fingers' can be dredged from the channels already dredged. When the dredges are on a floor dredging horizon they may use different cutter and swing speeds to minimise the quantity of tailings left behind (remnant tailings).

Whilst a cut layer is dredged, the water level within the TSF must remain at +/-0.5 m the optimal level. On completion of each cut layer, the TSF water level must be reduced to the next optimal water level as quickly as possible within the rate of change limits; nominally 0.5 m per week, or 2.0 m per 4 weeks.

Tailings transfer

The dredged tailings are transferred to Pit 3 via a dedicated single overland pipeline for each dredge. The pipelines are connected directly to the discharge of the floating pipeline from the dredge on the eastern notch. Tailings are discharged into Pit 3 via either subaqueous or subaerial deposition (during subaqueous maintenance periods). Further detail on the deposition of dredged tailings into Pit 3 is discussed in Section 9.3.2.

Process water return Pit 3 to TSF

Upon deposition in Pit 3, the TSF and mill tailings will consolidate. Process water mixed with the tailings is continuously expressed as the tailings consolidate. The process water that flows upwards (decant) and rainwater are recovered at the Pit 3 surface and returned to the TSF. This is shown in the block diagram in Figure 9-30.

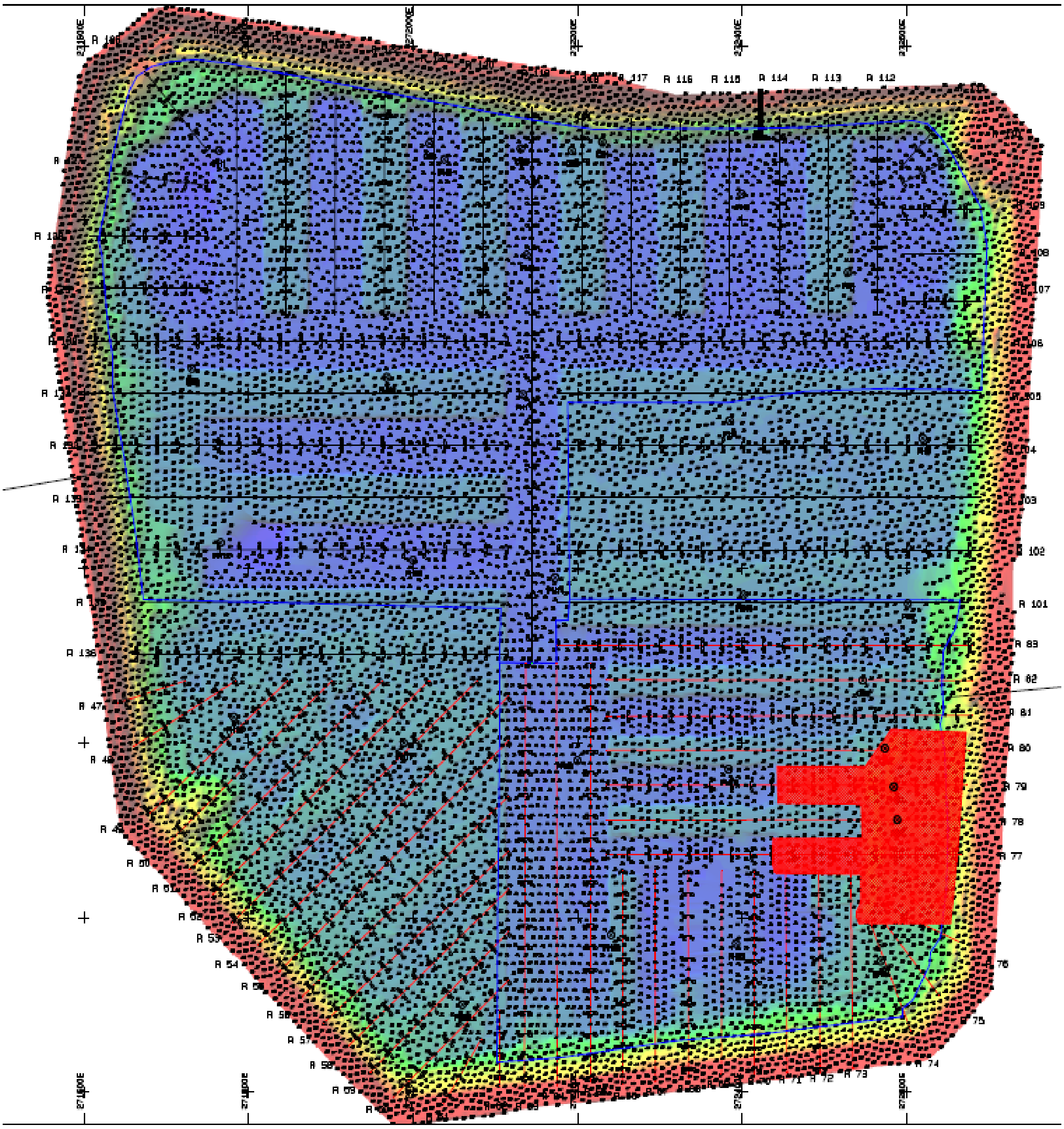


Figure 9-29: Dredge run lines evident as alternating shades of blue in this survey of the TSF

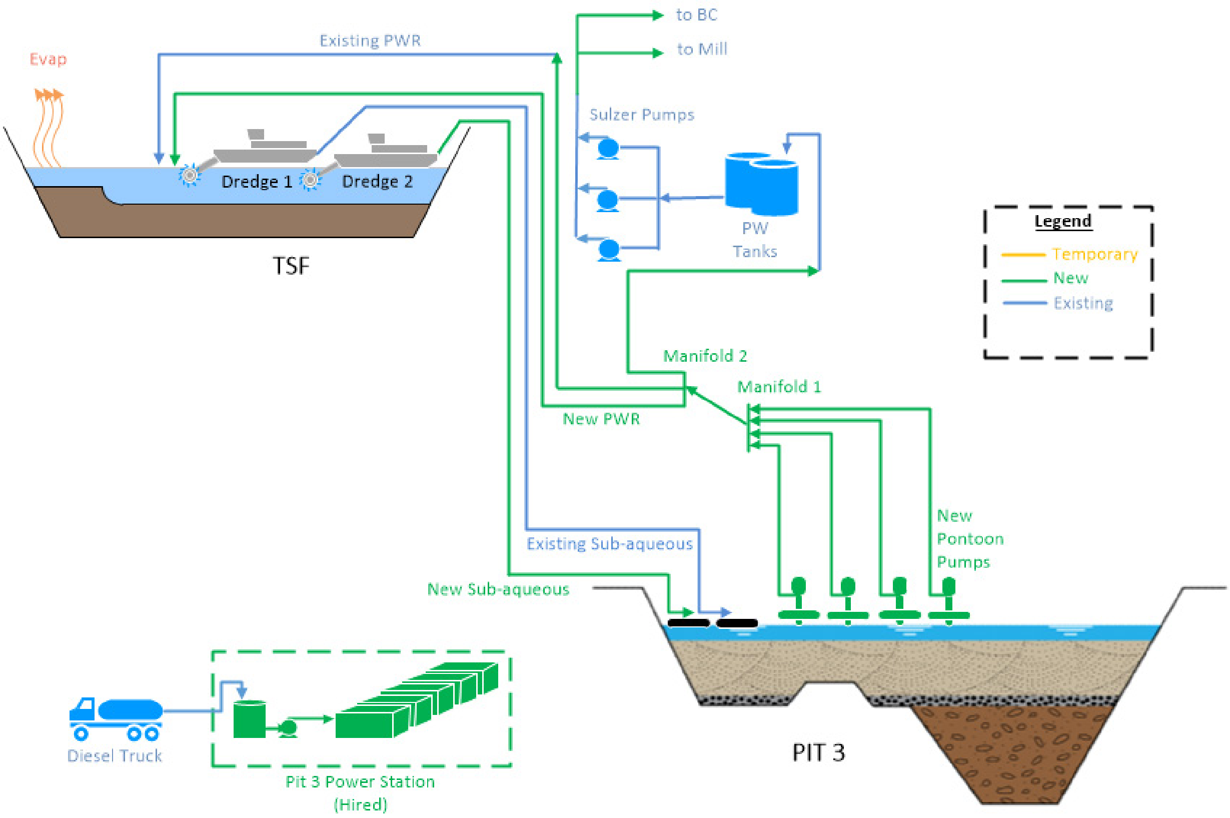


Figure 9-30: Process water return from Pit 3 to the TSF

TSF 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 have implemented a wall and floor cleaning program. Whilst the cleaning program progresses, ERA continue to collaborate with stakeholders to determine the final criteria to confirm compliance with condition 11.2.

The tailings must also be cleaned from the walls to eliminate the risk of moisture build-up between the remnant tailings on the wall and the clay layer within the wall. Such moisture build-up could result in erosion of the clay core with the potential to impact the integrity of the TSF walls.

The wall cleaning program developed by ERA employs excavators to scrape remnant tailings from the internal TSF walls, progressively transferring the tailings down the walls and into the dredge pool. ERA have purchased an amphibious excavator that will enable wall access from within the dredge pool, where conventional excavators cannot be used.

The excavators have optional screening tilt buckets to allow screen rock armour during scraping, ensuring that only tailings material is then transferred into the dredge pool. A sorter/stacker is also used to sort out any larger rocks and transfer only the tailings into the dredge pool.

Images of the remnant tailings on the walls, clean walls, excavators and stacker are provided in Figure 9-31 through Figure 9-33.

Any final tailings material on the walls is washed down the wall during the wet season. In order to better facilitate this ERA will trial a hydraulic monitor (hydraulic mining equipment) to 'wash' the tailings from walls using high pressure water. If successful, this method will be employed for both wall and floor cleaning.

As of June 2020, the wall cleaning program was 45 percent complete.

Figure 9-31: Typical remnant tailings on TSF wall after dredging

Figure 9-32: Land based excavator cleaning tailings off North wall of TSF

Figure 9-33: Sorter/stacker removing rocks before placing tailings into dredge pool.

TSF floor cleaning

The dredges will remove most tailings material from the floor of the TSF. However, due to the presence of buried waste material, large displaced rock armour, and ‘spill’ from the dredges, some remnant tailings will remain on the TSF floor following the completion of the dredging program.

ERA has commenced floor cleaning trials with the Jabiru dredge, these will be ongoing during 2020 to inform the final TSF floor cleaning plan. Details of the current program are provided below.

TSF North east ramp

The ramp in the north-eastern corner of the TSF (Figure 9-34) is founded on tailings and will therefore need to be removed and the underlying tailings subsequently recovered.

Figure 9-34: Aerial image of the North-Eastern ramp

Dredging of the tailings in the vicinity of the ramp has the potential to undermine the ramp. Presumably, as the water level is lowered, the tailings underlying the ramp will drain down, but at a lower rate than the pond level, creating an elevated phreatic head under the ramp. This mechanism typically reduces slope stability.

As the ramp has been constructed from dump rock it may not be suitable for dredging. Undermining of the ramp (to allow it to fall into the pond for reclamation by the dredge) is unlikely to be viable without extensive damage to the riprap and potentially the low-permeability clay core of the TSF wall.

ERA has now commenced the deconstruction of this ramp and cleaning of any tailings material using the wall cleaning techniques described above.

Foreign material removal

A 2012 magnetometer survey (Fugro 2012) reported “a very strong anomaly on the south-eastern side of the TSF, 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 9-35. The primary objective of the survey was to locate any potential buried iron objects which could impact proposed dredging operations.

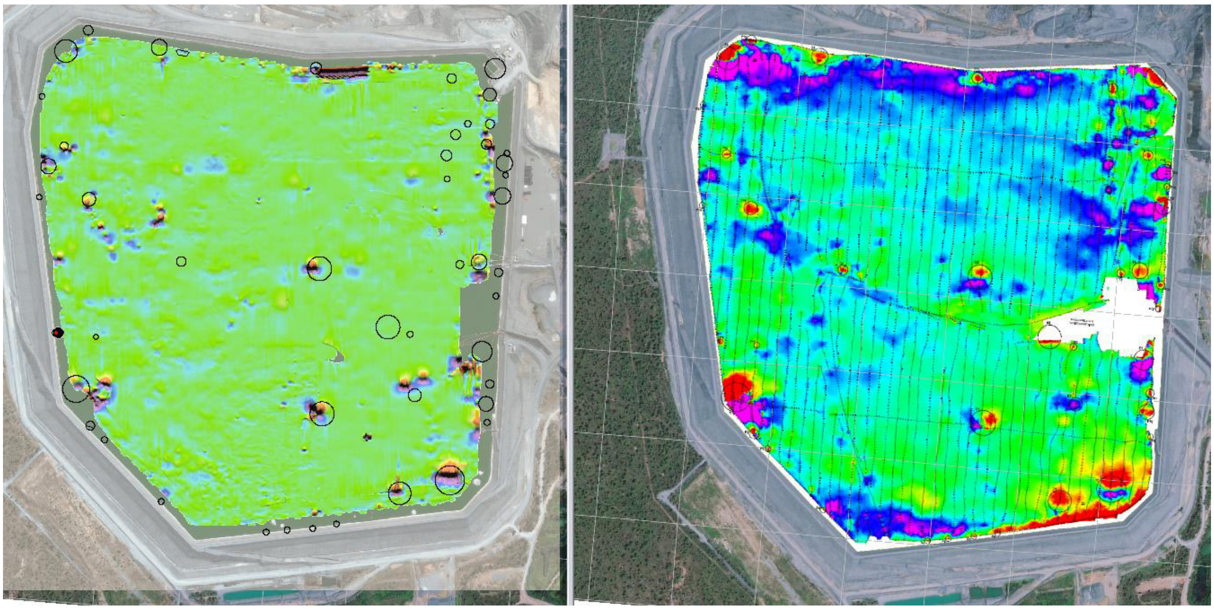


Figure 9-35: April 2019 Magnetic Anomaly Map (left frame) comparison with the 2012 Magnetic Anomaly Map (right frame)

As expected, objects were identified close to the TSF embankment, whilst the central area was relatively free of anomalies. The magnetometer detected a very strong anomaly on the south-eastern side of the TSF, 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, 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.

The Dredging Stability Assessment report (Coffey 2015) states that debris close to the actual embankment includes:

- recycle pump barge and power pole(s) – West Wall of the TSF
- steel cables
- ropes
- fuel drums

- dumped oversize rockfill, and
- plastic sheeting

Throughout the dredging operations, foreign material has been encountered as expected. To facilitate dredging this material is either removed from the TSF, cleaned and stored or placed temporarily on the walls as it is encountered. All waste material found in the TSF will either be buried in-situ, transferred to Pit 3 or transferred to RP2 for final burial.

TSF wall notches

The progressive reduction in water level associated with the dredging operations necessitated the creation of notches within the TSF walls to facilitate safe access to floating infrastructure and to improve return water pumping efficiency. To date, three notches have been successfully constructed; the East wall notch, to improve the pump efficiency for process water and tailings pipelines, and stages one and two of the North wall notch, to allow safe access to floating infrastructure in the TSF.

Two shallow notches will also be constructed in the second half of 2020 in the western wall and south eastern corner of the TSF to allow access into the TSF for wall and floor cleaning activities.

Prior to the construction of each notch the dam engineer from Coffey Services Australia provides ERA with engineering designs and completes the required stability assessment. The design and assessment is also reviewed by an independent specialist to meet the requirements of the Rio Tinto Group Standard D5 – Management of tailings and water storage. Regulatory approval is also sought prior to the execution of notch works where such notches will result in a change to the certified clay core crest height and associated decrease to the maximum operating level (MOL) of the TSF.

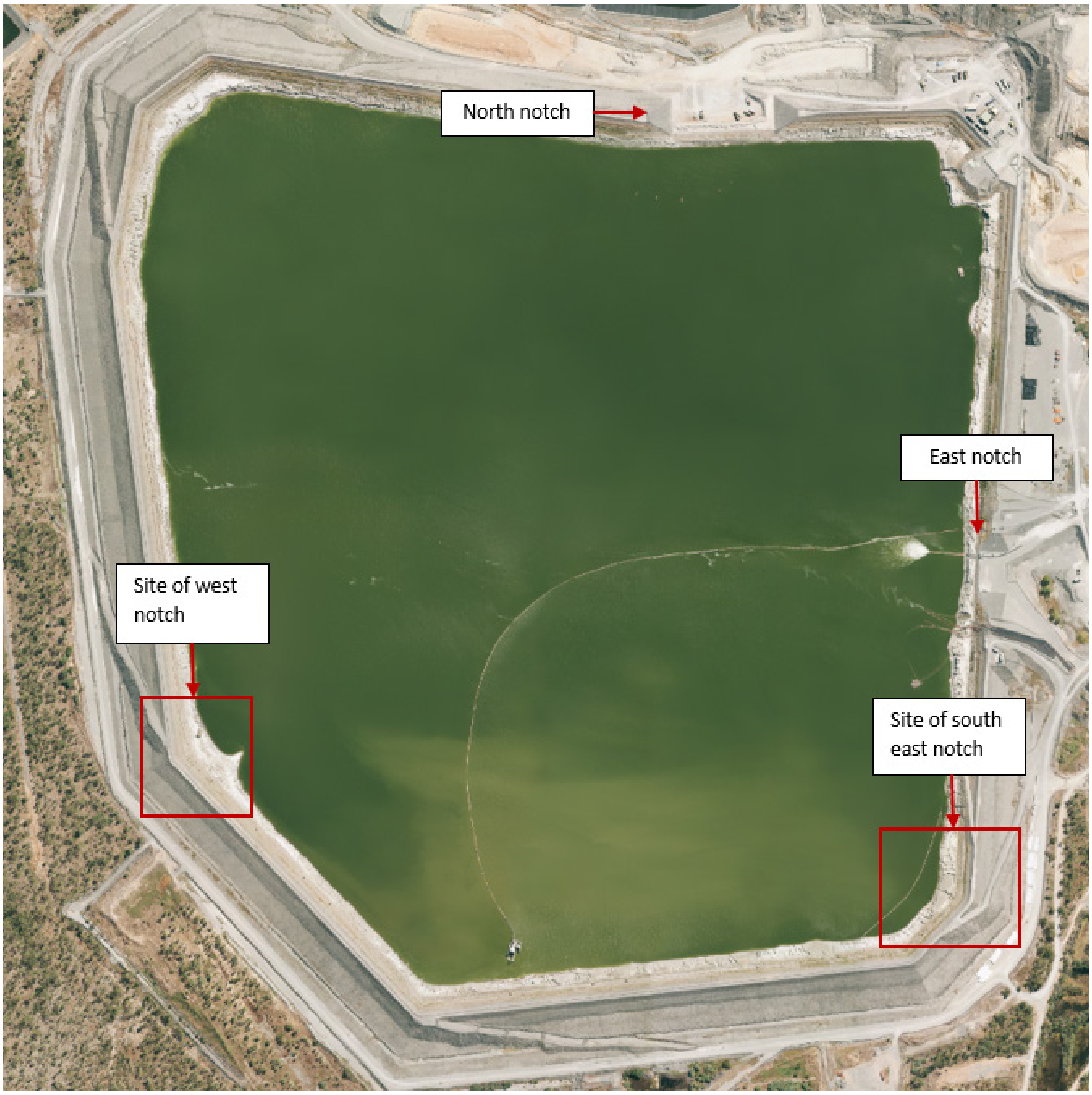


Figure 9-36: Location of notches within the TSF walls

9.3.3.3 Planned rehabilitation

Current scheduled milestones for the closure of the TSF are provided in Table 9-22 andTable 9-23.

Table 9-22: Milestone tasks for closure of the TSF

Task	Scheduled
Dredging increased to full operational capacity, completion scheduled for January 2021.	January 2021
Decommissioning of the dredges and tailings transfer infrastructure. Removal of remnant tailings/contaminated material from the TSF floor and walls.	August 2021
TSF cleaned, process water returned from Pit 3 to TSF.	September 2021

Task	Scheduled
Process water storage in the TSF ends, and deconstruction commences.	August 2024
Removal of TSF walls complete. Final landform contouring complete and commence revegetation.	1 October 2024

Table 9-23: Closure schedule for the TSF

ACTVITY	TASK	STATUS	20	21	22	23	24	25	>26
Infrastructure	Construction of dredge to deliver tailings from TSF to Pit 3	Complete							
Piping	Installation of tailings transfer piping and infrastructure	Complete							
Demolition	Decommission dredge and tailings transfer infrastructure	Scheduled							
Tailings	Removal of remnant tailings and contaminated material from TSF	Ongoing							
Process water	Conversion to water storage dam	Scheduled							
Decommission	Decommission TSF	Scheduled							
Remediation	TSF floor remediation – if required	Scheduled							
Waste	Grade 1 (1s) waste coverage	Scheduled							
Landform	Surface contoured to final landform shape	Scheduled							
Erosion	Installation of erosion control features	Scheduled							
Revegetation	Revegetation	Scheduled							

TSF floor cleaning

The floor of the TSF slopes from south to north. The floor will therefore be exposed in the southern section of the TSF prior to the completion of dredging. This is currently expected in September 2020 (Figure 9-37). Heavy mobile equipment such as dozers, excavators (land based and amphibious) and trucks will be able to access the southern section of the floor. The type of heavy mobile equipment employed will depend on the capacity of the TSF floor following drainage.

A broad outline of the proposed methodology to clean the TSF floor is as follows:

- a cleaning sweep to maximise the volume of tailings removed by the dredges has commenced
- the amphibious excavator, hydraulic monitor, and other equipment as necessary, will continue from the wall cleaning onto the floor, clearing a work area for dozers and stockpiling any foreign material (riprap, foreign objects etc.)
- heavy mobile equipment will be used to push tailings toward the dredge pool, where it will be recovered and pumped to Pit 3
- water monitors (hydraulic mining equipment) will be used to wash the tailings towards the dredge pool and 'clean the floor'

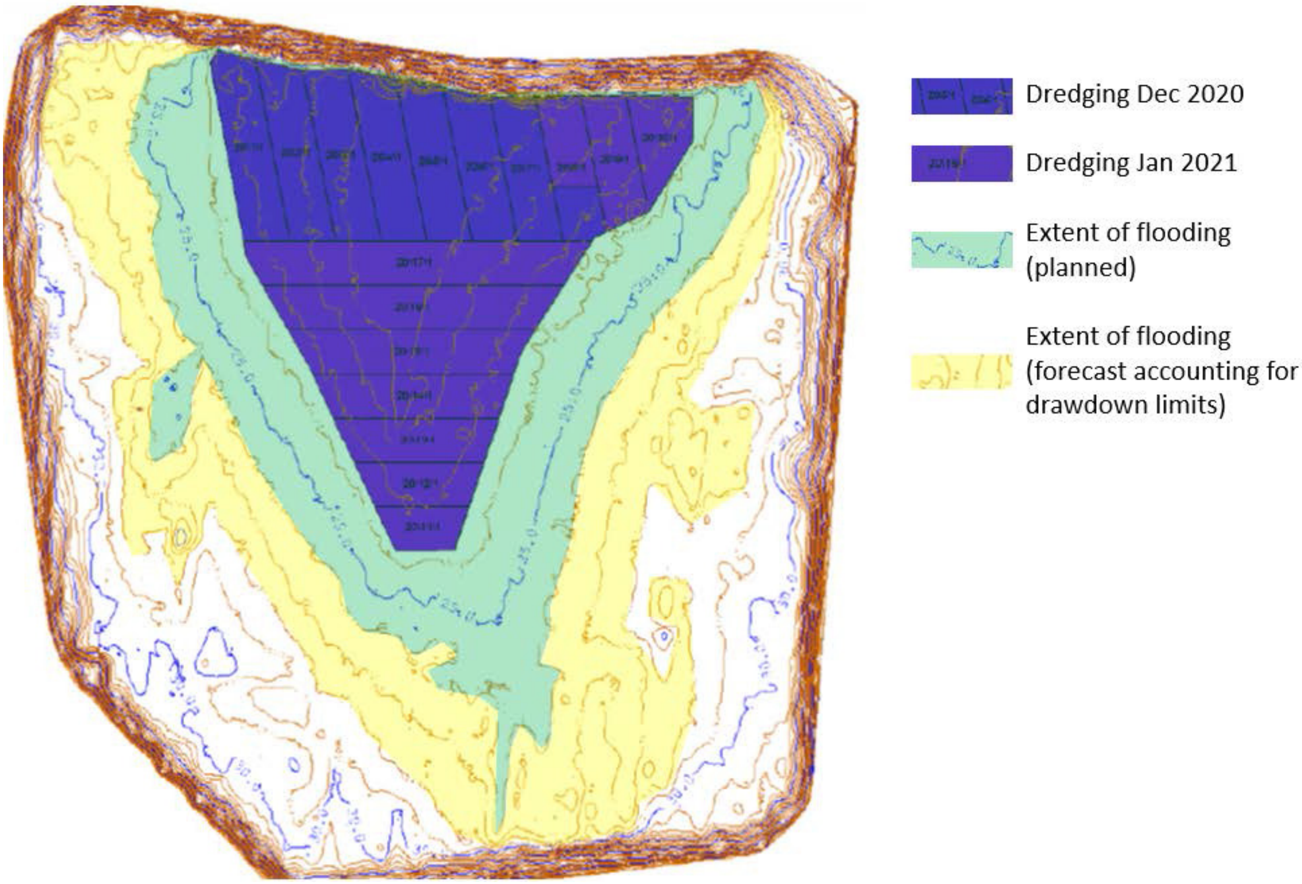


Figure 9-37: Mapping of water levels from the dredge plan

9.3.3.3.3 TSF subfloor material management

The management of contaminated sites is a critical step for rehabilitating Ranger mine and meeting closure criteria. The TSF 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 TSF 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 outcomes of supporting studies and a BPT assessment indicated that the most viable management option was to leave the subfloor material *in situ* as opposed to disposing the material within Pit 3. This outcome was important for informing the list of source terms for the closure of Pit 3 and to commence TSF deconstruction planning with consideration of future remediation options.

The outcomes of solute egress modelling undertaken by INTERA indicated that all options involving the transfer the TSF 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 TSF subfloor, and backfilling with waste rock, would further alter the hydraulic characteristics within the TSF 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 TSF) will not differ significantly if either the TSF subfloor material is retained *in situ* or removed, when taking into consideration the contribution from the broader TSF groundwater plume. The modelling work is discussed detail with Section 5.5.2.5.

The TSF subfloor risk assessment concluded that the risks associated with leaving the TSF subfloor material *in situ* can be adequately managed. Any potential consequences resulting from this management option are likely to be confined to TSF 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 would be investigated through further assessment.

Regulatory approval to leave the TSF subfloor *in situ* was received in August 2020. The TSF deconstruction application will include a BPT assessment of potential remediation options and an updated risk assessment to demonstrate how risk ratings can be improved.

Figure 9-38: Sampling of the TSF wall at North Notch 2 as part of the TSF wall and floor contamination sampling campaign

Dredge disposal

Due to the size and weight of the two dredges and associated workboats, this infrastructure will be dismantled prior to disposal. Options for disposal of the vessels include the following:

- burial in the TSF
- removal and burial in Pit 3 or RP2
- removal and decontamination for future sale

An environmental assessment, completed in 2018, determined the depth for burial of non-mineral waste as 6 m below final landform (Section 9.4.2). ERA has identified a suitable location in the south-east corner of the TSF; where the surface area and cover depths in relation to the final landform and minimum burial requirements allow for burial without need for further excavation. This option allows for the burial of the dredging equipment and any other miscellaneous waste material remaining in the TSF at the time of deconstruction.

The demolition contractor will dismantle and demolish vessels into suitably sized pieces to be spread within the available burial area. Vessels will be covered with waste rock during TSF deconstruction. The TSF burial option is currently being progressed, however sale of the vessels is still under consideration.

Process water storage

At the completion of the Pit 3 initial capping works, water in Pit 3 will be pumped back to the TSF for storage pending treatment. Once the process water volume in the TSF falls below 1 GL, the process water will be transferred out of the TSF into RP6. This allows the deconstruction of the TSF to occur, before the completion of process water treatment. Further details of process water storage have been provided in Section 9.4.3.1.

When the TSF is empty of process water, deconstruction will commence. During the deconstruction work the TSF will be converted to a pond water catchment. Any water captured in the TSF area after this time will be collected and transferred to Retention Pond 2 (RP2).

Upon completion of the final landform in this area, the TSF catchment will be converted to a release water catchment.

TSF deconstruction

TSF deconstruction will involve reducing the walls to final landform level. Wall material will be used to fill in the TSF basin. The majority of the material used in the construction of the TSF walls will fit into the TSF basin to achieve the final landform. A small volume of the wall material will 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 TSF deconstruction material quantities are shown in Table 9-24 with sequencing shown in Figure 9-39.

Table 9-24: TSF deconstruction material quantities

TSF Segment	Material Movement	Brief Description
TSF EAST	Excavation and distribution to final landform levels: 835,121 m^3 Final landform surface area: 24.99 ha	Deconstruction of the eastern TSF walls. Utilise material to shape final landform surface in the eastern area. Excess material taken to other site fill areas.
TSF WEST	Excavation and distribution to final landform levels: 2,440,743 m^3 Final landform surface area: 43.07 ha	Deconstruction of the western TSF walls. Utilise material to shape final landform surface in the western area. Excess material taken to other site fill areas.
TSF SOUTH	Excavation and distribution to final landform levels: 2,881,980 m^3 Final landform surface area: 98.15 ha	Deconstruction of the southern TSF walls. Utilise material to shape final landform surface in the southern area. Excess material taken to other site fill areas.

TSF Segment	Material Movement	Brief Description
TSF 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 TSF walls. Utilise material to shape final landform surface in the northern area. Excess material taken to site fill areas.

TSF plume

Gradual seepage from the TSF, 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 repeatedly over the years (Weaver 2010). Test work and studies were completed during 2019 to further define the plume and model the groundwater transport (Section 5.5.2.5). A BPT assessment of potential remediation options for this plume is planned to be completed in conjunction with the other TSF contaminated material, as discussed above. These assessments and any remediation plans required will be included in the TSF deconstruction application and subsequent updates of this MCP.

Landform and erosion control

The final surface of the TSF will be shaped to form the final landform, refer Section 9.4.5 for details. The TSF topography forms a drainage flow path running south to north along the historic Coonjimba Creek.

Sediment and erosion control features for the TSF domain have been described in Section 9.4.5.3.

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 TSF deconstruction application, to be submitted for approval in 2023 and included in the subsequent update of the MCP

9.3.3.4 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 planning.

The 2023 MCP will provide details of both the TSF deconstruction and the associated contingency planning.

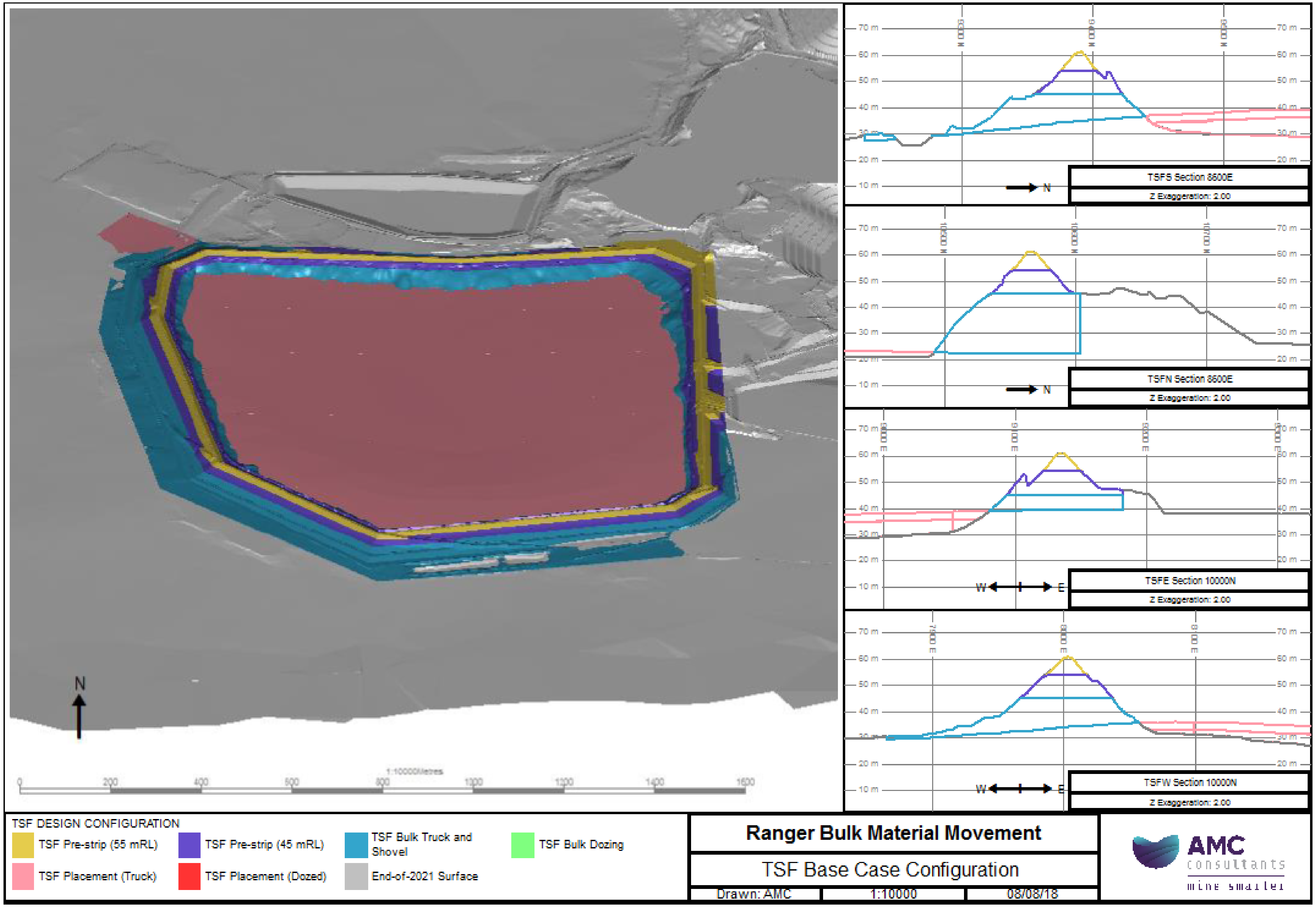


Figure 9-39: TSF wall deconstruction sequence

9.3.4 Land Application Areas

Figure 9-40: Djalkmarra and Djalkmarra Extension Land Application Areas (May 2019)

Land application areas (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 (Section 9.3.7) 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 sprayheads). Figure 9-41 and Figure 9-42 provides some examples of infrastructure at each LAA
- completion of any remediation works, as determined from contaminated sites and best practical technology assessments
- scarifying of any tracks, as required
- completion of any infill revegetation, as required

Figure 9-41: Infrastructure for removal at Corridor Creek LAA (Oct 2019)

Figure 9-42: Infrastructure for removal at Corridor Creek LAA

A preliminary assessment of the total percentage of each LAA requiring rehabilitation 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 9-25).

Table 9-25: Area of the LAAs

#	LAA		AREA (ha)
A	Corridor Creek LAA	Total area:	131
		Planned rehabilitation (10%):	13.1
B	Magela A LAA	Total area:	33
		Planned rehabilitation (100%):	33
B	Magela B LAA	Total area:	20
		Planned rehabilitation (70%):	14
C, D	Djalkmarra East (DLAA) & Djalkmarra West (DLAA ext) LAA	Total area:	38
		Planned rehabilitation (50%):	19
E	Retention Pond 1 LAA	Total area:	46
		Planned rehabilitation (80%):	36.8
F	Retention Pond 1 LAA ext.	Total area:	8
		Planned rehabilitation (10%):	0.8
G	Jabiru East LAA	Total area:	52
		Planned rehabilitation (80%):	41.6
LAA – TOTAL HA			328
TO BE REHABILITATED – TOTAL HA			158

9.3.4.1 Completed rehabilitation

There has been no progressive rehabilitation undertaken of the LAA sites to date.

9.3.4.2 Current rehabilitation

Assessments are currently underway to determine the level of contamination in the LAAs (Section 5.5.2.4). These assessments will form the basis of a best practical technology assessment to determine what consequences will be considered as low as reasonably achievable for LAA remediation, thereby informing appropriate remediation plans for each. Further detail on the ALARA process is provided in Appendix 8.1. The rehabilitation percentages detailed in Table 9-26 will be reviewed for each LAA following the assessement.

9.3.4.3 Planned rehabilitation

Table 9-26: Closure schedule for LAA rehabilitation

DOMAIN	ACTIVITY	TASK	STAGE	20	21	22	23	24	25	26>
LAAs	Assess	Assessment of contamination in soils	Ongoing							
	Demolish	Staged removal of infrastructure	Scheduled							
	Remediate	Remediation, if required	Scheduled							
	Revegetation	In fill revegetation, if required	Scheduled							

As described above and shown in Table 9-25, 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). As detailed above, a best practical technology assessment will be undertaken to assess the level of remediation required at each LAA. Following this determination, revegetation will be undertaken following the Ranger Mine Revegetation Strategy (Appendix 5.1) and the general approach which is described under the Section 9.4.6. Detailed remediation plans, as required, and revegetation plans for the LAAs will be provided in future updates of this MCP.

9.3.4.4 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.

9.3.5 Process plant, water treatment plants & other infrastructure

Figure 9-43: Process plant, mill and water treatment plants (May 2019)

This domain as shown in Figure 9-43, includes all infrastructure from the processing plant, administration block, heavy vehicle area, gatehouse and water treatment plants. Other miscellaneous infrastructure around site is also discussed in this section in regards to demolition.

A discussion on the activity of water treatment is provided in Section 9.4.3, whilst this section describes the removal of the water treatment infrastructure.

The following infrastructure 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:

- offices of the Environmental Research Institute of the Supervising Scientist (ERISS)
- external services (Telstra).

9.3.5.1 Completed rehabilitation

As milling will continue until the end of 2020, there has been no progressive rehabilitation completed within this domain.

9.3.5.2 Current rehabilitation

Work has commenced on decommissioning and decontamination for any infrastructure within the processing plant that is no longer in use. This includes:

- laterite plant

- ore sorter
- leach pachuca tanks

The main goals of the decommissioning and decontamination implementation strategy are:

- conversion of the Ranger Project Area (RPA) from its current operational state to a decommissioned state
- 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
- walk-down, punch-listing (checklist) and handover to the demolition contractor

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 demolition (Q1 2023).

9.4.1.1 Decommissioning

The overall shutdown of the plant has three steps, which are linked to the progression of decontamination works:

1. initial emptying and flushing of the energised plant, performed as per current ERA procedures for a major maintenance shutdown
2. shutdown, de-energisation and isolation of assets as required, to enable safe completion of decontamination (e.g. to enable confined space entry for intrusive cleaning or inspection works)
3. shutdown, de-energisation and isolation of all remaining assets to enable safe completion of demolition (e.g. de-energisation and isolation of the lighting, small power, services and utilities systems which has to remain active during decontamination)

Decommissioning will be phased to align with demolition. The main stages of the decommissioning works are represented in Figure 9-44. 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). The application for a permit will outline 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. The permit application will be submitted following the cessation of uranium oxide production. Decommission works can only proceed following the receipt of, and in accordance with the permit.

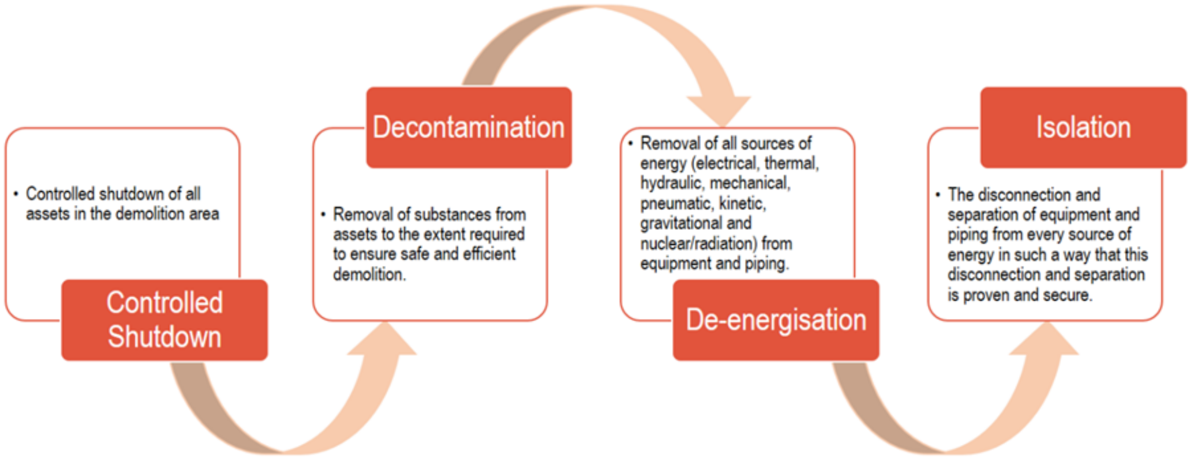


Figure 9-44: Decommissioning stages

The decommissioning phase involves the decontamination of assets in the demolition area. This work is required to ensure safe and efficient demolition and disposal. It will include the following activities:

- decontamination of piping and in-line items
- decontamination of equipment
- preparation of equipment to be disposed whole and intact. This is applicable to equipment containing loose internals that are contaminated with radioactive material.
- documentation of equipment that cannot be decontaminated as an identified residual hazard. The type of hazardous material, along with the reasons why it could not be decontaminated, will be documented appropriately.
- demonstrating completion of decontamination activities by spray painting the asset on site and highlighting, initialling and dating the asset on the decommissioning drawings
- emptying of all stockpiles
- hosing, flushing and emptying of bunds and sump tanks
- draining of oil from transformers, gearboxes, hydraulic systems and lubrication systems and steam cleaning of large oil reservoirs
- opening of all manual valves, drains, vents to demonstrate a vented and free-draining state
- removal of all hazardous materials as per ERA standard
- completion of radiation surveys on the exterior of assets and in the general demolition area, as per ERA standards and operating procedures

- completion of gas clearance surveys, where required

All de-energisation and isolation activities of the demolition area will be divided into electrical and control, piping, structural and miscellaneous and all activities will be completed according to ERA standards.

A decommissioning sequence has been determined for the areas of the plant based on the interaction of the plant decommissioning with other activities in the overall closure project. The criteria that determines, at a high-level, the sequence in which the area can be decommissioned, are as follows. Each plant area is colour coded according to the sequencing in the decommissioning (Figure 9-45):

- Infrastructure not in use (highlighted in yellow): Decommissioning of these assets can commence at any time.
- Infrastructure not required post-mill operation (highlighted in green): Decommissioning of these assets can commence after the mill stops operation. Some areas will require a Permit to Decommission Facility from the Australian Safeguards and Non-Proliferation Office prior to the start of decommissioning.
- Infrastructure required for continuity of services (highlighted in blue): Decommissioning of these assets can only proceed after the continuity of services scope of work has been completed.
- Laydown areas (highlighted in light pink): These areas are currently in use but require minimal decommissioning work prior to handover to the demolition contractor. Decommissioning is to proceed as the areas become available with ramp-down of operations.
- Infrastructure required for water treatment (highlighted in red): Decommissioning of these assets can only proceed after treatment of process water is completed.

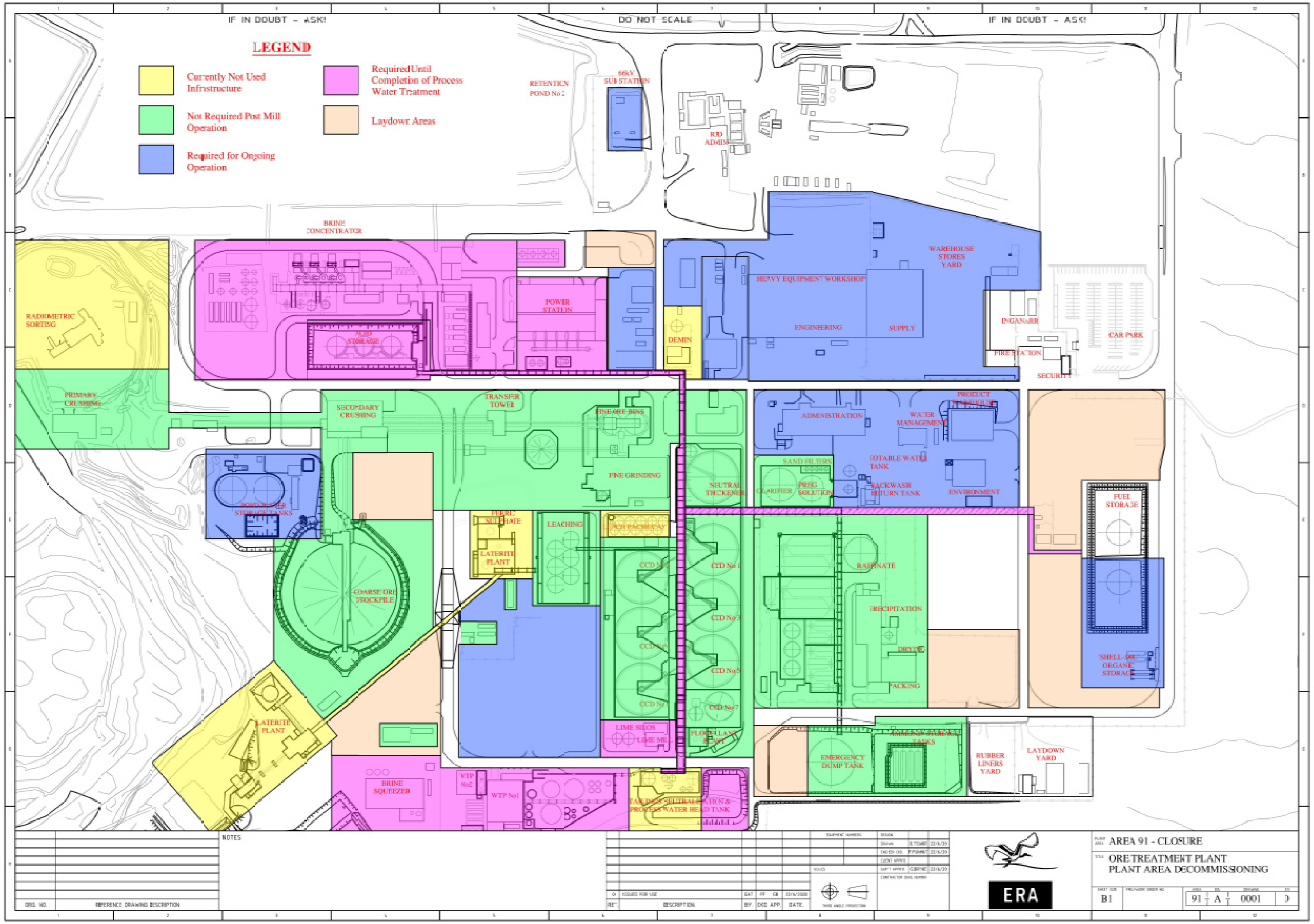


Figure 9-45: Plant decommissioning sequence

The interim 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 once the existing system of sump pumps are shutdown. This shall include the following activities:
  - sampling and testing of rainwater in 'decontaminated' sumps to confirm that it is still sufficiently contaminated that it cannot be released
  - design and 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 or spray paint
- 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, and
  - results of radiation survey, gas clearance surveys and underground services surveys appended to the work pack.
- Walk-down of the demolition area (without the demolition contractor) to confirm completion of all activities in the decommissioning work pack and punch-listing (checklist) incomplete items. 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, and
  - 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). As a minimum, the following checks are expected to be requested by the demolition contractor:
  - verification that all energised piping systems (i.e. services) that have lines passing into the demolition area have been air-gapped
  - verification that all de-energised piping systems that have lines passing into the demolition area and have all block valves, drain valves and vent valves open
  - verification that all underground pipes passing into the demolition area have been air-gapped, where they pass above ground outside of the demolition area
  - verification that all cables passing into the demolition area via cable trays/ladders have been air-gapped
  - verification that all underground cables have been air-gapped, where they pass above ground outside of the demolition area
  - review of any items of note as marked up on check sheets (e.g. residual hazardous materials, underground pipes with fluid in them)
  - review of all gas free clearances and sampling points

9.4.1.3 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 operations.

Key aspects of the continuity of services plan:

- Essential services are assumed to remain operational, as per the current operating system, until commencement of Phase 1 demolition (Table 9-30).
- Services within the Phase 1 demolition zone which are required after demolition are subject to continuity of services.
- Central “hub” for infrastructure post-plant decommissioning will be in the decommissioned Ranger 3 Deeps area
- 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 221 piping tie-ins for various services. These services are split into ten separate packages of work in the following services:

- acids and reagents
- portable water
- plant air
- diesel
- fire water
- miscellaneous
- pond water
- instrument air
- process water
- sewage.

9.3.5.3 Planned rehabilitation

Current schedule milestones for demolition are provide in Table 9-27.

Table 9-27: Schedule key milestones for completion of demolition

Key milestone	Date
Decommissioning	Q1-Q3 2021
Commence Phase 1 demolition	Q1-Q3 2023
TSF ready for deconstruction (RP6 ready for process water storage)	Q2 2024
Complete decant pumping from Pit 3 to TSF	Q1 2024
Complete process water treatment	Q1 2025
Commence Phase 2 demolition	Q2 2025
Undertake remediation of any identified contaminated sites	Q3 2025
Final landform earthworks	Q3 2025
Revegetation	Q4 2025
Handover / end of RPA lease	08 January 2026

The schedule for closure activities in this domain is provided in Table 9-28.

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Table 9-28: Schedule of closure activities for the processing plant, administration buildings and water treatment structures.

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	26>
Processing plant, admin buildings and water treatment infrastructure	Services	Continuity of services	Ongoing							
	Decommissioning	Decommission of processing plant and place in care and maintenance.	Scheduled							
	Demolition	Phase 1 demolition of plant and place in stockpile for placement in Pit 3 / RP2. Removal of footing to 1.5 m depth	Scheduled							
	Remediation	Remediate if required	Scheduled							
	Demolition	Phase 2 demolition: Removal of water treatment infrastructure, including pipelines and services	Scheduled							
	Demolition	Administration infrastructure	Scheduled							
	Remediation	Remediate if required	Scheduled							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							

Demolition and disposal

All plant, equipment, buildings and other structures will be removed unless approval of the Traditional Owners and Commonwealth Minister is provided for infrastructure to remain on the RPA.

Demolition is defined as the tearing down of buildings and other structures (including the underground works) 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 ground level
- all piping to a depth of 1.5 m below ground
- all cabling to a depth of 1.5 m below ground
- bitumen surfaces from roads
- asbestos
- loose solid materials across the sites
- processing of demolished materials to 1 m x 1 m lengths to ensure maximum density can be achieved at the disposal location
- removal and final disposal of the materials and hazardous waste

Demolition differs to deconstruction. Deconstruction involves dismantling structures to preserve valuable elements for reuse. Deconstruction will occur where it is unsafe and/or there is a danger of damaging other assets that are required for the continuity of services. The use of deconstruction methodologies will be minimised as this takes more time and is thus considerably more expensive.

Demolished items must be buried on site at 6 m level deep below final landform, refer Section 9.4.2. Due to this ERA requirement, infrastructure will be disposed of in Pit 3, RP2 or other purpose excavated locations on site. 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.

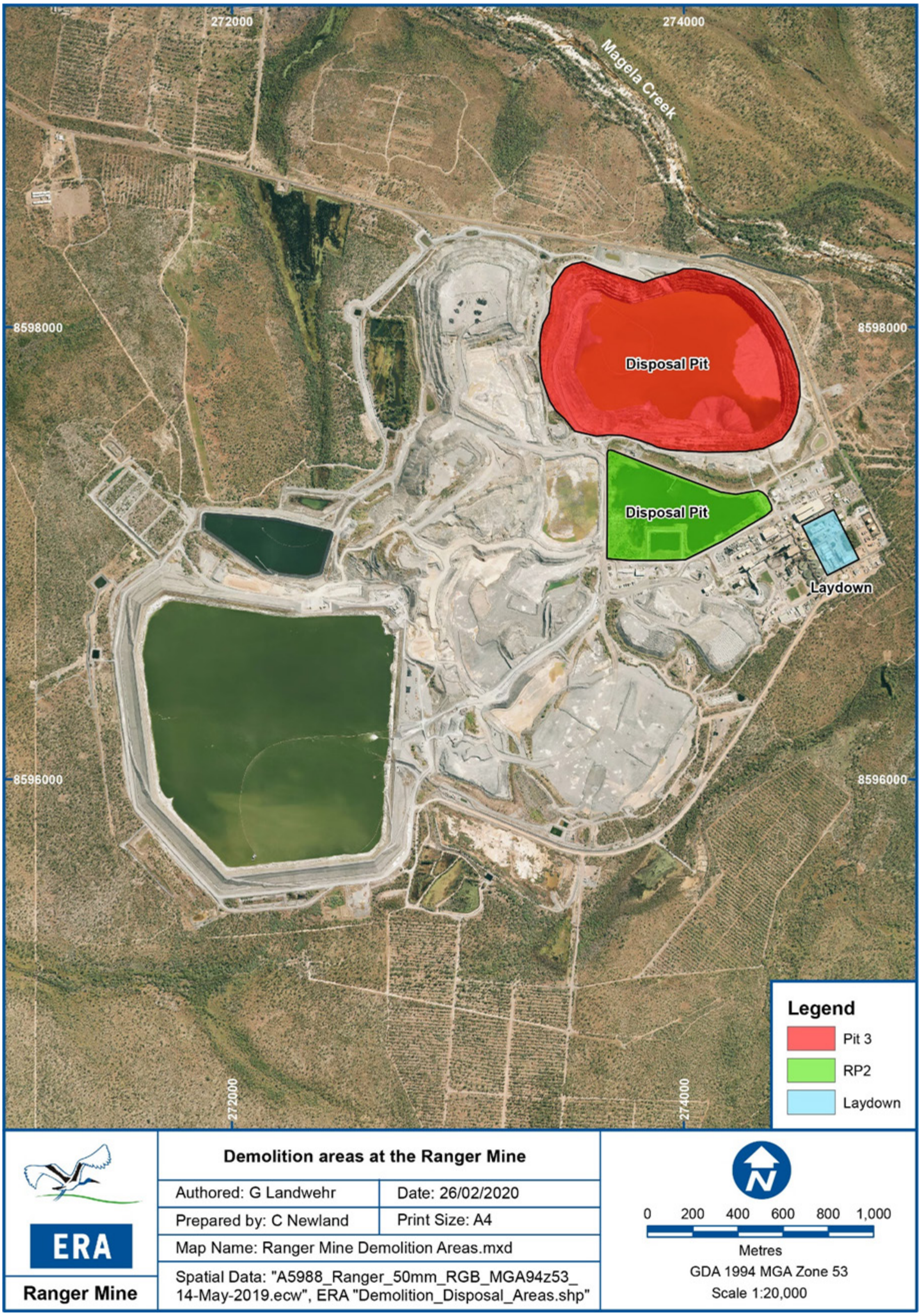

Figure 9-46: Areas for disposal of demolition material

Table 9-29: Demolition phases

Phase	Approximate duration	Associated infrastructure
1	January 2023 to December 2023	Mill, processing plant and tailings transfer infrastructure
2	April 2025 to September 2025	Process water treatment / transfer, mine and closure activities infrastructure
3	October 2027 to December 2027	Post-closure management infrastructure

The following demolition methods will be used to demolish the facilities on the RPA:

- manual demolition
- mechanical demolition
- cut and pull
- induced collapse
- 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 used, the demolition contractor will provide a detailed explosives plan 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 9-30. The key infrastructure and services for Phase 2 works are listed in Table 9-31: Phase 2 demolition areas.

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.

Table 9-30: 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
Engineering and supply	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
Sewage treatment	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 – laboratory and laundry relocated to R3D
Plant services	All – One compressor relocated to Water Treatment Plant 1 (WTP1)

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 (Figure 9-46) 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
- asbestos drums

The key assumptions for Phase 1 are:

- all Phase 1 demolition material to be disposed of in Pit 3

- 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
- disposed items in Pit 3 to be buried 6 m below final landform (Section 9.4.2)

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
- items disposed in RP2 are to be buried 6m below final landform

Table 9-31: Phase 2 demolition areas

Area	Infrastructure/service demolished
Bulk fuel storage	All remaining infrastructure and services
R3D	All remaining infrastructure and services
Brine concentrator	All remaining infrastructure and services
Mine centre	All remaining infrastructure and services
Water treatment plant 3 (WTP3)	All remaining infrastructure and services
Power station	All infrastructure and services
Security, gatehouse and emergency services	All remaining infrastructure and services
Acid storage	All remaining infrastructure and services
Orica yard	All remaining infrastructure and services
Tailings Storage Facility (TSF)	All remaining infrastructure and services
Retention ponds	All remaining infrastructure and services
WTP1 and WTP2	All remaining infrastructure and services
Brockman bore field	Remain post-closure for potable water supply

9.3.5.4 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.

9.3.6 Stockpiles

Figure 9-47: Stockpile area (May 2019)

Bulk material movement from the stockpiles is covered in the activities Section 9.4.4.

9.3.6.1 Completed rehabilitation

A 3.6 ha section of the stockpile Stage 13.1 (Areas A-C), became available for revegetation at the beginning of 2020 (Figure 9-48). ERA used this area to conduct opportunistic, small-scale precursor revegetation trials to inform future large-scale Pit 1 activities.

Stage 13.1 (Areas A-C) is the remainder of a waste rock stockpile that 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. On inspection, the surface material was identified as relatively fine compared to previous revegetation experience such as on the trial landform. The area was ripped at 3 m intervals to a depth of 50 cm to provide surface roughness and alleviate any compaction.

Area A (0.6 ha) did not require additional surface works and 1,207 tubestock of 22 species were planted out on the 16th and 17th of April 2020. All of the planted tubestock are part of trials under investigation by the ERA. These trials are further described in 9.3.1.3.

Figure 9-48: Native seedlings planted on Stage 13.1 (8 July 2020)

9.3.6.2 Current rehabilitation

Refer to bulk material movement section (Section 9.4.4).

9.3.6.3 Planned rehabilitation

Mining of stockpiles for the backfilling of Pit 3 and creation of the final landform is scheduled to commence in October 2022. Mining material from stockpiles and the TSF is scheduled for completion in September 2025.

The bulk material movement (BMM) plan provides for excavation of areas above the final landform (in the stockpiles and TSF) when there is nearly 100 percent acceptable material for the final landform. However, mineralised material will be mined below the final landform height in many areas of the stockpiles and will be placed into Pit 3. Therefore, a proportion of material in the stockpiles will remain in place as it is not mineralised and is already below level of the final landform.

Figure 9-49: Mining Stage 10 of the stockpile area (waste is transferred to backfill Pit 1)

Table 9-32: Schedule for closure activities for the stockpile area

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	26 >
Stockpiles	Waste	Bulk backfill	Scheduled							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							

Landform & erosion controls

Earthworks for final landform construction, including erosion control structures, will be implemented after the bulk material movement from the stockpiles is complete (Section 9.4.5).

Revegetation

The two remaining sections of Stage 13.1 will be revegetated in October 2020 (Area B) and early 2021 (Area C, pending Pit 1 logistics). Area B (~1 ha) is planned to be planted out in October 2020 and will be part of a 'dry season/build up' planting trial. Area C (~3 ha) will be revegetated in early 2021 with 'general planting' which consists of overstorey and midstorey species typical of local Eucalypt-dominated woodland ecosystems, planted at 1000 stems/ha.

Revegetation of other stockpile areas will be undertaken following the Ranger Mine revegetation strategy (Appendix 5.1). A detailed revegetation plan for the stockpiles will be provided in future updates of this MCP.

Figure 9-50: Planting areas A, B and C of Stage 13.1

9.3.6.4 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
- Contingencies for unsuccessful revegetation or erosion control are covered in Section 9.4.5.7.

9.3.7 Water management areas

Figure 9-51: Retention Pond 1 (RP1) and RP1 Wetland Filter (May 2019)

Figure 9-52: Retention Pond 2 (May 2019)

The effective management of water at the Ranger Mine is critical for successful operations and closure and to ensure the surrounding Kakadu NP remains protected. There is an ongoing need to actively manage water throughout the closure phase. By January 2026, however, all water management areas will need to have been rehabilitated. These water management areas include:

- pond water storage (RP2 and RP6)

- release water storage (RP1, GCMBL and Sleepy Cod)
- wetland filters (Corridor Creek wetland filter and RP1 wetland filter)
- various water management sumps
- onsite billabongs that have received release discharge water

This section provides a summary of how the various water management catchments will be managed and an outline of the overall plan for closure of these water management areas. Land application areas are also water management areas, but are discussed under a separate domain (Section 9.3.4). Further details of each water management area, the different classes of water at Ranger Mine, and their use during operations is provided in Section 9.4.3.

Figure 9-53: Corridor Creek Wetland Filter (November 2019)

9.3.7.1 Completed rehabilitation

No progressive rehabilitation has been possible to date as all water management areas are in use.

9.3.7.2 Current rehabilitation

There is no current rehabilitation underway as there are no areas available.

9.3.7.3 Planned rehabilitation

The exact timing and methods for the rehabilitation of the various water management areas will depend upon a number of factors, primarily rainfall and continued need. Currently, within the closure schedule, each is assumed to undergo rehabilitation as late as possible. This is expected to commence in 2023 and been staged through to the end of closure, depending upon the level of rehabilitation required.

Table 9-33: Schedule for water management area closure activities

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	26 >
Water management areas	Decommission	Remove lining of RP6, and infrastructure of RP 2, 3 & 6	Scheduled							
	Landform	Surface contoured to final landform shape (RP 2, 3 & 6)	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							

Catchment management

This section describes the major activities associated with the conversion of catchments throughout closure from pond or process water to release water. The Ranger Water Management Plan describes the detailed aspects of water and catchment management on the RPA.

Each catchment may comprise several elements, such as retention ponds, sumps, collection basins and groundwater interception ponds. The staged formation of the final site landform results in water catchments being converted to release water catchments over time. Once the final landform of an area is completed, it becomes a release catchment. Any rainfall captured on final landform areas will be directed to release, in accordance with the Ranger Water Management Plan.

Due to the slope of the final landform, surface runoff water from some of the catchments will need to be actively diverted, or collected and pumped, to prevent it from reporting to pond or process water catchments. This is currently managed by operations through the Ranger Water Management Plan, and this will continue throughout closure.

Pond water storage

Pond water collected on the RPA is transferred to RP2 (the main pond water storage) or RP6. Water inventory within the ponds is maintained to a minimum level to ensure the supply of pond water to the mill. The total inventory of pond water is balanced between RP2 and RP6 to prevent the overflow of RP2 into Pit 3.

When operations cease, the required minimum inventory of pond water is substantially reduced. The primary use for pond water at this stage will become dust suppression. The total inventory of RP6 will be transferred to RP2, most likely in the dry season. This allows the conversion of RP6 to a process water storage (see details below). RP2 will then become the only pond water inventory on the RPA. RP2 will remain an open pond water store and catchment until the collection and treatment of pond water is completed.

Retention Pond 6

To allow earlier deconstruction of the TSF, process water in the TSF will be transferred out of the TSF into RP6. This is initiated once the process water volume in the TSF falls below a threshold level. The total process water storage volume of RP6 is approximately 800 ML. This plan assumes that the transfer of water from TSF to RP6 will take a maximum of one month, after which, RP6 is the only process water store on the RPA.

When water transfer starts, all infrastructure associated with process water must be relocated from the TSF to RP6. This includes infrastructure associated with:

- WTP brine discharge
- Brine Squeezer brine discharge
- Brine Squeezer process water feed
- BC concentrated brine discharge
- BC process water feed
- HDS plant process water.

Whilst RP6 has historically been used for storage of pond water, it was originally designed with the ability to store process water, being fitted with a lining system and both an underdrain system (to mitigate uplift) and a leak detection/recovery system. The RP6 conversion plan outlines the conversion of RP6 to a process water store. RP6 will remain a process water store and catchment until the treatment of free surface process water is completed.

Once the free process water inventory reaches zero then the demolition of RP6 will commence. This will involve the removal of the liner and the subsequent burial in RP2, followed by the recontouring of the site to form the final landform

Retention Pond 2

RP2 is an identified site for the disposal of waste generated during Phase 2 demolition. Once all the pond water has been treated on site, RP2 will be prepared to receive waste material from Phase 2 of demolition. Details of the volume available for storage in RP2 and the types of material to be disposed have been detailed in Section 9.4.2. Following the completion of waste disposal, the pond will be backfilled to final landform with waste rock. 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. ERA is currently designing waste disposal sites to have a minimum thickness of waste rock material cover of 8 m.

Release water storage

Release waters are stored within RP1 and GCMBL. As detailed in the land application areas section (Section 9.3.4), 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 Section 9.4.1 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 receiving water of better quality and the BC distillate.

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 recontouring and revegetated. 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 a best practical technology assessment undertaken to determine if any additional remediation work is required.

Water management sumps

The Ranger Water Management Plan requires many sumps and pumps to manage the flow and separation of classes of water throughout the wet season. This will continue during closure.

As the construction of the final landform is progressed and catchments are converted to direct release, sumps will no longer be required. These sumps will be rehabilitated by the removal of any infrastructure, and by recontouring and revegetation.

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 direct release water from the final landform during and after closure.

Studies are currently underway to assess the rehabilitation strategy for these billabongs (Appendix 5.1). This information will be provided in future versions of this MCP.

Revegetation

Revegetation will be undertaken in accordance with the Ranger Mine revegetation strategy (Appendix 5.1). A detailed revegetation plan for the water management areas will be provided in future updates of this MCP.

9.3.7.4 Contingency planning

As the final rehabilitation plan for many water management areas is not complete, contingency plans have not yet been developed. Those areas that are simply being removed do not require a contingency plan.

If RP2 is later determined to be unsuitable as a waste disposal site, an alternative landfill will be constructed on site following an appropriate approval process.

Studies assessing the current level of contamination of various water management areas are currently underway and have been detailed in Section 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 this MCP.

9.3.8 Linear infrastructure

Figure 9-54: Multiple tracks east of Pit 3 (May 2019)

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. Areas included within this domain are indicated in Figure 9-54. 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 is near completion, and involved the collation of all the information on the ERA groundwater monitoring network. ERA are finalising the last aspect of Stage 1 through the implementation of AcQuire, a geoscientific data management software package which will be used to track the progressive rehabilitation of groundwater bores located across the RPA. Stage 2 will involve the ground-truthing of all collated data and tracking in AcQuire, and is likely to commence later in 2020. Stage 3 involves the active decommissioning of redundant infrastructure and is likely to commence late 2021.

The timing for the rehabilitation of linear infrastructure will be based on the utilisation requirements for operations and/or closure. Some linear infrastructure, for example the boundary fence and various access roads, may be required following 2026 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.

9.3.8.1 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.

9.3.8.2 Current rehabilitation

No current rehabilitation underway.

9.3.8.3 Planned rehabilitation

Table 9-34: Schedule for linear infrastructure closure activities

DOMAIN	ACTIVITY	TASK	STATUS	20	21	22	23	24	25	26 >
Linear infrastructure	Demolition	Remove any infrastructure in corridors (roads, tracks, service corridors, exploration lines, groundwater bores)	Scheduled							
	Landform	Recontour and/or rip if required. Block access to tracks	Scheduled							
	Infrastructure	Install fencing and/or signs if agreed to by TOs	Scheduled							

9.3.8.4 Contingency planning

There are no contingencies required for this domain. However, permission to leave infrastructure such as fencing and signage in place after January 2026 will be obtained before that time.

9.3.9 R3 Deeps decline

Figure 9-55: R3 Deeps portal and offices (May 2019)

The Ranger 3 Deeps (R3D) exploration decline (the decline) was constructed between May 2012 and December 2014, to allow for exploration and delineation of the Deeps resource associated with the proposed R3D underground mine, east of the Ranger Mine Pit 3 (Figure 9-55). 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, and the third drill rig was mobilised in November 2013. Drilling ceased in September 2014.

The proposed R3D underground mine project was not progressed and the decline has been in care and maintenance (C&M) since June 2015.

Closure planning has considered the major R3D infrastructure including the:

- decline (which is 2,710 m long, 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" which extends 185 m from the ground surface, through the weathered rock zone to approximately -8 AHD[4]) (Figure 9-57).

[4] AHD: Australian Height Datum.

Major infrastructure including pumps, fans, compressors, generators and refuge chambers will also be decommissioned and removed, where necessary.

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 updated decommissioning plan is planned to be submitted to stakeholders in August 2020 to provide updates to address stakeholder comments received in November 2018, the dewatering/pumping and water sampling regime, and actions completed to early 2020. These updates are included in the sections below.

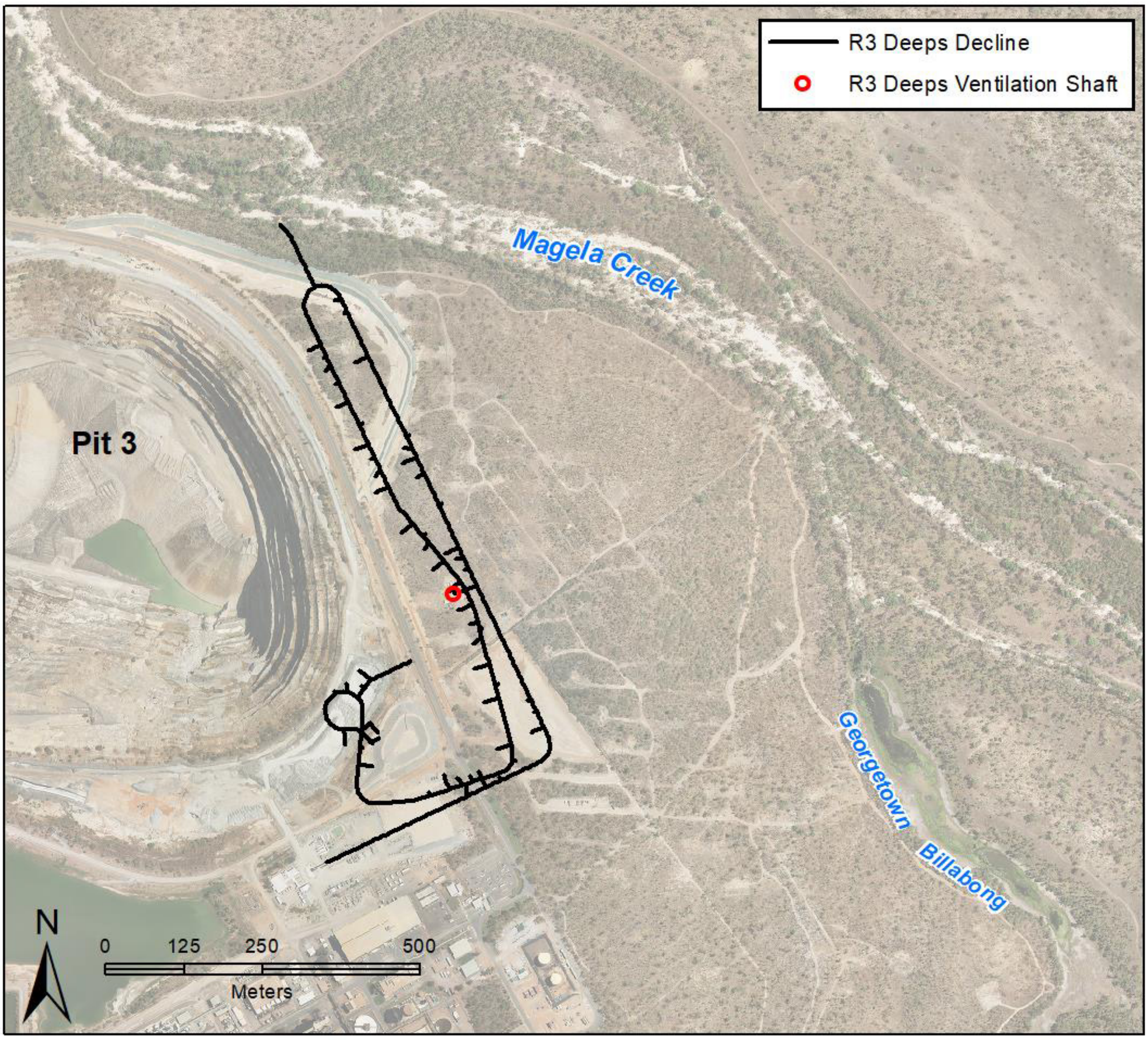

Figure 9-56: Plan view of the decline

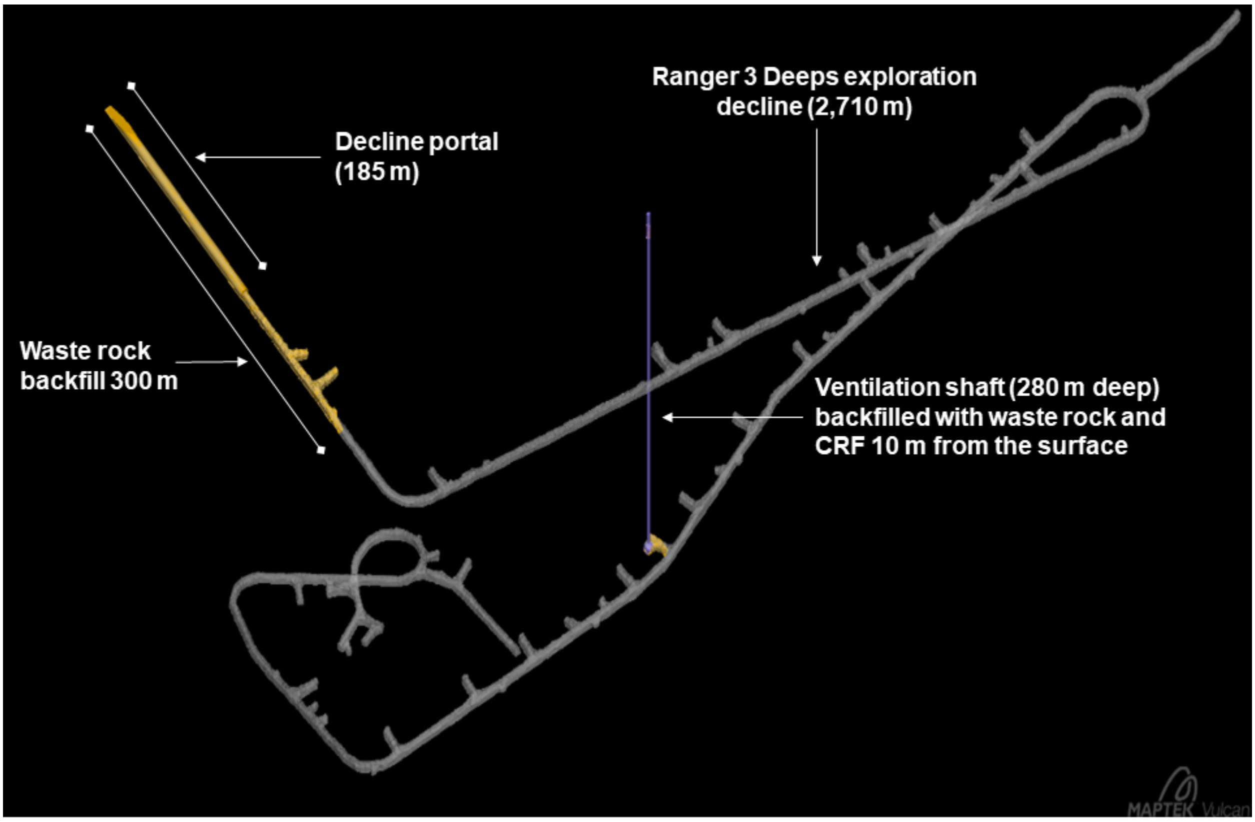

Figure 9-57: Oblique view of R3D decline and main closure elements

9.3.9.1 Completed rehabilitation

While the decline remains subject to a reduced care and maintenance (C&M) program, certain 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.

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
- installation of a temporary 500kVA, 1000 volt power system on the surface to power the existing ventilation fans

- 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 -25 mRL
- cleaning and radiation clearance of the removed infrastructure
- blocking of access to the decline through the portal
- 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 -25 mRL.

9.3.9.2 Current rehabilitation

Reduced care and maintenance activities are required until the completion of all rehabilitation works. These activities include:

- keeping the decline dewatered to -25 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
- 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.

The C & M program is ongoing and the Final Closure & Backfill Program will take place after the cessation of processing – this is currently anticipated to occur as part of the demolition of the mine site infrastructure. A full geotechnical inspection will take place at this time before access for final backfilling.

9.3.9.3 Planned rehabilitation

The reduced C&M activities until 2021 will maintain the water level in the decline at -25 mRL. Final closure activities after January 2021 will consist of the closure of the top portion of the ventilation shaft and waste rock backfill of 350 m of the decline from ground level. This includes 185 m of the decline portal (Figure 9-57). The original 300 m backfill commitment was extended to 350 m after a meeting with the SSB on 9 November 2018 to mitigate against any risk of decline collapse propagating through the weathered zone to the surface. The remainder of the ventilation shaft will be filled with sized waste rock with a 10 m section of CRF placed 10 m from the surface. The steel portal will be cut down and removed to ground level and the surface concrete pads and concrete collar in the vicinity of the ventilation shaft will be removed.

Only a few buildings remain to be removed from site, and this will occur once a suitable buyer can be identified. The timing for completion of the revegetation will be dependent upon this. The workshop area is planned for demolition when Pit 3 is available to receive waste materials.

Ventilation shaft closure

To progress permanent closure in 2021, the ventilation shaft will be filled with crushed rock (crushing to occur in the existing plant) up to the weathered zone. The last 20 m of the ventilation shaft is first filled with 10 m of cemented rock fill (CRF) and then 10 m of crushed rock to surface (Figure 9-58). The surface concrete pads and concrete collar will be removed. The volume of material for the waste rock plug is approximately 705 m^3, the volume of crushed rock in the ventilation shaft is approximately 2,025 m^3, and the volume of CRF is approximately 125 m^3.

Portal closure

The steel multi-plate tunnel will be dismantled/cut down to final ground level. The void will be backfilled and covered with waste rock. Figure 9-59 depicts the dismantling/cutting gradient required to reduce the portal to land surface. One metre of waste cover is required over the tunnel (at a gradient of 1 in 20; less than 2,500 m^3 of waste rock is required).

Decline closure

The weathered zone (approximately 350 m) of the decline will be backfilled with waste rock up to ground level. The four standpipe holes will be left with stainless steel valves closed and the holes will not be grouted (INTERA 2018). The volume of waste rock required to backfill the weathered zone is approximately 14,500 cubic metres.

Geotechnical considerations

The geological conditions (strength and weathering of schist) varied along the depth of the portal and decline. During the construction there was always a company geotechnical engineer onsite. Every development cut was mapped by a geotechnical engineer or geotechnically trained geologist, and the required ground support for that cut was determined. Considerations for closure of the decline and portal relating to these conditions are described in Table 9-35.

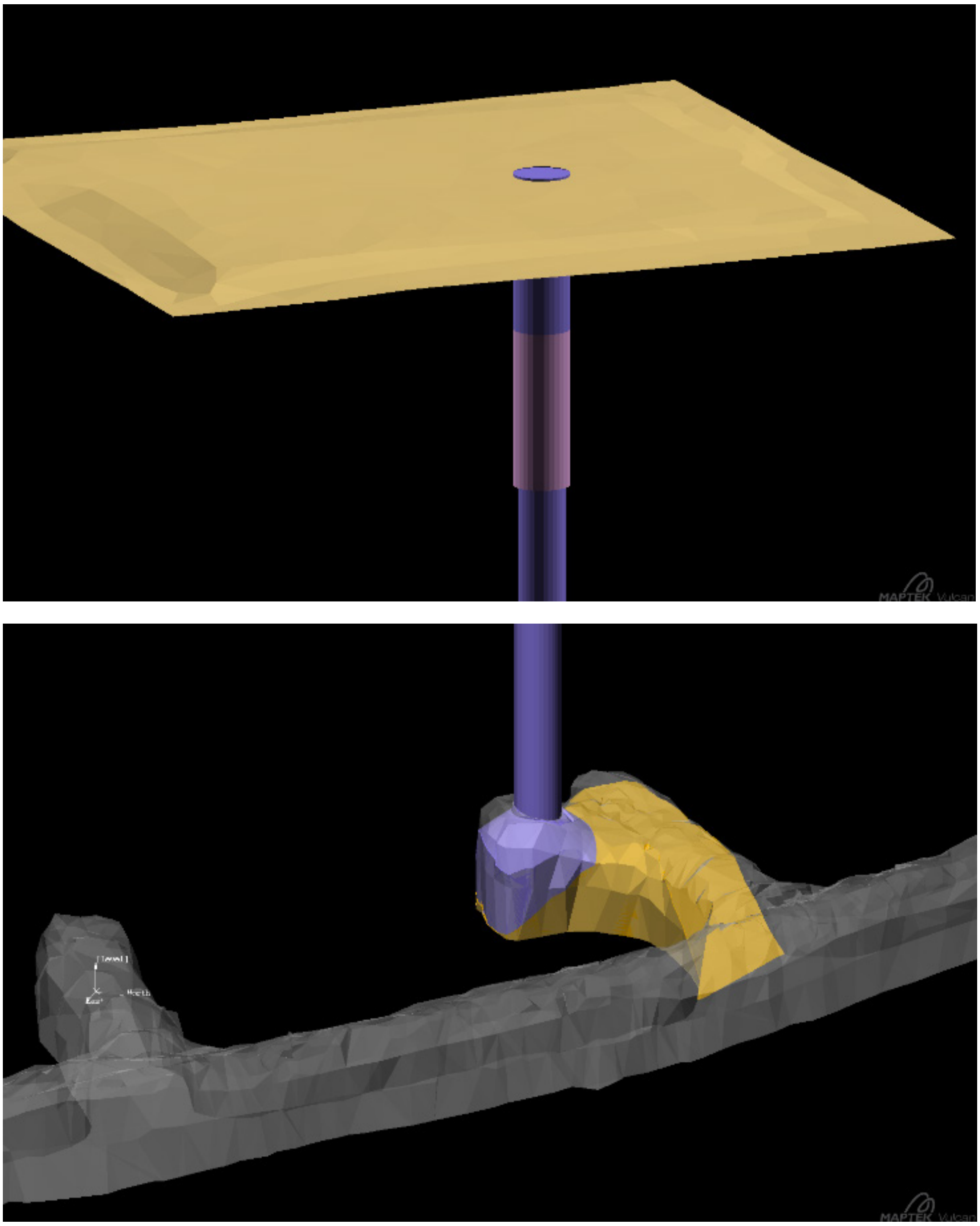

Figure 9-58: Backfilled shaft with waste rock plug (orange), crushed waste rock (purple); cemented rock fill layer (pink) with a crushed rock "cover" for the last 20 m of the weathered zone; and, concrete collar removed

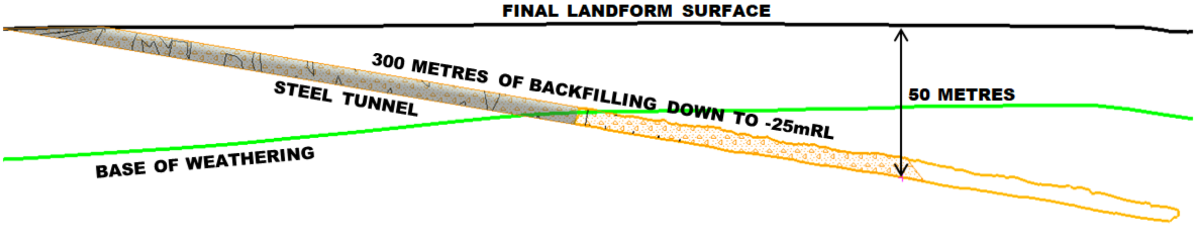

Figure 9-59: Schematic of backfilling detail to below weathered zone

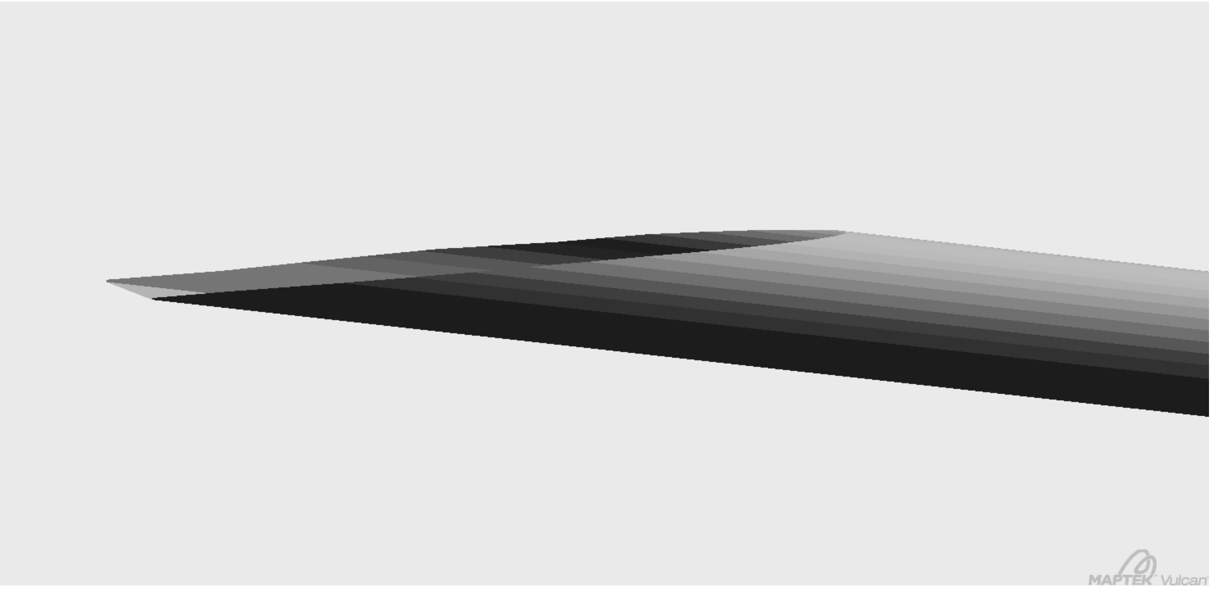

Figure 9-60: Dismantling and cutting gradient of the steel portal to ground level

Table 9-35: 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 boxcut was excavated; then a steel arched tunnel was constructed from the bottom of the boxcut back to ground level (Figure 9-61). The boxcut was progressively backfilled with sized waste rock and boxcut material. When the boxcut was excavated groundwater was intersected 6 m below surface at 17 mRL.

Figure 9-61: Boxcut and portal, completed in December 2012

The schist is foliated and jointed, giving rise to a blocky structure. Figure 9-62 shows the anticipated wedge geometry of potential failure blocks in the first leg of the decline. 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). This decline ground support has a design life of a minimum of 20 years, so the chance of a significant failure before backfilling is undertaken is extremely low.

Long term, any unfilled sections of decline may start to fail. Blocks could fall out from the back (roof) and side walls. The failed material falls apart taking up 30 to 40% more volume than the *in situ* rock (simply because the broken pieces do not fit together as well and take up more room). Eventually the failure cannot continue because the void is completely filled with caved material. Any potential failure blocks are supported by the fallen material. This mechanism is documented in Brady and Brown (2014). If failure material is not removed the maximum height a progressive failure will propagate is determined by the bulking factor of the fall material and the volume of void available to be filled.

To determine the maximum height a progressive failure of the decline could propagate, a structurally controlled failure of the decline was simulated (Murphy 2018). A grid of failure surfaces was generated using structural mapping data for the first leg of the decline. A maximum possible failure was propagated in 10 logical steps. A bulking factor of 30% was applied to the fall (cave) material. After 10 failures, the available void was effectively zero and the failure could not propagate any further. Figure 9-63 shows the failure grid that was applied (decline profile grey, ultimate failure profile shown in black), and the 10 failure surfaces and the 10 cave material surfaces.

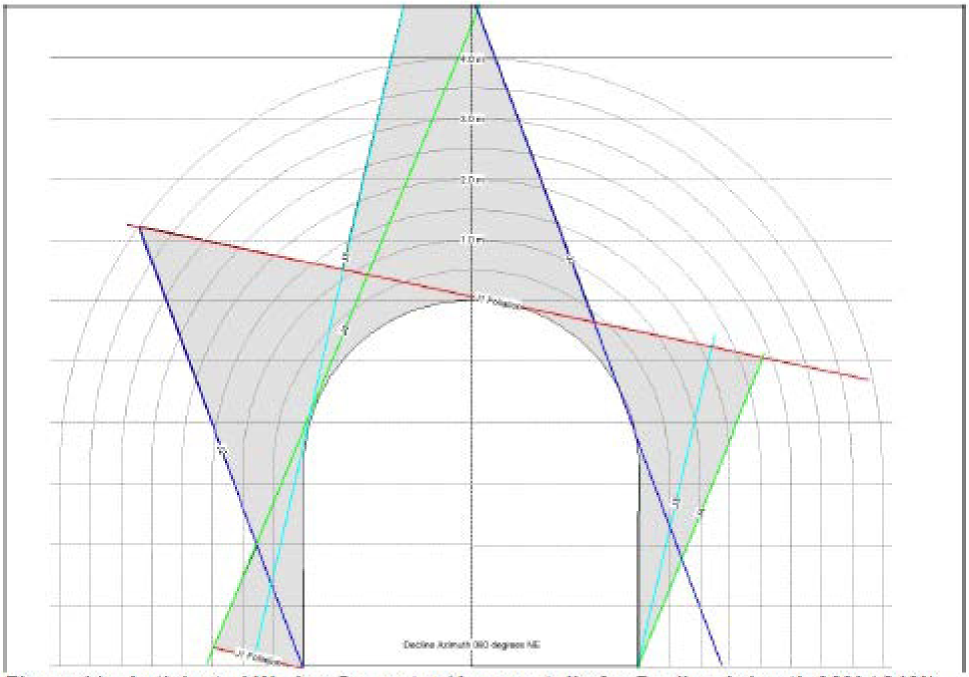

Figure 11: Anticipated Wedge Geometry (Apparent dip for Decline Azimuth 060° / 240°)

Figure 9-62: Potential structurally controlled wedge failures (ERA GCMP 2017)

The bulking factor of 30% is conservative. The weathered schist at the Ranger Mine has an *in situ* specific gravity of 2.6 t/m^3 and the bulk density of weathered material on the stockpile is 1.7 t/m^3. The bulking factor is about 40% and so the failure height would be reduced by around 5 m compared to the 30% case.

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. The shaft goes through some fairly weak zones and is it reasonable to expect that over an extended period of time that if left unfilled the weak areas would eventually fail. The shaft is vertical so the volume of void available for fall material is the volume of the shaft and the rill area at the shaft base. The only way to guarantee the long-term stability of the shaft is to completely backfill it and the rill area at the base of the shaft.

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).

9.3.9.4 Contingency planning

The closure of the Ranger 3 Deeps decline is well advanced and so no contingency plans are required.

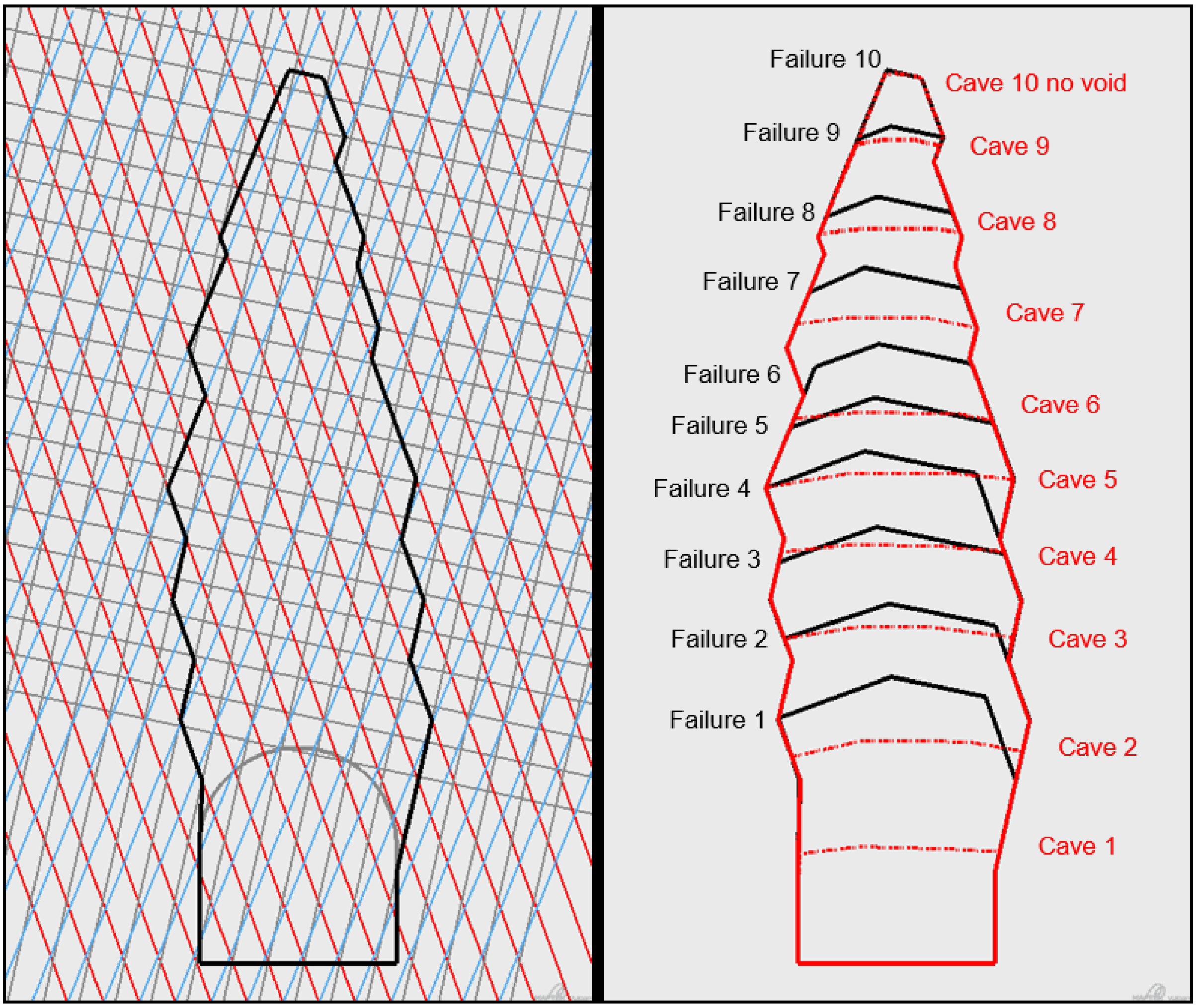

Figure 9-63: Cross-sections of decline and possible ultimate progressive failure. The left picture shows the rock structure for the first decline leg and the right picture shows the progression of failures and caved material height

9.3.10 Miscellaneous

9.3.10.1 Gagadju Yard

Figure 9-64: Gagadju Yard (May 2019)

Completed rehabilitation

There has been no rehabilitation of this site.

Current rehabilitation

There is no current rehabilitation activity at the site.

Planned rehabilitation

Infrastructure 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 Gagadju Yard , other than remedial revegetation works if required.

9.3.10.2 Ranger Mine Village

Figure 9-65: Range Mine Village (May 2019)

Completed rehabilitation

The contactor camp, and nearby old workshop area, had all infrastructure and concrete removed. The accommodation and other demountable units were sold, where possible.

A 1.4 ha site was revegetated on the 24th and 25th of February 2020 (Figure 9-67). 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 different 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 was performed during a rainy period and no irrigation has been used in the area.

Figure 9-66: Ranger Mine Village area prior to planting (January 2020)

Figure 9-67: Rehabilitation site at Ranger Mine Village (June 2020)

Current rehabilitation

There are no current ongoing rehabilitation activities at the site.

Planned rehabilitation

The remaining infrastructure disturbance at the site will be rehabilitated in a similar manner 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.

9.3.10.3 Nursery / coreyard

Figure 9-68: Nursery and old core yard at Jabiru East (May 2019)

During 2018 and early 2019, ERA converted the old exploration area in Jabiru East into a nursery to support closure operations. 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.

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 post-2026 monitoring and maintenance phase. A base for the completion of monitoring and maintenance of the site will be required post-2026, and the nursery and associated office area would be suitable for this purpose

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. ERA has legal obligations to keep certain core and this core material will be transported to Darwin for secure storage prior to 2026. All remaining core will be disposed to Pit 3 during the backfill operations.

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.

9.3.11 Magela Levee

Figure 9-69: Magela levee (May 2019)

Completed rehabilitation

No rehabilitation has been completed as the levee is still utilised for water diversion.

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 (Section 9.3.11.1) 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.

9.3.11.1 Borrow pits

Figure 9-70: Borrow pit for TSF lift

Figure 9-71: Borrow pit for Magela Creek Levee (May 2019)

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 TSF lift located at the proposed site for Retention Pond 5 that was not constructed (Figure 9-70)
- borrow pit for the construction of the Magela Creek levee (Figure 9-71).

The site of the old RP5 will be recontoured as part of the final landform for the corridor creek catchment.

The levee borrow pit will have levee material returned, recontoured 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.

9.3.11.2 Landfill sites and bioremediation pad

Figure 9-72: Temporary waste storage facility on the western edge of Pit 3 (May 2019)

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 to this 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 TSF;
- domestic waste landfills to the north of Pit 1; and
- temporary industrial waste landfill to the west of Pit 3.

Completed rehabilitation

Contaminated sites sampling of the historic landfills and the bioremediation pads were completed during 2019. Details of this are provided in Section 5.5.2.5. This information has been used to define a source term for inclusion into the whole of site groundwater solute transport model (Section 5.5.2.5). The results of this model are expected in late 2020 and 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 TSF, and the bioremediation pads will be finalised once the best technology assessments are completed and detailed included in updates to this MCP.

9.3.9.6.4 Contingency planning

No contingency planning is required for this site.

9.3.11.3 Explosives magazine area

Figure 9-73: Old magazine site (May 2019)

Completed rehabilitation

All explosives have been removed from the magazine and it has been de-registered.

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.

9.3.11.4 Trial landform

Figure 9-74: Trial landform (May 2019)

Completed rehabilitation

A 6 ha landform and revegetation trial was established in 2009-2010. Revegtation and faunal recolonisation trials continue to be undertaken on this landform as described in Section 5.5.4.

Current rehabilitation

Ongoing trials are underway on the 6 ha site to further establish understorey and improving the overall biodiversity and weed management.

Planned rehabilitation

The trial landform will be integrated into the final landform, requiring the removal of infrastructure and reshaping of edges.

Contingency planning

Appropriate weed and fire management will be implemented as necessary.

9.3.12 Airport

Figure 9-75: Jabiru airport (May 2019)

The airport at Jabiru East and other infrastructure, such as the Environmental Institute for the Supervising Scientist (ERISS) 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.

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, and from 2021, ERA does not intend to use the airport for its operations. 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. However, in the absence of an agreed plan, ERA will begin a process to close the airport some time in 2021, with rehabilitation likely to commence in 2024.

9.3.12.1 Completed rehabilitation

No rehabilitation has been completed to date.

9.3.12.2 Current rehabilitation

No rehabilitation is currently occurring on the site as it is still operating as an active airport.

9.3.12.3 Planned rehabilitation

Planning for removal of the airport is in the initial stages. A desktop assessment of contaminated sites will be completed in the coming year. This will determine if further sampling is required prior to completion of a best practical technology assessment of remediation options.

The airport tourist centre contains asbestos. Demolition will include provision for the removal of this asbestos for burial in Pit 3.

Demolition of the airport will include the following elements:

- removal of all infrastructure, either off site or burial in Pit 3 or RP2
- removal of the bitumen airport strip
- removal of security fencing
- remediation of contaminated sites, as required
- ripping of hard stand areas
- revegetation

The access road to the airport will remain to allow access to the ERISS and Telstra buildings.

9.3.12.4 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.

9.4 Closure activities

Closure activities are those that occur across multiple domains and, although referred to within domains, are discussed in detail within this section.

9.4.1 Contaminated sites

This section describes any generic information on the closure activities related to contaminated sites that is not presented within a specific domain. Section 5.5.2.5 presents details regarding contaminated sites studies. The following section relates to closure activities required as a result of those studies. Closure activities relating to LAAs, and potential contamination, are discussed in Section 9.3.4

The *Contaminated Land Risk Register* (ERA 2018) has been developed and is maintained by the site environment team at the Ranger Mine, in accordance with the operational *Hazardous material and contamination control plan* (Appendix 9.5). The *Contaminated Land Risk 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 Land Risk 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). Any new potentially contaminated land as a result of operational activities occurring after this review will be added to the *Contaminated Land Risk Register* by the site environment team and will be incorporated into closure investigations if required.

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.

In December 2019 and January 2020, a contaminated sites drilling program was completed. Targeted areas defined by the gap analysis were sampled as part of this campaign in April 2019. The areas identified as requiring further work included the:

- historical landfill
- emergency dump tank
- leaching counter current decanters
- former sulfur stockpile
- power station
- shellsol underground and aboveground tanks
- bioremediation pad
- TSF walls

Results from this drilling program, in addition to the knowledge base captured in historical investigations, the feasibility study and gap analysis, will be used to inform BPT assessments to determine what impacts will be considered as low as reasonable achievable for each contaminated site. A summary of this contaminated sites drilling program is summarised in Section 5.5.2.5.

An objective for closure is that, where needed, soils will be remediated to a level where their environmental impact is as low as reasonably achievable. The preferred option identified during the BPT assessment will be progressed whilst the other options then form the contingency plan, prioritised by rank. Outcomes of contaminated sites assessments will be included in future versions of the MCP.

Table 9-36 summarises the contaminated sites, grouped into major site areas, based on location, contamination risk and proposed remediation strategies. This table will be updated as BPT assessments and appropriate remediation, if required, are completed and will be detailed in future MCPs.

Table 9-36: Proposed management of contaminated land

Area	Sites included	Proposed Treatment	Further Work
Ranger Mine area			
Processing Plant	Processing plant area including all sites identified in processing plant area in Figure 5-89.	Remove surface infrastructure, a selective scrape of surface soil to be undertaken as determined by BPT assessments and place in Pit 3. Area to be backfilled with waste rock.	Ongoing groundwater monitoring. Assessment of soil contaminant/s mobility and risk to key receptors. Refine groundwater source terms. BPT assessments undertaken to determine appropriate remediation approach, if required.
Tailings Storage Facility (TSF)	TSF and sumps	Remove all tailings, thereby reducing head pressure of groundwater plume under the TSF. Contaminated natural ground below the TSF to remain in-situ post closure.	Further work required to determine if groundwater remediation is required to protect environmental receptors post closure. Ongoing monitoring to support further assessments including source term development for post closure groundwater modelling and remediation options assessment. Remediation options to be assessed through BPT and the TSF deconstruction application.
Pit 3	Pit 3	All tailings and surface mill infrastructure, including hazardous materials and contaminated soil to be disposed of in pit, on top of a geotextile layer, and covered with waste rock.	Disposal of hazardous waste in pit to be approved through Pit 3 application approval. Waste remaining post-closure of the pit will be disposed of in RP2. A register is to be kept detailing material disposal of in Pit 3 and RP2. Standalone backfill plan required.
Stockpile area	Stockpile areas, mine maintenance workshop, mine washdown bay, historical landfill and dredge diesel unloading, storage, and pumping.	Workshop areas (including washdown bay, diesel unloading, storage and pumping) will be treated similar to the processing plant area. Area to be covered in waste rock. Remainder of stockpile area requires no additional remediation.	Further sampling and BPT assessments required to determine an appropriate ALARA remediation approach.

Area	Sites included	Proposed Treatment	Further Work
Wetlands			
Ponds	SED2B, RP1WLF, RP1, RP2, RP3, RP1WLF-Sumps, RP6, Corridor Creek wetland filter network (six cells), Georgetown Billabong, Coonjimba Billabong	Currently assumed sites do not require scraping or waste rock cover. Surface infrastructure to be removed and sites to be left as is.	Further investigations required to confirm areas do not need to be scraped and covered with waste rock. Sampling required to confirm whether remediation is required for billabongs and RP1WLF. BPT assessments to be undertaken.
LAAs and Irrigation Areas	Magela A, Magela B, Djalkmarra East & West, Jabiru East, RP1 & RP1 Ext, Corridor Creek	Removal of all infrastructure (spray heads, pipework etc), remediation to be undertaken as determined by BPT assessments, revegetation as detailed in Section 9.3.4 with local native species.	Undertake BPT assessments to confirm appropriate remediation approach for each LAA, if required.
Other Infrastructure			
Infrastructure in Jabiru East	Underground storage tanks, exploration wash bay, septic tanks at Ranger Mine village, Gagadju workshops	Remove surface infrastructure and scrape of surface soil as required. Soil to be disposed of in pit.	Exploration wash bay will remain for duration of revegetation activities and to be removed following closure (ie post-2026).
Pit 1	Current domestic landfill, bioremediation pad, historic/decommissione d and buried industrial landfills, Tailings Dam pipe corridor.	Remove surface infrastructure, leave sites *in situ* as under final landform. Surface scrape Tailings Dam pipe corridor and place in Pit 3.	BPT assessments to be undertaken as required.

9.4.2 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 9.5)

ERA has identified that the following hazardous wastes will be onsite at cessation of ore processing activities (8 Jan 2021):

- 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-hazardous[5]) – 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 9-37.

Table 9-37: 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
TSF tailings (June 2019)	4.9 Mt
Estimated tailings produced in mill Jun 19 – Dec 20	1.27 Mt

[5] Current testing of samples indicates no significant radiation or contamination

Waste Material	Amount
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	
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
Tailings Dam (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 2023	40 – 50,000 m^3
Phase 2 demolition to RP2 H2 2025	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	

Waste Material	Amount
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

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. The following aspects were assessed:

- 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
- Ranger Conceptual Model (plant plumes)

The outcome of the assessment determined that revegetation was the most restrictive aspect for minimum depth of waste rock. This is associated with plant available water and rooting depth in waste rock.

9.4.3 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 minesite 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 early enough to allow for deconstruction of the water storage facilities prior to the closure of the RPA in January 2026.

ERA has completed water modelling using operation simulation modelling (OPSIM) which is validated annually by an external party. The Water Model defines the management of water until closure of the RPA. Assumptions in the model, as described below, form targets that must be achieved to meet the closure schedule.

Pond water treatment will continue with the existing water treatment plants discharging permeate to available wetland filters and LAAs until 2025. 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 9-76 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 February 2020 predicted a zero process water inventory before 2026 (refer Section 2.2.9.7). This water model assumes the following for future active process water treatment:

- The BC continues to be the principal route for process water treatment. Distillate production capacity in 2020 is 2.10 GL/a, rising to 2.53 GL/a in 2021 following the BC3 fan upgrade. BC treatment concludes in mid-2025 once all process water sources have ceased. As described in Section 9.3.2.3, 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. This HDS plant operates through to the end of 2022.
- The Brine Squeezer treats low salt process water resulting in 1.2 ML/d of release water. This reverse osmosis based treatment operates through to mid-2025.

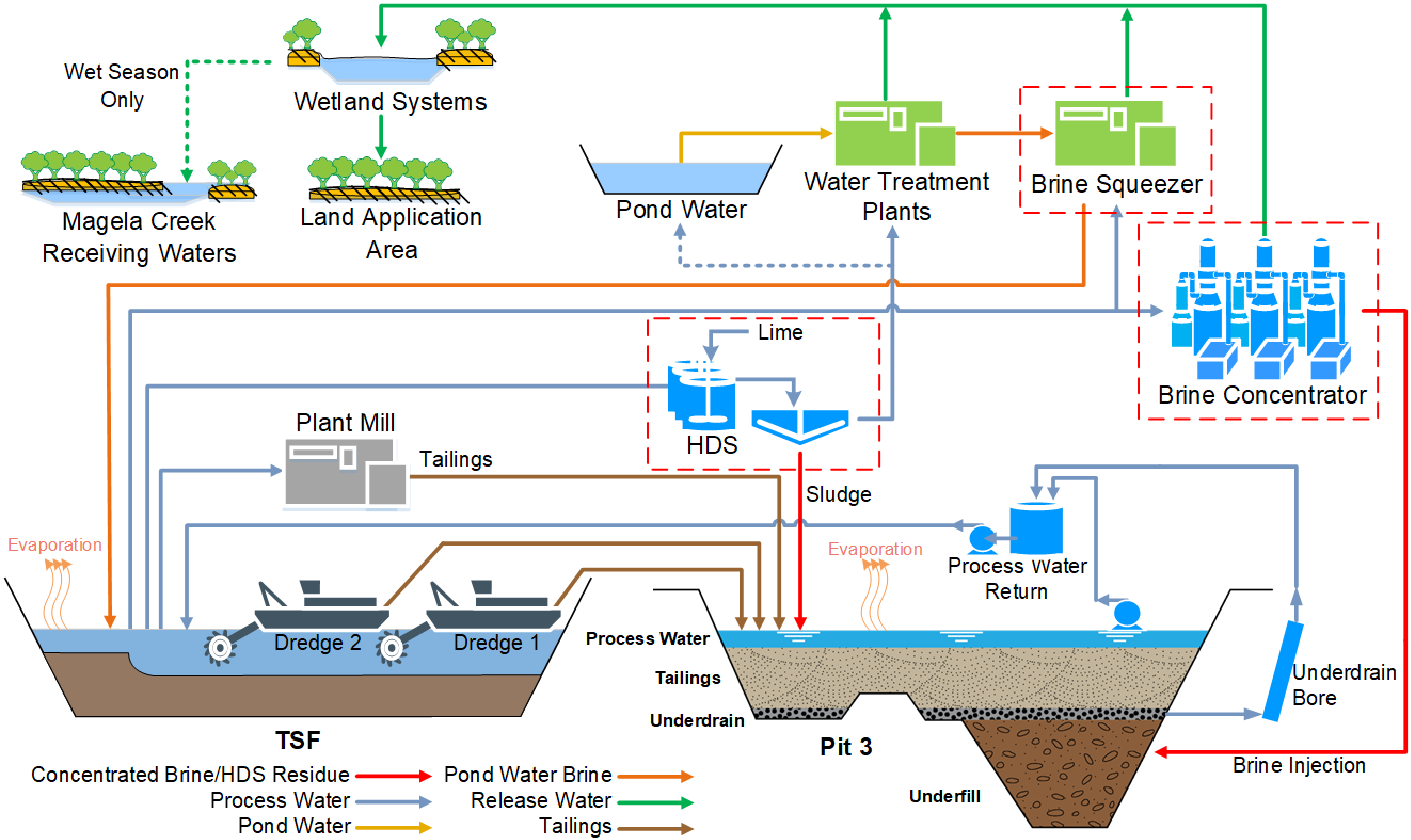

Figure 9-76: Process water flow diagram for the current water model

Note that under the current version of the site water model (February 2020), the assumed closure activity timeline may differ from what has been progressed with site operations. The process water inventory is actively tracked in situ, whilst the water balance model is updated regularly to provided references for future water treatment planning. The next version update is expected in August 2020. Additional water treatment facilities may need to be installed if the expected water treatment and inventory targets are not met, see contingency details in Section 9.4.3.6.

9.4.3.1 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.

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; details of the Pit 3 underfill and brine injection system have been provided in Section 9.3.2.1.

The BC draws its feed as follows:

- Prior to the end of tailings deposition: from the bulk process water inventory stored in either Pit 3 or the TSF.
- After the end of tailings deposition and prior to September 2021, when cleaning of the TSF is complete: from bulk process water stored above the tailings in Pit 3.
- After cleaning of the TSF and prior to August 2024, when process water is transferred to RP6: from bulk process water inventory stored in the TSF.
- After the transfer of process water from the TSF to RP6, until the free process inventory is zero: from bulk process water inventory stored in RP6.
- After the free surface process water inventory is zero, until the end of tailings consolidation expression (July 2025): tailings consolidation expression directly from the decant wells in Pit 3
- Water treatment plant brine directly from the Brine Squeezer
- Underdrain water directly from the underdrain bore

BC capacity is specified via the flow of product distillate. The BC initially had a distillate production capacity of 5.0 ML/d and has been slowly increasing through operational excellence programs. At data input cut-off for the MCP of end June 2020, the average BC distillate production was 5.4 ML/day.

The water management strategy requires the capacity of the BC to be increased to 6.92 ML/d. The increase in capacity is based on upgrading BC3 by installing a 2.1 MW vapour recompression fan, identical to the current fans of BC1 and BC2. Currently, BC3 is fitted with a 1.2 MW fan. The new fan is to be installed adjacent to the existing fan and tied into the existing vapour ductwork. The block flow diagram for the BC3 fan upgrade is provide in Figure 9-77: Block flow diagram for BC3 fan upgradeThe upgrade to BC3 increases recovered water production, which subsequently increases flows throughout most of the existing plant. Several existing items of equipment must be upgraded for these increased flows, including:

- most of the continuously operating pumps
- specific major process pipelines
- the steam system
- the electrical substation
- the power station and diesel generators

The BC fan upgrade has commenced with operation expected to begin in February 2021.

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. All sources of process water are expected to conclude by July 2025, and operation of the BC will then cease.

9.4.3.2 HDS Plant

The HDS plant was built in 2005 and overhauled in 2009. Plant operations ceased due to operability issues and with the installation of the BC. Subsequently, parts from the plant were re-purposed elsewhere on site.

The plant has recently been restored to its 2009 condition and ERA has obtained approval to operate the recommissioned plant with discharge of the product water to the pond water inventory. Provisional approval has also been obtained to direct the product water on to the pond water treatment plant 1 (WTP1) to complete additional test work on the product water quality. It is expected that the confirmation of this water quality will occur in the second half of 2020, with the permeate then being approved for release.

Subject to ongoing studies and the subsequent approval of a long term sludge disposal option it is planned to operate at approximately 2 ML/day of process water feed until such time as either it is no longer required to achieve inventory reduction or plant demolition is required to maintain the overall rehabilitation schedule.

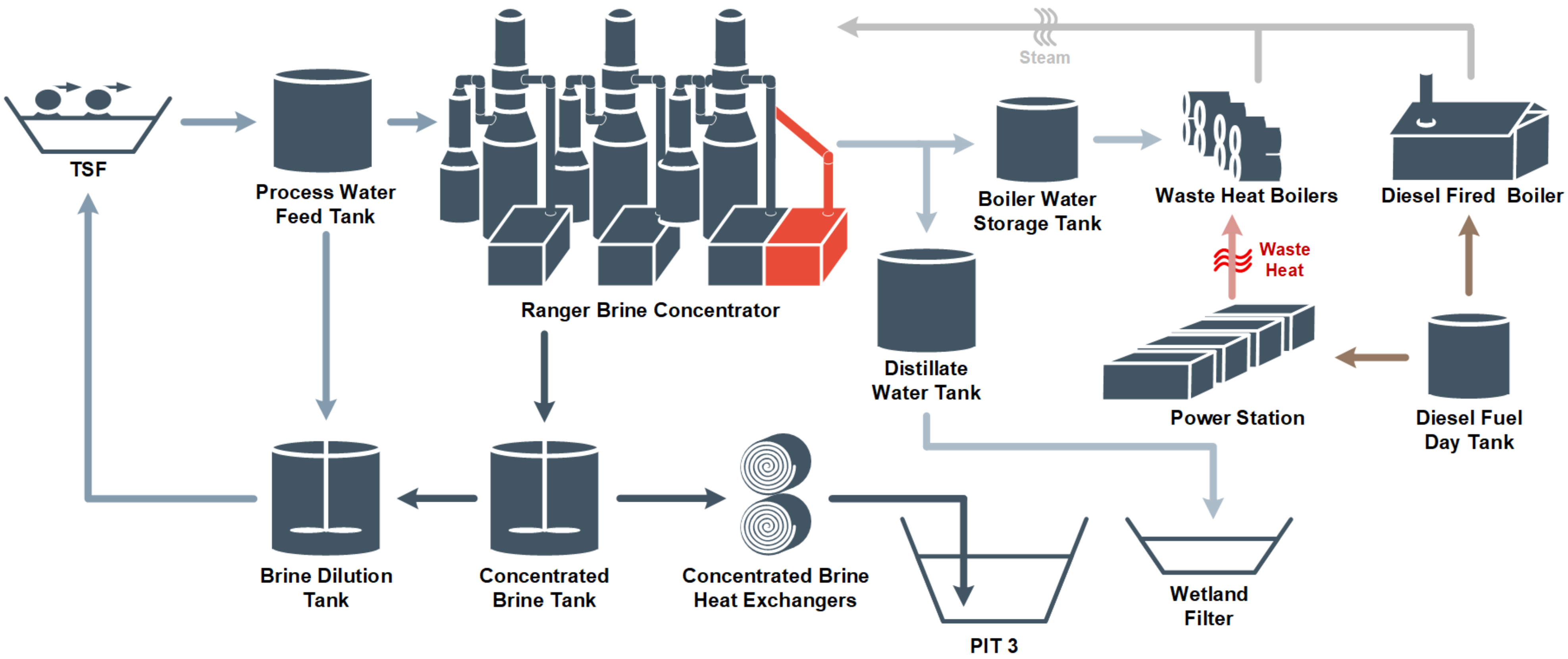

Figure 9-77: Block flow diagram for BC3 fan upgrade

The HDS plant treats process water, through to a water quality similar to pond water, through two processing stages (Figure 9-77Figure 9-78). 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.

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.

The combination of the sludge from primary and secondary softening is discharged from the HDS plant into the processing plant neutralisation tank and then pumped to Pit 3 via existing mill tailings pipeline. Within Pit 3, the sludge will be co-disposed with mill and dredge tailings, 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. Treated water is discharged from the HDS 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.

When treating high salt process water drawn from the bulk process water inventory, the capacity of the HDS plant is limited by the rate at which solids can be settled and separated from solution in the primary thickener. The generation of solids within the primary softening part of the HDS process is directly proportional to the TDS concentration of the feed. The strategy to achieve the treatment rate required of the HDS plant, of 2 ML/d of process water feed, is then to limit the solids generation in the process by operating the HDS plant on low TDS process water.

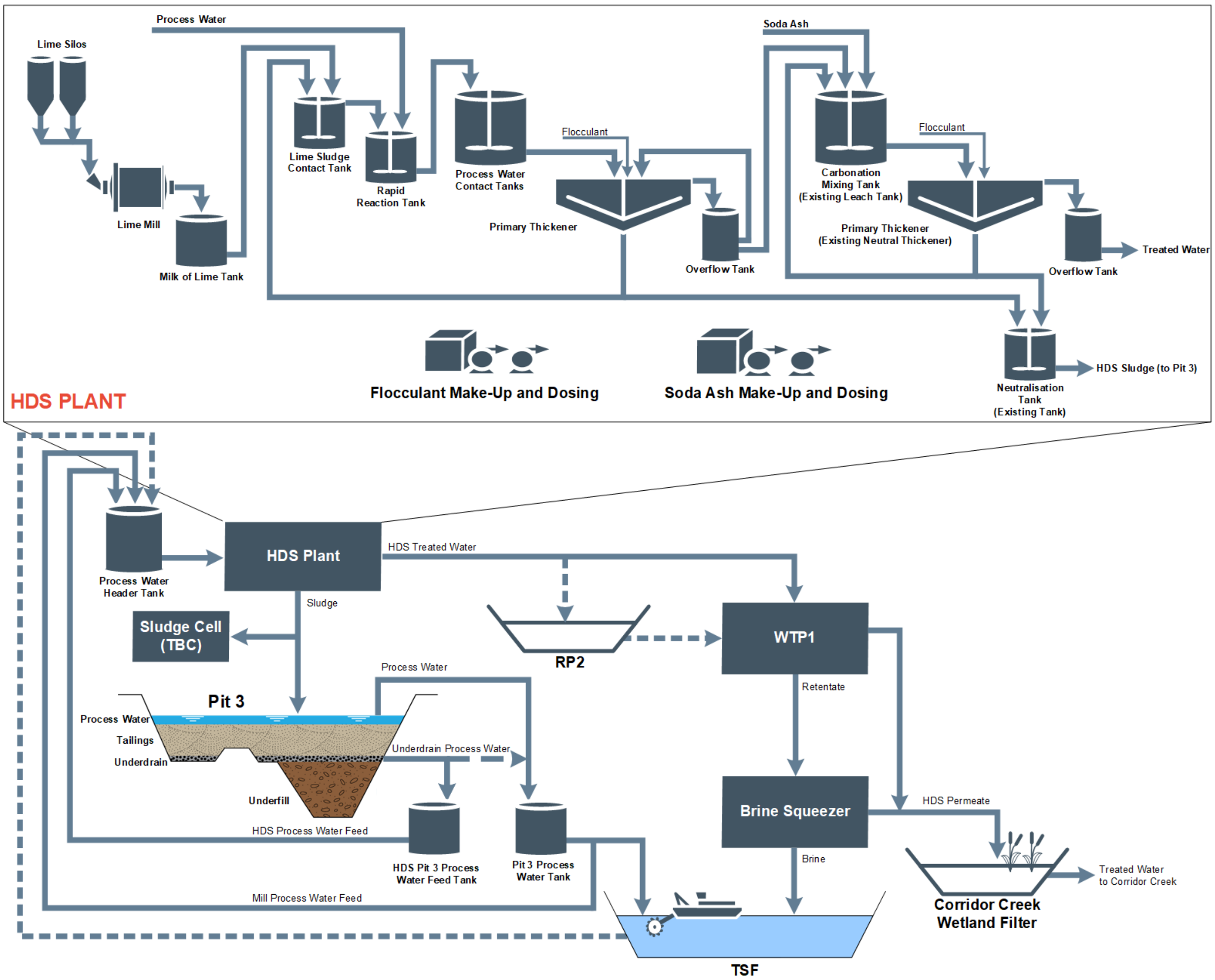

Figure 9-78: HDS Plant Block Flow Diagram

Initially the HDS plant will be fed with Pit 1 decant water, which has a lower salt content than the bulk process water inventory. That source is expected to be depleted in the second half of 2020, at which time the Pit 3 underdrain bore is expected to operational and will provide the lower salt water. When process water flow from Pit 1 or the Pit 3 underdrain bore is not sufficient to match plant capacity, the feed to the HDS plant will be supplemented with process water drawn from the bulk inventory in the TSF and Pit 3.

9.4.3.3 Brine Squeezer

The Brine Squeezer is a reverse osmosis style water treatment plant that further extracts clean water from the reject of pond water treatment (Section 9.4.3.4). 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.

The Brine Squeezer was constructed during 2018 and the first half of 2019, has been process commissioned and is awaiting the conclusion of performance testing when sufficient quantities of pond water, and thus pond water brine, are available in the 2020/21 wet season.

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 1.2 ML/d of release water to be generated from the Brine Squeezer (or a similar alternative treatment process) as a consequence of treating process water. This rate of release water generation is approximately the spare capacity of the Brine Squeezer after treating pond water treatment reject.

ERA commenced a continuous piloting and subsequently a full plant trial in the second half of 2020 to establish the capacity of the Brine Squeezer technology to treat a range of process water sources (of varied salt concentration and chemical composition). This trial will consider low salt sources of process water, such as that drawn from the Pit 1 decant or Pit 3 underdrain bore and also process water that has been subject to some degree of pre-treatment through the HDS plant, to remove metals that are problematic for reverse osmosis based treatment processes.

9.4.3.4 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 TSF, 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 final landform catchment is converted to release.

9.4.3.5 Schedule of progressive plans

The sequence for process water storage during the closure phase, with approximate dates, is provided in Table 9-38

Table 9-38: Sequence for process water storage

TIMING	TASK
January 2021	After tailings deposition has finished (post tailings transfer from the TSF to Pit 3 and mill operations), all process water will be transferred to Pit 3 to allow cleaning of remnant tailings solids from the TSF.
September 2021	Following the cleaning of the TSF, free process water will be split between the TSF and Pit 3. The volume in Pit 3 will vary to suit the requirements for the installation of wicks in the Pit 3 tailings and the operation of the barge for hydraulic placement of the initial Pit 3 cap. The balance of free process water will be stored in the TSF.
October 2022	On completion of hydraulic placement of the initial Pit 3 cap, all free process water in Pit 3 will be transferred to the TSF, to allow for bulk material movement to backfill Pit 3.
August 2024	Once the free process water inventory has sufficiently reduced, free process water will be transferred from the TSF to RP6.
July 2025	The free process water inventory will have been drawn down to zero.

Figure 9-79: WTP 1 – reverse osmosis membranes

9.4.3.6 Contingency plans

The final volume of process water that will require treatment prior to the end of closure 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:

- extend the operation of the HDS plant post-2022
- purchase a second Brine Squeezer and/or
- construct and operate additional evaporative plant

There is potential for rainfall scenarios to exceed the capacity of the above contingencies, particularly a significant rainfall occurring late in the closure phase. Should this occur, the identified contingency would see water treatment extend following closure. It should be 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, see Section 9.3.2.1.

Extend HDS plant operation

HDS plant operation is constrained to the end of 2022 due to the availability of Pit 3 as a sludge disposal repository. HDS plant operation can be extended by one year to the end of 2023 if an alternative sludge disposal repository can be identified, without impacting other closure schedule activities. Such an extension in operations could add over 1 GL of additional capacity for process water treatment.

Operation of the HDS plant post-2023 would impact mill demolition requirements, due to the HDS plant requirement for use of mill infrastructure such as the lime silos and lime mill.

Studies on options for HDS sludge disposal post-2021 are underway. It is possible that a suitable sludge disposal option will not be identified, in which case the extension of HDS plant operation will not available as a contingency.

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, and an implementation plan. The plan must include the trigger for proceeding so as to optimise evaporator impact on process water treatment in the closure phase.

Post-closure water treatment

Should a number of higher than predicted wet seasons occur, in particular late in the closure project, additional water treatment capacity may be required in order to meet the final closure date in January 2026.

In the case of a very large late wet season, ERA may not be able to treat all the process water prior to the final closure date. In this case an application would be submitted to the MTC requesting that water treatment infrastructure, including ponds, be allowed to remain on site for a period to allow for completion of this treatment. This would be requested under the current Clause 2.3 of the Environmental Requirements (ERs).

> *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.*

9.4.4 Bulk material movement

The bulk material movement (BMM) plan was updated in the Feasibility Study. It included the movement of all waste rock to final destination and the construction of the final landform. Specific details of the closure plan for Pit 1, Pit 3, TSF deconstruction and the final landform are presented within the specific domains in the implementation section above. This section provides the overall material movement plan.

The BMM activities will be executed after tailings has been transferred from the TSF 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 Section 9.3.2.3.

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 the correct section of Pit 3 and that the Pit 3 backfill is not ramp constrained.

Mining of stockpiles for Pit 3 filling and final landforms is scheduled to commence in October 2022. Mining material from stockpiles and the TSF is planned to be completed in September 2025. The final landform construction will be an ongoing process commencing March 2023 to enable areas to be released progressively for revegetation. This will enable revegetation works to be completed by the completion of closure milestone (8 January 2026). Using predominantly excavators and trucks, a total of approximately 96 Mt of material will be moved.

The BMM plan excavates areas above the final landform (stockpiles and TSF) when there is nearly 100 percent acceptable material for the final landform. 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 9-81 and Figure 9-82 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 bulk material movements achieved monthly in the closure mine plan are shown in Figure 9-80.

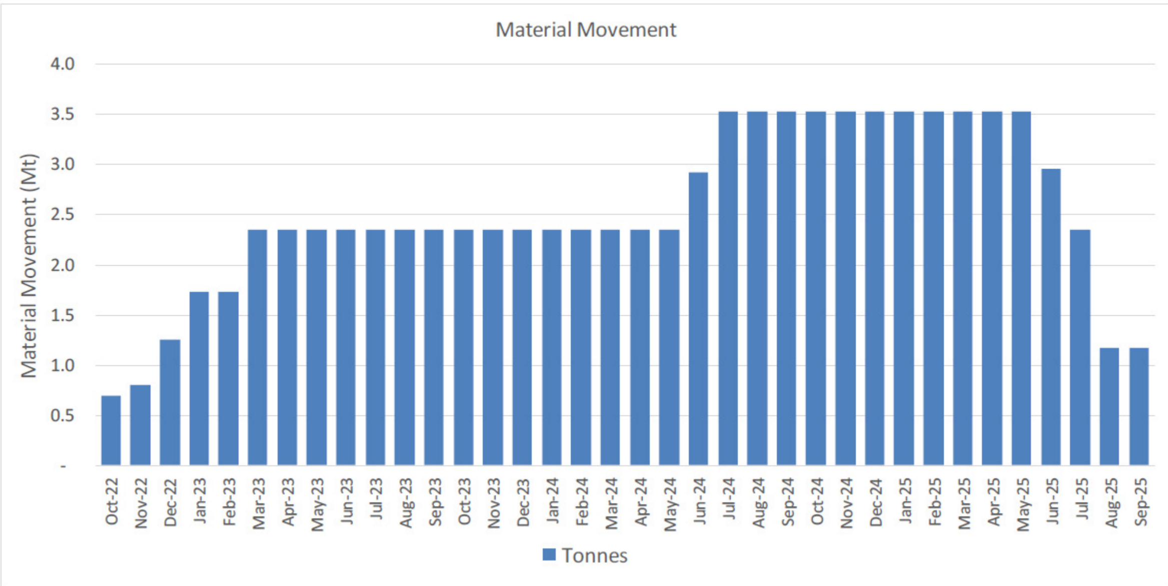

Figure 9-80: Bulk material movement scheduled monthly rates

The ramp-up in October 2022 to February 2023 reflects slower placement rates for Pit 3 secondary capping placement. The increase from June 2024 reflects additional work-fronts established at the TSF. There is a ramp-down in production from June 2025. The production plan was optimised for minimising peak mining equipment and for achieving the required rate of handover of final landforms to the revegetation contractor.

Further details are provided in Section 9.4.5**,** which together provide a summary of the BMM and final landform timing.

The materials placement production is shown in Figure 9-83. The designation surface is areas other than Pit 3, TSF or the stockpile areas. An increase in productivity is required from June 2024 to accommodate TSF works and achieve required progress for final landform handover.

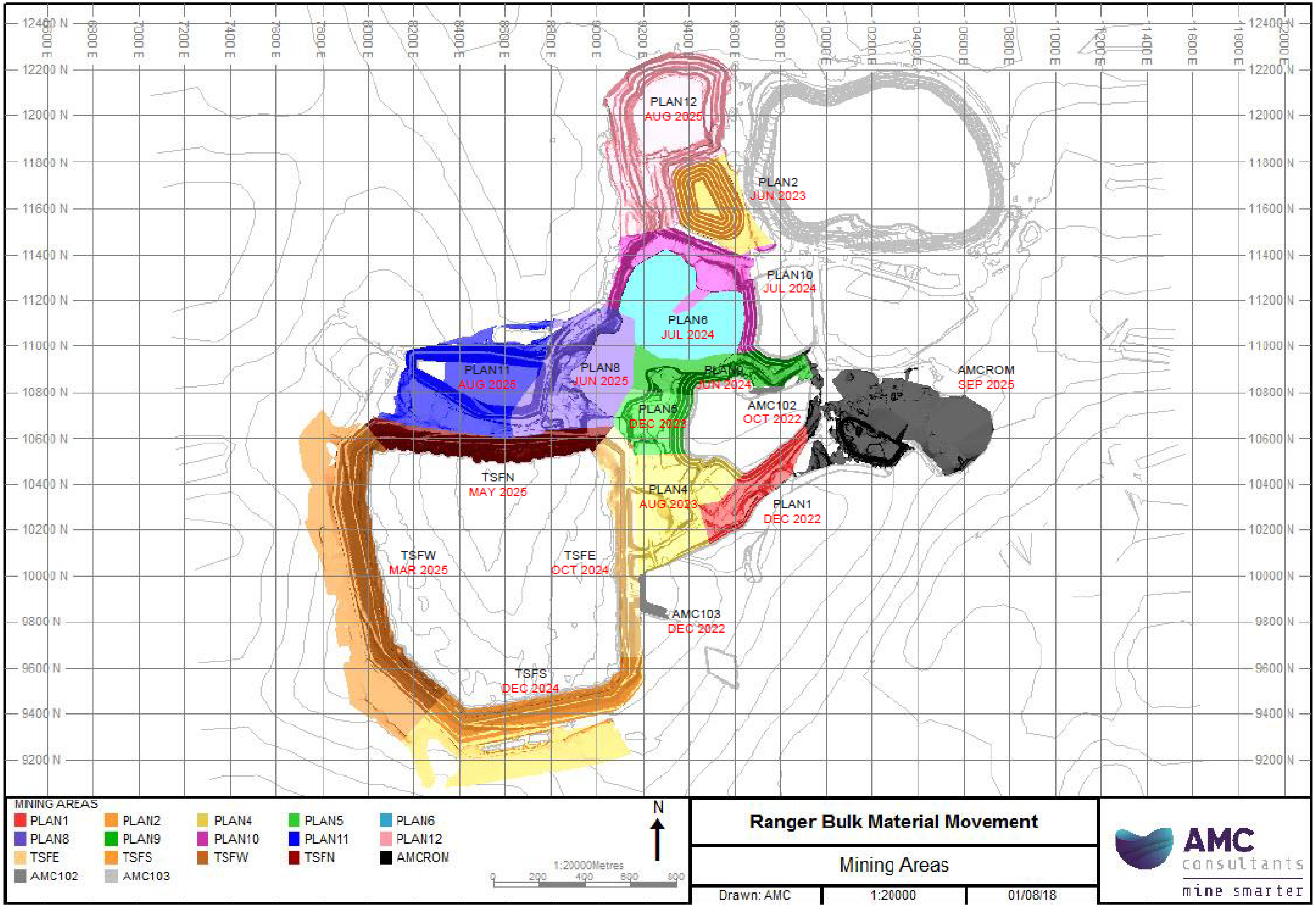

Figure 9-81: Material movement excavation areas

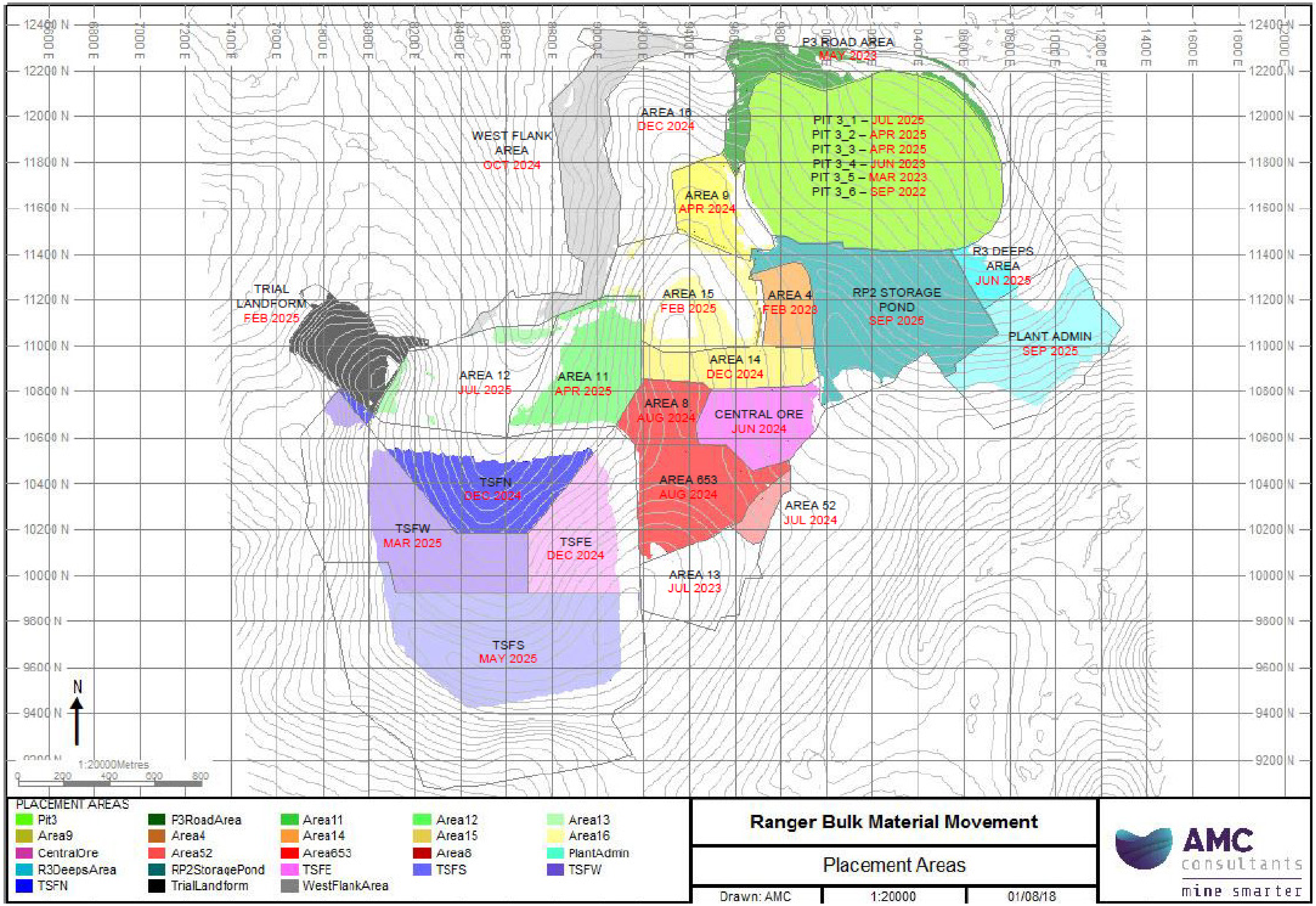

Figure 9-82: Material movement placement areas

Table 9-39: 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**

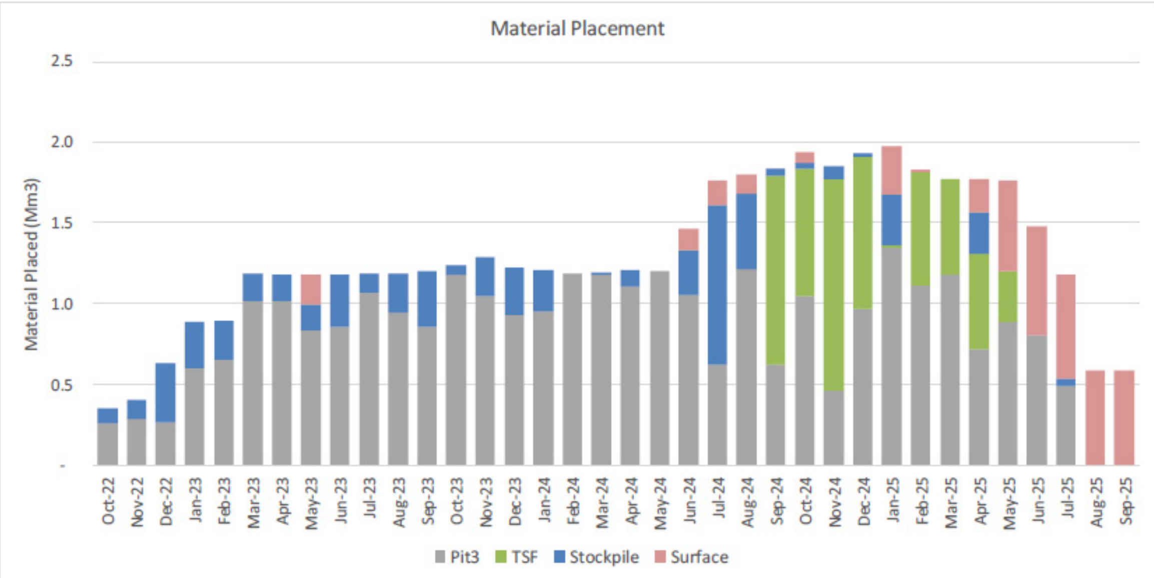

Figure 9-83: Bulk material placement rates

The location, quantity and grade of material in each stockpile is provided in the block model. The current mine plan influences the closure mine plan for location and quantity of stockpiled material forecast to be in place at the start of closure works (after December 2020). Current mining activities are taking place in the southern end of the stockpile area, with material being transferred to the Run-of-Mine (ROM) area to be fed to the mill for processing.

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. The uranium oxide ranges present within the stockpiles are detailed in Section 2. 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 9-84. The majority of mineralised material is in the southern stockpile areas. Mineralised material stockpiled for processing will be processed prior to commencement of closure. The majority of non-mineralised material is in the central and northern stockpiles as well as within the TSF walls. Non-mineralised material is present in the southern stockpiles as well, as confirmed in the block model.

All mineralised material will be placed below final landform surfaces. 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. The discrimination plan is reflected in Section 9.4.5.1. 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 TSF 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.

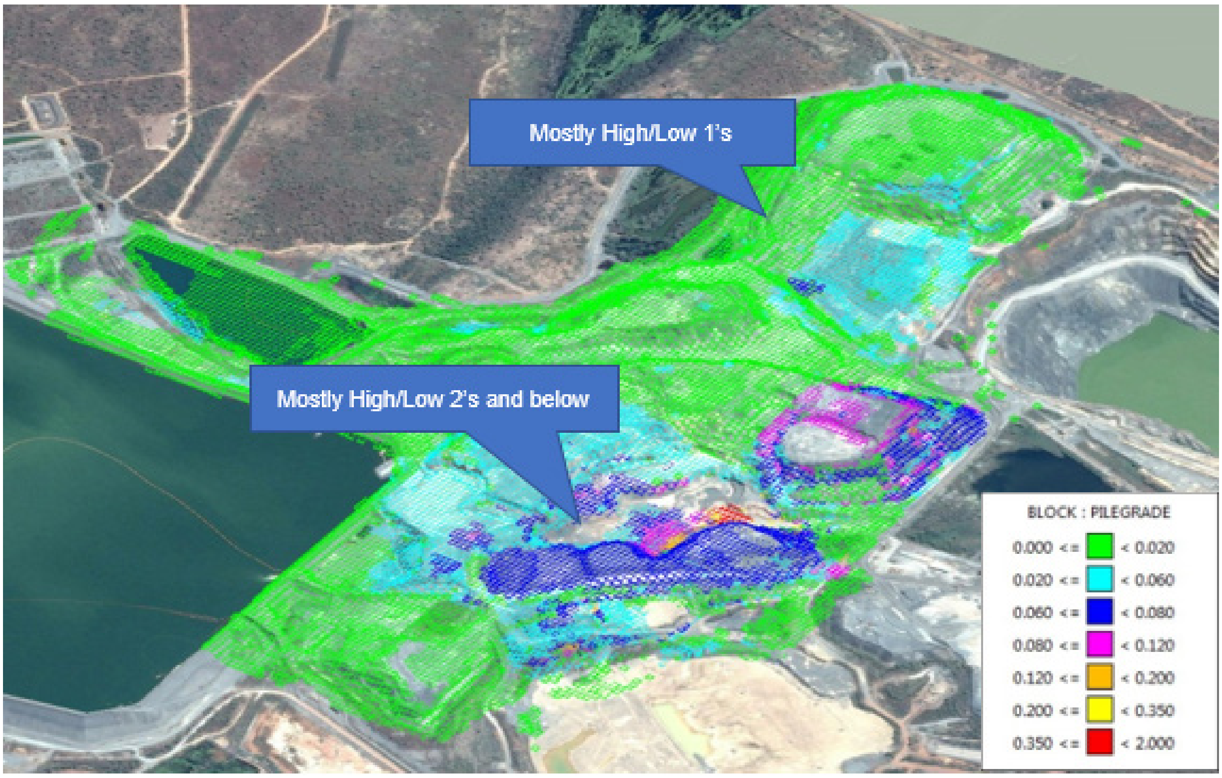

Figure 9-84: Stockpile material grades variance

9.4.5 Final landform / Surface preparation

The final landform is an area, and could be defined as a domain rather than a closure activity. However, it has been included within the activities section, and each of the rehabilitation steps (such as erosion control) will apply to the separate domains. The area of the final landform will be 795 ha. A figure of the boundary of the final landform is provided below (Figure 9-85)

During the closure feasibility study, the final landform topography was updated (to create Digital Elevation Model (DEM) Version FLV6.2) and included progression of the following aspects from the prefeasibility study design:

- material balance for closure works (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. Figure 9-86 and shows the proposed final landform topography.

Figure 9-85: Final landform boundary

Figure 9-86: Final landform topography contours on current aerial photo

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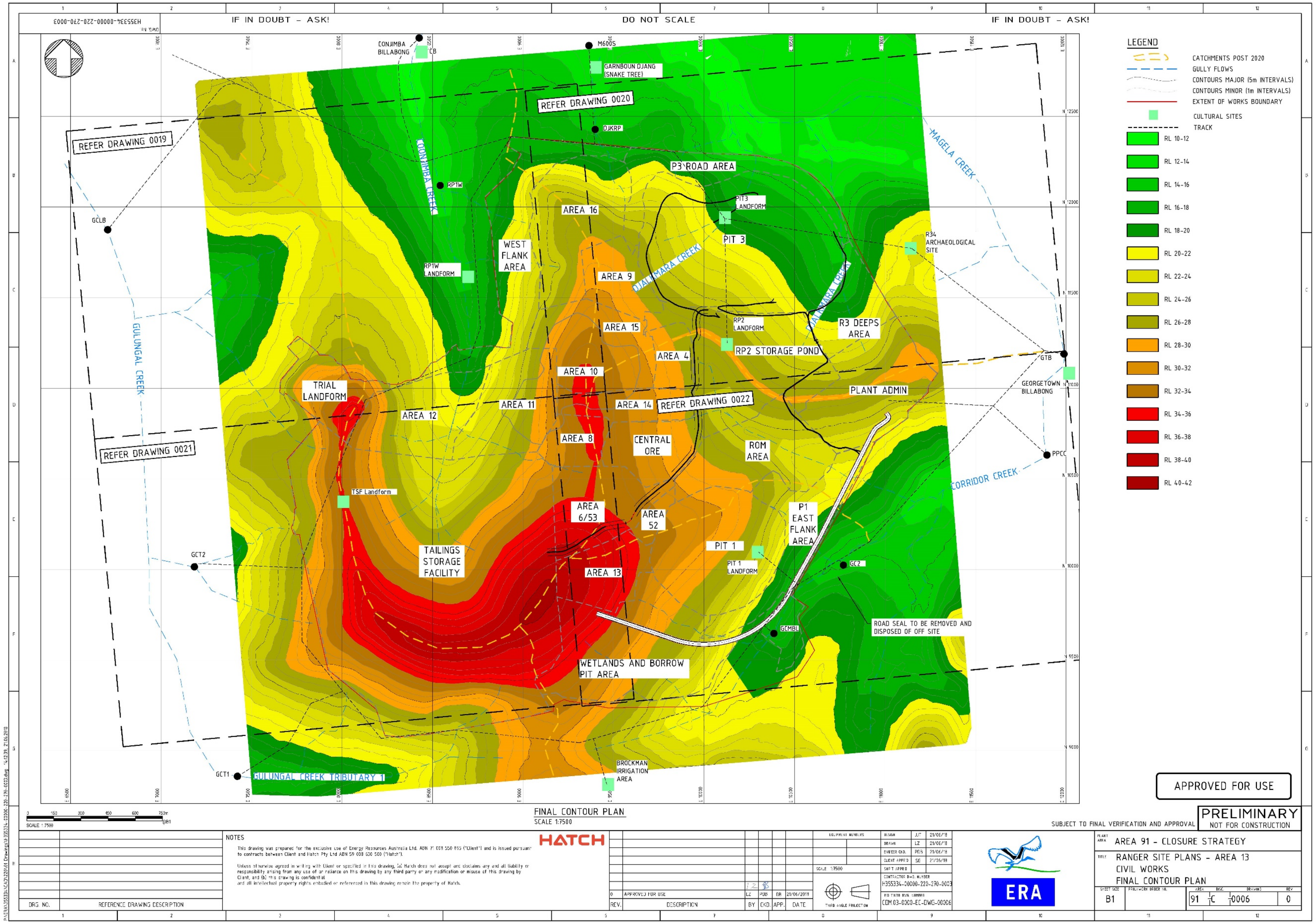


Figure 9-87: Final landform contours

9.4.5.1 Source of waste rock for surface layer

The surface layer of the final landform will be constructed as 1s waste rock (non-mineralised) to ensure that radiation doses are as low as reasonably achievable.

The results of an extensive drilling program in 2008 allowed a block model of the stockpiles to be developed and identified non-mineralised 1s material in several locations in the stockpiles (Section 9.4.4). 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 (Vulcan and XPAC) have been used to schedule 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.

The use of grade 1 material (<0.02 percent U_3O_8) for the Pit 1 final layer will be confirmed using both the stockpile grade block model and truck load gamma analysis via a discriminator (ERA & ELA 2018). Discrimination of every load will occur in specified locations such as the ore stages. Discrimination of every 50 loads will occur in large areas of 1s material where it can be unequivocally demonstrated in the stockpile model that these stages are non-mineralised material. Additional controls include strictly enforced communications and the implementation of the special areas bounded by no-go stakes. Checks of the Tritronics database and reconciliation against the predicted model grades, will also be completed. Any major portions of above grade fill materials detected will be excavated and redirected to the correct location.

ERA will include in its routine operational records, information on the general source and destination locations of surface layer material. Other routine operation activities to be undertaken during construction of the final landform include surveying and mapping of the excavation and fill surfaces.

9.4.5.2 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 5.5.4).

The design and construction methodology for the final landform has been based on the studies outlined in Section 5. 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 needs 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 (Trial Landform). 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 physical characteristics of the source material will be assessed visually by the mining team during construction of the final landform cover. Methods for characterisation of waste rock for final landform construction will be refined during construction of the Pit 1 final landform cover and will be able to be applied to other areas of the final landform. Adaptive management for sourcing waste rock for construction will also be refined during construction of the Pit 1 final landform, and may include field assessment of physical characteristics, selective mining of stockpiles and selective placement of different waste rock types depending on the targeted location within the final landform cover.

The final landform will be constructed to achieve the final landform model, which was updated in 2018 during the Ranger Closure Feasibility Study (Digital Elevation Model (DEM) Version FLV6.2). Frequent surveying and GPS guidance will enable the design 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 consolidation 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.

9.4.5.3 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 and 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 (Appendix 9.3 and Figure 9-93). The key changes to the final landform design surface are summarised below:

- Flow paths are now diverted further from the Pit 1 region, which had previously raised concerns.

- 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.
- Modelling conducted with the inclusion of the sediment control structures demonstrated a reduction in velocities upstream.
- The 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. The 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 circumstance where the PMP was to occur.

The changes to the final landform design surface were incorporated into the final landform surface DEM Version FLV6.2. This 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).

The 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 detailed within this section.

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 significantly reduced. Several of these treatments are being trialled on Pit 1 to help inform the final measures. The treatments applied to the various areas of the final landform will depend upon a number of factors, including slope and location.

The two main surface treatments are revegetation and ripping. Revegetation is a critical action in reducing erosion from the site as the roots act to bind the soil together, the canopy helps intercept 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 (Section 9.4.6).

The current areas of the final landform identified as requiring ripping are shown in Figure 9-88. These were the locations of higher flow identified in the flood modelling completed during the Ranger Closure Feasibility Study. A ripping spacing of 3-4 m was chosen to allow the safe operation of a small excavator and all-terrain vehicles during planting. Previous examples of waste rock ripping are shown in Figure 9-89 and Figure 9-90.

Some shallow ripping of the landform surface is required to allow water to infiltrate and to 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 and the Gundjeihmi Aboriginal Corporation have indicated that ripping of the landform may impact traversibiilty, so it should be minimised wherever possible. To address these stakeholder concerns ERA is conducting a ripping trial on the Pit 1 landform (Section 9.3.1.3). The outcomes of this will inform the final landform ripping plan and will be included in subsequent MCP updates.

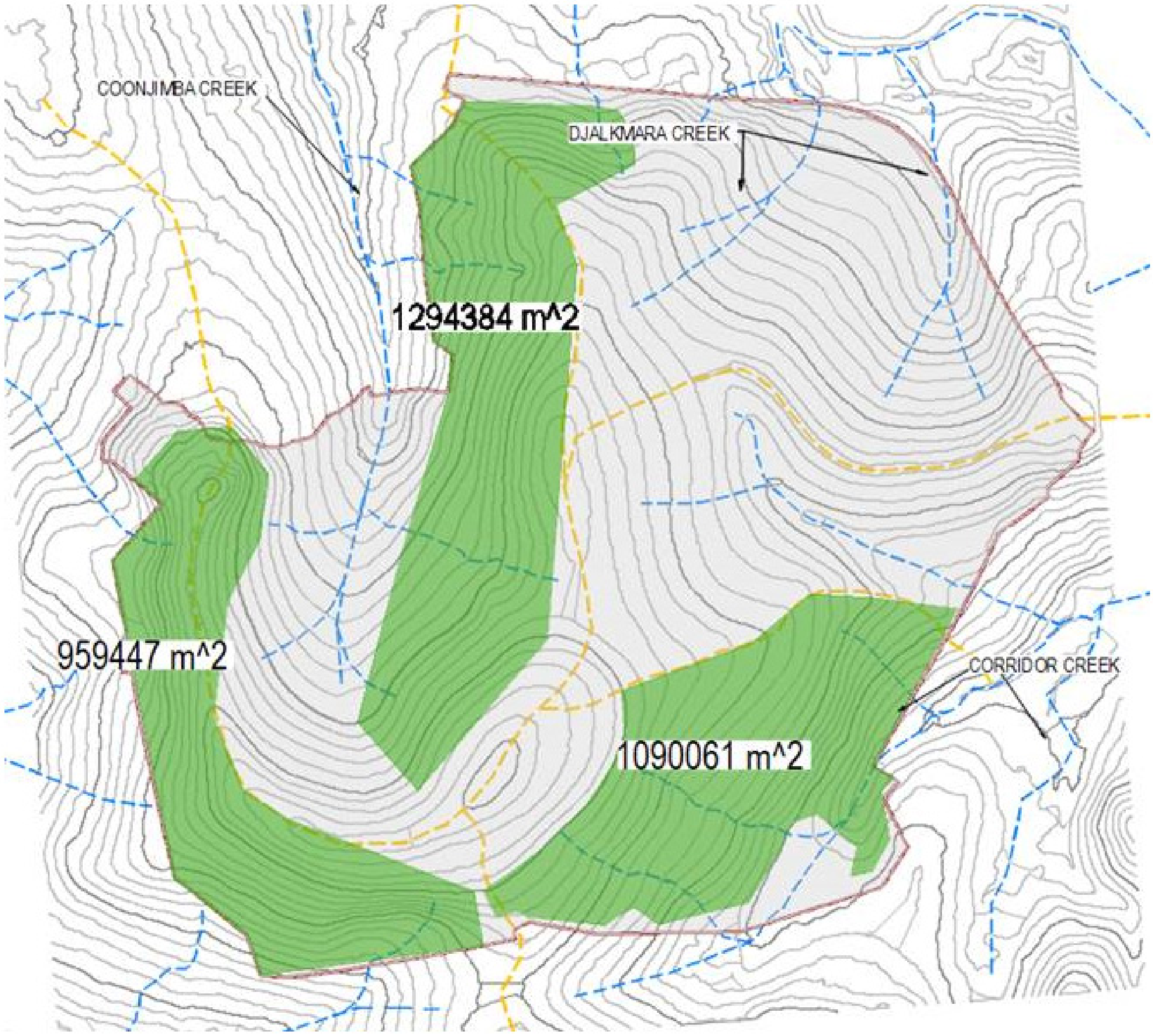


Figure 9-88: Footprint of final landform requiring contour ripping

Figure 9-89: Contour ripping on trial landform trial of 2m interval (2010)

Figure 9-90: 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 where 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 was made to ensure both edges are tied into the crest height level to ensure proper functionality.

The following catchments will have environmental rock bars:

- Coonjimba Creek (CJ) (four rock bars)
- Djalkmarra Creek (DJ) (three rock bars)
- Corridor Creek (CR) (two rock bars)

Environmental rock bars will be placed upstream of the main sediment control structure, as these are considered the major flow paths and are near key areas such as Pit 1, Pit 3 and the TSF. Figure 9-93 shows the location of each along with the storage data. Figure 9-91 shows the typical section for the environmental rock bars. Table 9-40 provides design details for typical rock bars.

Table 9-40: 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

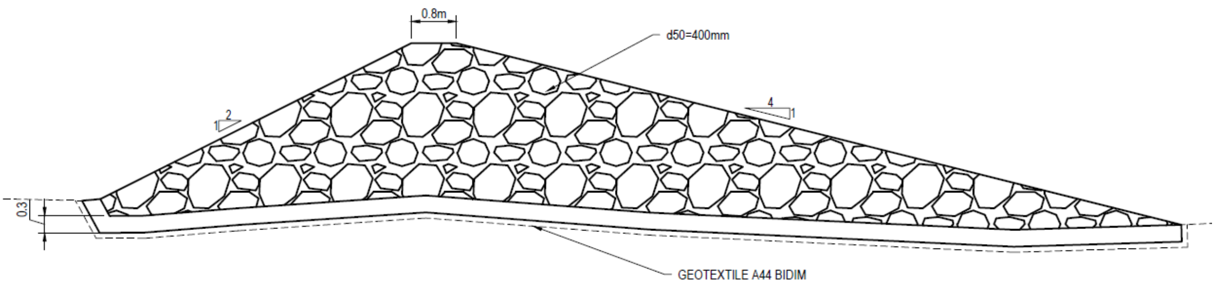


Figure 9-91: Environmental rock bars – section view

The general drawings of the environmental rock bars planned for installation on the final landform and provided in Appendix 9.2.

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 9-93 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 9-41 shown on Figure 9-92. The designs in these figures are typical for these structures.

Table 9-41: 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

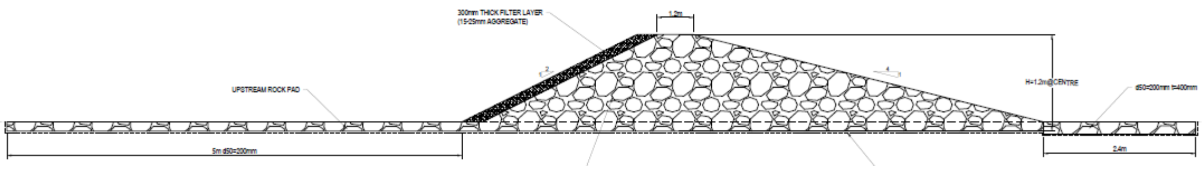


Figure 9-92: Boundary sediment control structure – section view

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 and provided in Appendix 9.2.

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

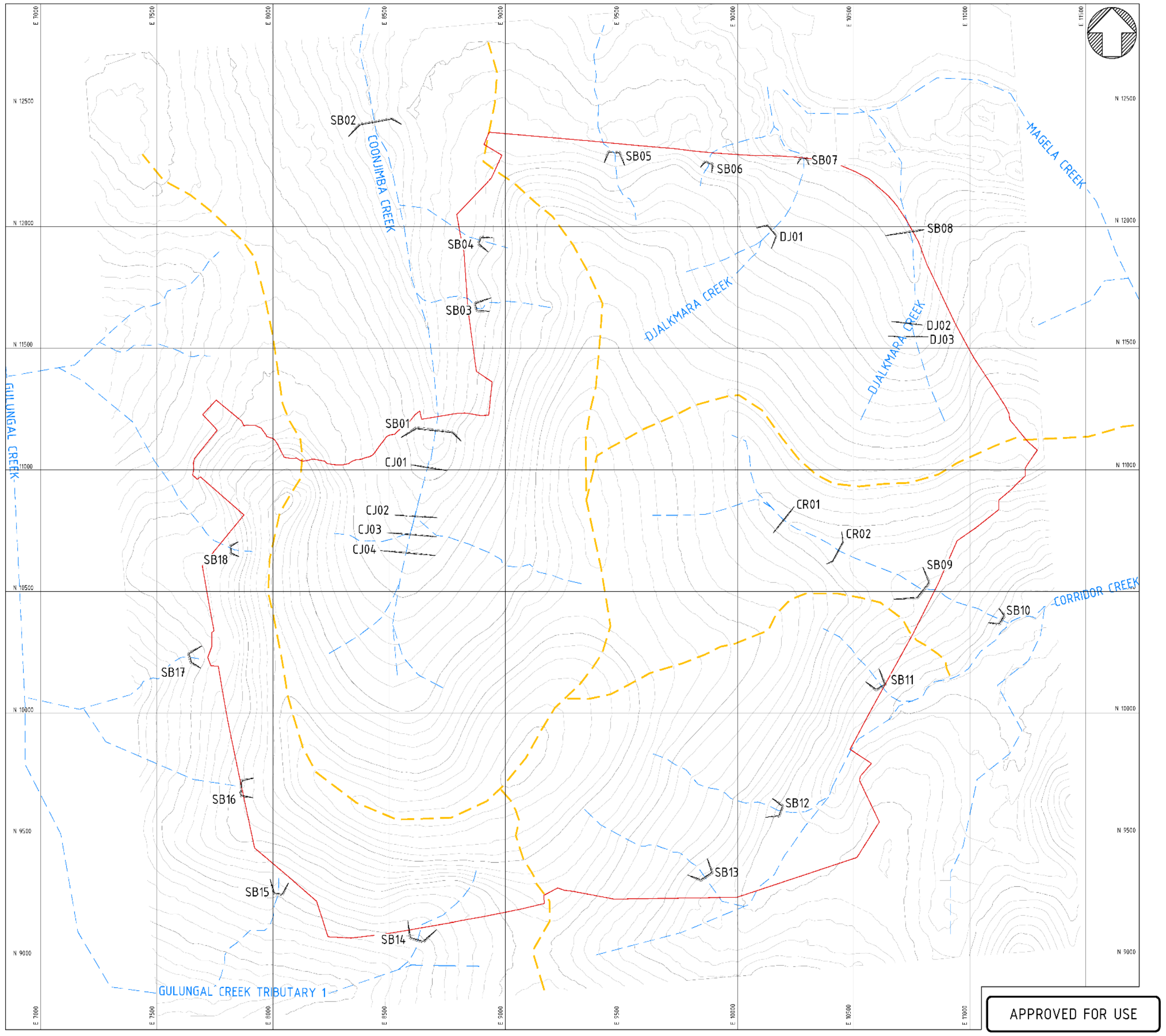
*ALL BOUNDARY SEDIMENT BASINS ARE 1.2M HIGH AT CENTRE. BASIN AREA AND STORAGE VALUES ARE THEORETICAL AS STRUCTURES DESIGNED AS LEAKY ROCK WALL (PERMEABLE).

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
- SEDIMENT BASINS (SB)
- ENVIRONMENTAL ROCK BARS



APPROVED FOR USE

CATCHMENT PLAN – FINAL LANDFORM
SCALE 1:7500

SUBJECT TO FINAL VERIFICATION AND APPROVAL

PRELIMINARY
NOT FOR CONSTRUCTION

HATCH

AREA 91 – CLOSURE STRATEGY
GENERAL – AREA 00
CATCHMENT PLAN
FINAL LANDFORM

DWG. No. H355334-00000-220-290-0048

Figure 9-93: Catchment plan for final landform with sediment basins and environmental rock bars

9.4.5.4 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 500-1500 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 are under consideration for trialling at Pit 1.

9.4.5.5 Access track installation

Revegetation Execution tracks

Revegetation execution tracks provide access for equipment and teams undertaking:

- irrigation installation and removal
- tubestock planting
- 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
- 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
- Traditional Owners to access the area, spend time on country etc. (Section 8)

9.4.5.6 Schedule of progressive tasks

The final landform construction of Pit 1 has commenced and is scheduled for completion in August 2020. The remainder of the final landform construction will not commence until March 2023 and will be ongoing to enable areas to be released progressively for revegetation (Figure 9-100). This will enable revegetation works to be completed by the closure milestone (8 January 2026).

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.

9.4.6 Revegetation implementation

Revegetation planning and implementation will be guided by the ERA revegetation 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 and tubestock production. 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 (herbicide application, irrigation installation, planting site cultivation)
- tubestock planting (hole digging, fertiliser application, planting, watering in and/or irrigation)

Post-planting monitoring and maintenance activities including ongoing irrigation management, vegetation monitoring, infill and understorey planting, weed, fire and feral animal management are covered in Section10.

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 over a five-year period. 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 1062 ha of land to rehabilitate and revegetate for the successful closure of the Ranger Mine, including 795 ha of waste rock covered area. Unless specified in the respective domain descriptions in Section 9.3 above, all areas shall receive the following standard revegetation treatment.

9.4.6.1 Revegetation domains and species selection

As described in detail in the Section 5, revegetation domains will be developed to reflect any physical and/or chemical constraints that may impact the type of revegetated ecosystem that is able to be re-established. These ‘revegetation domains’ will each have a suitable ‘agreed conceptual reference ecosystem’ identified, which will form the basis of the species list and target densities for revegetation planning and implementation (Table 9-42). Whilst the conceptual reference ecosystems are yet to be finalised, the intention is to revegetate the majority of the landform post mining with open eucalypt-dominated woodlands that have similarities to the native vegetation typical of the surrounding areas near Ranger and within Kakadu NP. In the meantime, a list of agreed tree and shrub species has been developed based on reference site monitoring, revegetation trials, and cultural consultation with Traditional Owners and forms the basis of current revegetation planning (Table 9-43).

Table 9-42: Information available for the major physical and/or chemical constraints.

Potential Constraint	Planning Information Source
Material type and relationships to plant water availability, rooting depth and so on	- The final landform design (currently v6.2) 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

Over 60 species are currently being considered for initially establishment as tubestock, with a nominal planting density of 1,000 stems per hectare to allow for attrition during plant establishment and subsequent ecosystem development. The vegetation establishment strategy, including more detail on target species, is described in the Section 5.5.4.

Other than species lists and plantings densities specific to the different revegetation domains, the revegetation execution shall follow a standard series of general steps as outlined below.

Table 9-43: Agreed tree and shrub list for Ranger revegetation

TREES	
Acacia aulacocarpa	*Grevillea decurrens*
Allosyncarpia ternata	*Grevillea pteridifolia*
Alphitonia excelsa	*Hakea arborescens*
Asteromyrtus symphyocarpa	*Lophostemon lactifluus*
Brachychiton diversifolius	*Melaleuca argentea*
Brachychiton megaphyllus	*Melaleuca cajuputi*
Buchanania obovata	*Melaleuca dealbata*
Corymbia bleeseri	*Melaleuca leucadendra*
Corymbia chartacea	*Melaleuca nervosa*
Corymbia confertiflora	*Melaleuca viridiflora*
Corymbia dichromophloia	*Owenia vernicosa*

TREES	
Corymbia dunlopiana	*Pandanus spiralis*
Corymbia foelscheana	*Planchonia careya*
Corymbia latifolia	*Stenocarpus acacioides*
Corymbia polysciada	*Sterculia quadrifida*
Corymbia porrecta	*Syzygium eucalyptoides* subsp. *bleeseri*
Elaeocarpus arnhemicus	*Syzygium eucalyptoides* subsp. *eucalyptoides*
Erythrophleum chlorostachys	*Syzygium suborbiculare*
Eucalyptus miniata	*Terminalia carpentariae*
Eucalyptus phoenicea	*Terminalia ferdinandiana*
Eucalyptus tectifica	*Terminalia pterocarya*
Eucalyptus tetrodonta	*Vitex glabrata*
Eucalyptus tintinnans	*Xanthostemon eucalyptoides*
Gardenia megasperma	*Xanthostemon paradoxus*
SHRUB / SMALL TREES	
Acacia difficilis	*Coelospermum reticulatum*
Acacia dimidiata	*Ficus racemosa*
Acacia hemignosta	*Gardenia fucata*
Acacia latescens	*Grevillea dryandri*
Acacia mimula	*Jacksonia dilatata*
Banksia dentata	*Persoonia falcata*
Calytrix achaeta	*Petalostigma pubescens*
Calytrix exstipulata	*Verticordia cunninghamii*
Clerodendrum floribundum	*Wrightia saligna*
Cochlospermum fraseri	
SHRUBS	**PALMS**
Grevillea goodii	*Livistona humilis*
Petalostigma quadriloculare	*Livistona inermis*

9.4.6.2 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 15 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 9-94. Area-specific revegetation plans, including required species stems per hectare, inform the tubestock and seed collection plans are derived, including inputs of knowledge (e.g. previous nursery performance & phenological traits of targets species within the target provenance zone) and data (e.g. seed lot testing results). 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, and modification of the collection plan to respond to any low collections and also 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 of seed, KNPS air dry the seed and process it until it is 'clean' of chaff and other material. ERA is accountable for final storage of the delivered seed and maintains the seed management database with all relevant information for each seed lot.

Seed may lose viability over time, and sub-optimal preparation or storage conditions risk accelerating this. Some species have seeds that will keep for many years (such as many Eucalypts) while some cannot be stored for long at all and should be used in the same year that it is picked (such as many native grasses). Seed collection strategies must take these storage timeframes into account to ensure that seed of the best possible quality is available when needed. Seed longevity in storage is highly dependent on seed moisture content and storage temperature. Seed picked for rehabilitation at Ranger is dried, packaged and stored in two secured, climate-controlled storage rooms to preserve seed quality and longevity.

The closure revegetation program is highly influenced by the timing of the rehabilitation schedule, especially the bulk material movement completion and handover process and the January 2026 completion deadline. Whilst some tubestock (and therefore seed) is required early for 2020/21 wet season planting of Pit 1 areas, the majority of planting will occur in the 2024-2025 (inclusive) period.

The majority of seed has a long enough longevity to be collected early and stored to be on hand when required. Collection of these species has already commenced and is progressing well. The plan is that these species should be fully stocked before the peak tubestock propagation and planting period commences.

Some seed, however, can only be used 'fresh' and these collections must be timed to optimise seed availability and time from planting. Whilst pro-active collection strategies and storage improvements aim to extend seed longevity, there remains a risk that 'fresh' 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 reconnaisance will ensure that collections tactics are primed for the instance when they are available and required, to make sure that targets can be achieved and quality is maintained. In addition to this, these species (especially those of particular ecological or 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
- propagation of tubestock from vegetative material (rather than seeds)
- 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.

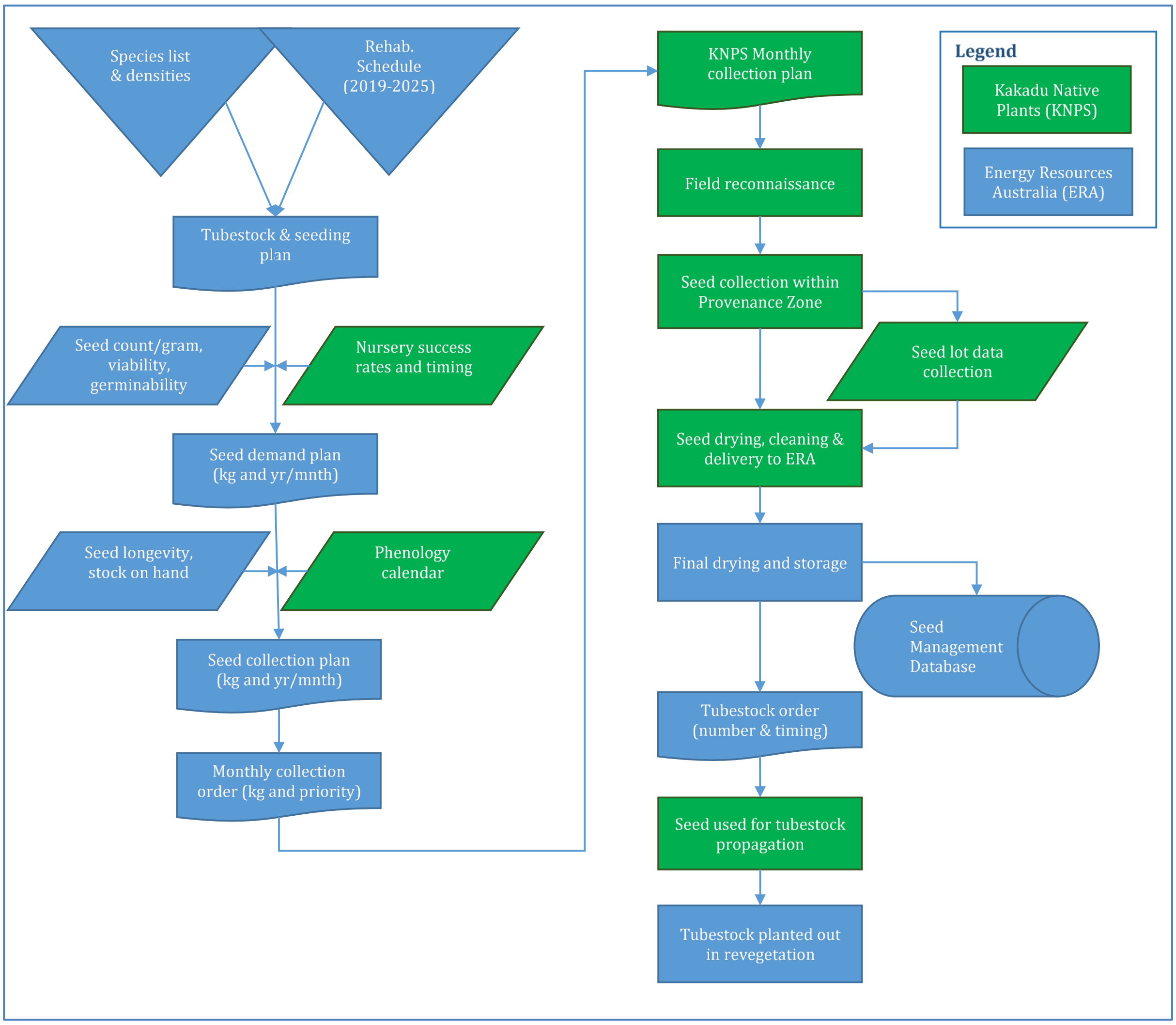


Figure 9-94: Flow chart of seed collection program

Tubestock propagation

Tubestock is propagated in the recently commissioned ERA Nursery near the current exploration yard, north of Jabiru East LAA. Current annual capacity is 250,000 seedlings which is more than sufficient for the 2020-2024 revegetation requirements. For the 2025 peak demand it may be necessary to temporarily expand the facility and/or engage additional, approved suppliers and options for this are being explored (Section 9.4.6.8).

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.

Propagation of tubestock for any given area of revegetation commences approximately 4-6 months before the target planting out date, depending on the expected growth rate of the species and the growing season (e.g. some species may germinate or grow slower in the cooler dry season months). The seed collection program is also based on this timeline so that sufficient seed of target species is available for propagation each time. If any particular species is not available exactly on time for propagation (e.g. due to seasonal impacts to seed collection), they can always be introduced later on during the infill planting program. It is highly unlikely that these will ever be the key overstorey, framework Eucalypt species as these generally have long seed storage times and collection can start early and cover a number of years.

9.4.6.3 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 will be applied for approximately 6 months with a reduced rate of irrigation for the last 3 months to encourage trees to develop deep root systems, important for accessing water during the dry season and withstanding strong prevailing winds.

Based on experience on the trial landform (Daws and Poole 2010; Lu et al 2019), plants will be irrigated for the first three months to receive an average of 2mm/day, adjusted dependent upon temperatures, evaporation, infiltration and rainfall. For the 3 to 6 month period, this will be reduced so that the soil profile is saturated but allowed to dry before further irrigation.

The proposed irrigation design will utilise above ground, rotational sprinklers connected by polypipe networks to generator-powered pumps at the two water sources (RP1 and GCMBL), and if required, additional bore field sources. Wherever possible, irrigation equipment will be relocated and reused following each 6 month irrigation period. Irrigation infrastructure will be installed after final land forming is complete and prior to planting by teams of workers laying out the pipe network and installing required connections.

Monitoring and maintenance of the irrigation system during operation is critical. In the 2010 trials, an irrigation lateral was found to have been chewed by dingoes/feral dogs and required repair (Daws & Poole 2010). Other issues that may arise include mechanical damage to piping, sediment clogging up filters and smaller-aperture fittings, pump failures and more. Any damage or malfunctioning of the irrigation equipment must be recognised within 48 hours of occurring to ensure there is no 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.

9.4.6.4 Preventative weed control

Substrates used in the construction of 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 and, where required, these areas will be treated with a pre-emergent, residual herbicide prior to planting. The requirement for the pre-emergent herbicide shall be based on a risk assessment considering, among other things, risks relating to; proximity to weeds in adjacent areas, risk of substrate contamination; and substrate type (noting that areas of high fines may be more disposed to weed invasion than rocky areas).

9.4.6.5 Mechanical planting site cultivation

Initial planting of tubestock will be at a density of between 800-1200 stems per hectare (averaging approximately 1000 st/ha) which requires spacing of between 2.5 - 3.5 m. To achieve a ‘natural’ planting effect (e.g. Figure 9-95), planting sites shall be positioned non-uniformly across the prepared surface, along and between (but not in) the rip lines where they occur. Planting sites shall be cultivated by an excavator auger attachment (Figure 9-96) 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 (Figure 9-97).

Figure 9-95: View of a 'natural' tree planting distribution and also the flat ground space among trees at Jabiluka revegetation site, Feb 2016. (Note that the surface at Ranger Project Area will be rougher due to waste rock substrate).

Figure 9-96: 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 9-97: A mechanically cultivated planting site.

9.4.6.6 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. If required, the revegetation area should be irrigated prior to planting to moisten the substrate and reduce plant stress.

The ERA Standard Operating Procedure (SOP) for Planting Tubestock shall be followed, which includes the requirement for a job hazard analysis prior to starting to identify hazards for the particular revegetation area/project. Following the SOP will ensure the planting task is completed safely, efficiently, and with the quality required to deliver high plant survival rates and rapid early growth. The SOP covers the following key steps:

- 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 9-98 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 9-98, Step 2).
- Place tubestock into the planting hole. Plants in biodegradable pots can be placed directly into the hole (reducing transplant shock), and plants in plastic pots shall be removed from the pot and carefully placed into the hole, and then backfilled with loose material. The surface of the potting mix should be just below the final surface leaving a 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 9-98, Step 3).
- Newly planted tubestock shall be watered in, either by the irrigation system, low pressure hoses or watering cans.
- For individual plants requiring monitoring, a stake or tag shall be placed into the ground at least 10 cm from the base.

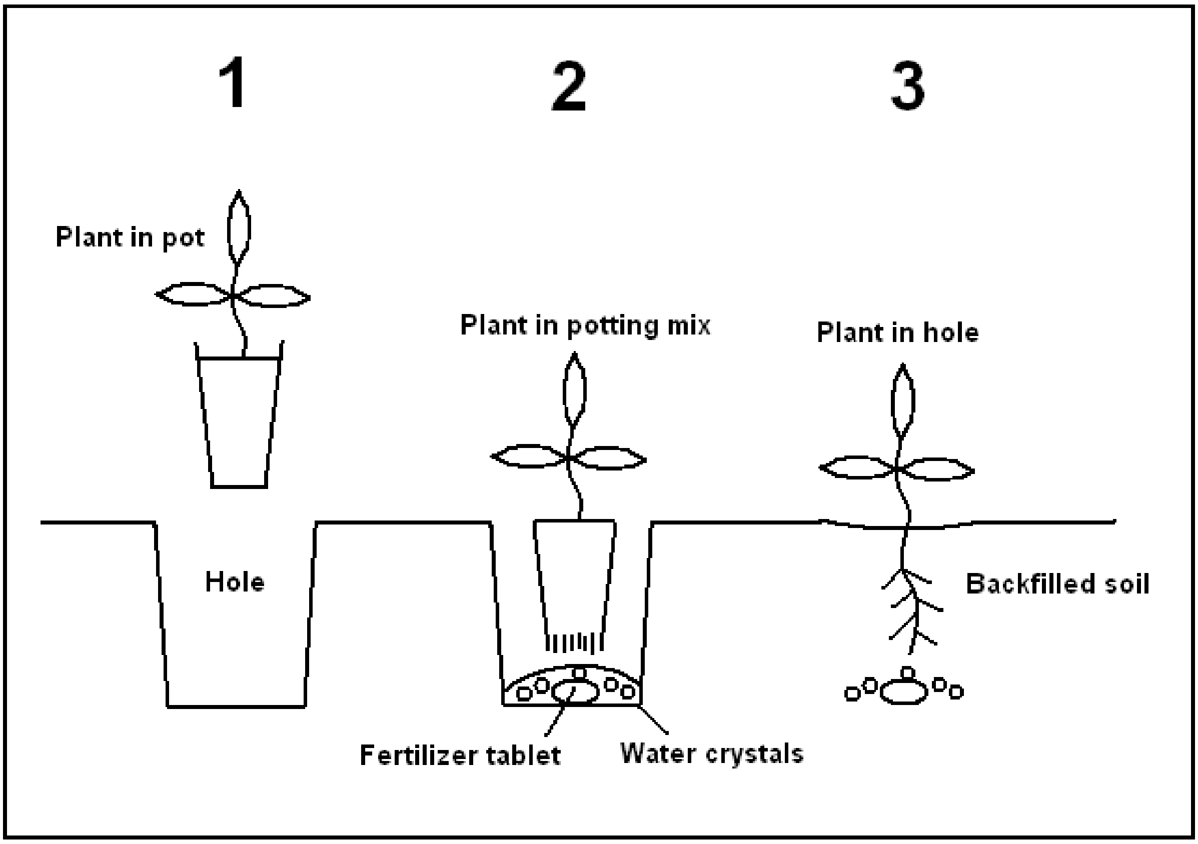


Figure 9-98: Tubestock planting out steps

9.4.6.7 Schedule of progressive tasks

A key consideration of the closure strategy was to provide progressive handover of final landforms to facilitate achievable revegetation production rates for contractors. A rate of 1.5 hectares per day revegetation day was set as a target.

The progressive release of final landforms output from the feasibility study that achieves this rate is shown in Figure 9-100.

Figure 9-99: Example of a completed, revegetated area (Stage 13.1).

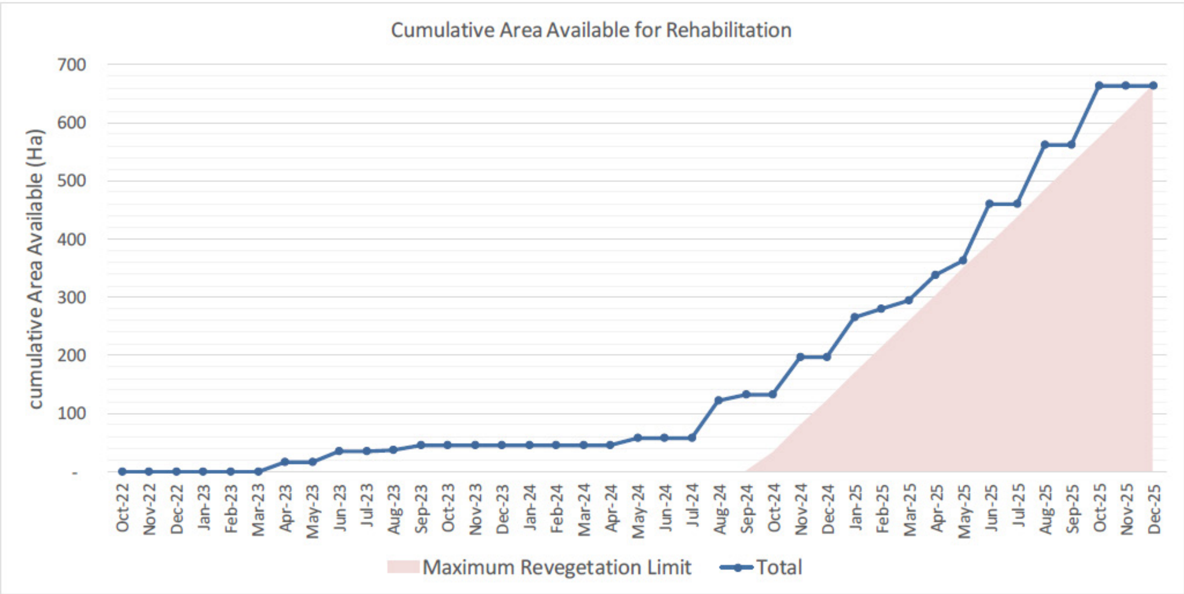


Figure 9-100: Cumulative handover of completed final landforms

9.4.6.8 Contingency plans

Tubestock production

The Ranger Mine nursery has been commissioned with a current annual capacity of 250,000 plants. ERA has identified two suitable contingency options to mitigate potential issues associated with tubestock production:

- A temporary expansion of the on-site Nursery facility could support the anticipated peak demand during 2025
- ERA will establish an arrangement with a suitably qualified service provider to grow tubestock from seeds provided by ERA, should the need arise. Under this option, the provider would be required to supply tubestock in accordance with the intended nursery and seedling specifications (e.g. soilless substrate, mycorrhiza inoculation and fertilising, seedling quality).

Seed collection

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
- 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.

The closure revegetation program is highly influenced by the timing of the rehabilitation schedule, especially the bulk material movement completion and handover process and the January 2026 completion deadline. Whilst some tubestock (and therefore seed) is required early for 2020/21 wet season planting of Pit 1 areas, the majority of planting will occur in the 2024-2025 (inclusive) period.

Collection of species with seed storage longevity has commenced in earnest and targets are being tracked against the plan. The plan is that these species should be fully stocked before the peak tubestock propagation and planting period commences.

Some seed, however, can only be used 'fresh' and these collections must be timed to optimise seed availability and time from planting. Whilst pro-active collection strategies and storage improvements aim to extend seed longevity, there remains a risk that 'fresh' 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 collections tactics are primed for the instance when they are available and required, to make sure that targets can be achieved and quality is maintained. In addition to this, these species (especially those of particular ecological or 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
- propagation of tubestock from vegetative material (rather than seeds)
- 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.

9.5 Overall closure implementation schedule

The Ranger Mine closure implementation comprises a number of key tasks. Closure milestones for demolition completion and target dates are included in Table 9-44. In accordance with the Ranger Authorisation all closure activities require ministerial approval before proceeding. All identified closure projects are scheduled for submission for approval ahead of planned implementation (Section 3.4).

Table 9-44: Key milestones for completion of demolition

Key Milestone	Activity Reference	Date
Pit 1 Backfill (date for completion)	KM-34	31-Aug-20
BC Fan Upgrade Construction.(date for project completion)	KM-33	20-Jan-21
Dredging Complete Milestone	KM-04	31-Jan-21
TSF Floor Clean. (date for completion)	KM-31	10-Aug-21
Pit 3 Closure MTC Final Approval	KM-41	14-Sep-21
Pit 3 Wicking (date for completion)	KM-35	22-Jan-22
Pit 3 Geotextile (date for completion)	KM-08	11-Jun-22
Pit 3 Initial Cap (date for completion)	KM-36	8-Sep-22
Commence Bulk Material Movement	KM-09	27-Oct-22
Commence Phase 1 demolition	9140-88	05-Jan-23
Commence of Revegetation	KM-10	22-Apr-23
Commence TSF Deconstruction	KM-11	3-Aug-24
Process Water Inventory at Zero (Date From Water Model)	KM-13	3-Mar-25
Pond Water Inventory at Zero (Date From Water Model)	KM-15	1-May-25
Commence Phase 2 demolition	KM-14	1-May-25
Complete decant pumping from Pit 3	4244-02	25-May-25
Complete process water treatment	4231-03	31-May-25
Final Land Form Completion	KM-16	30-Sep-25
Closure Execution Schedule Planned Finish Date	KM-17	25-Nov-25
Completion of Revegetation (Initial Planting)	KM-18	25-Nov-25
End of RPA Lease	KM-32	08-Jan-26

9.6 References

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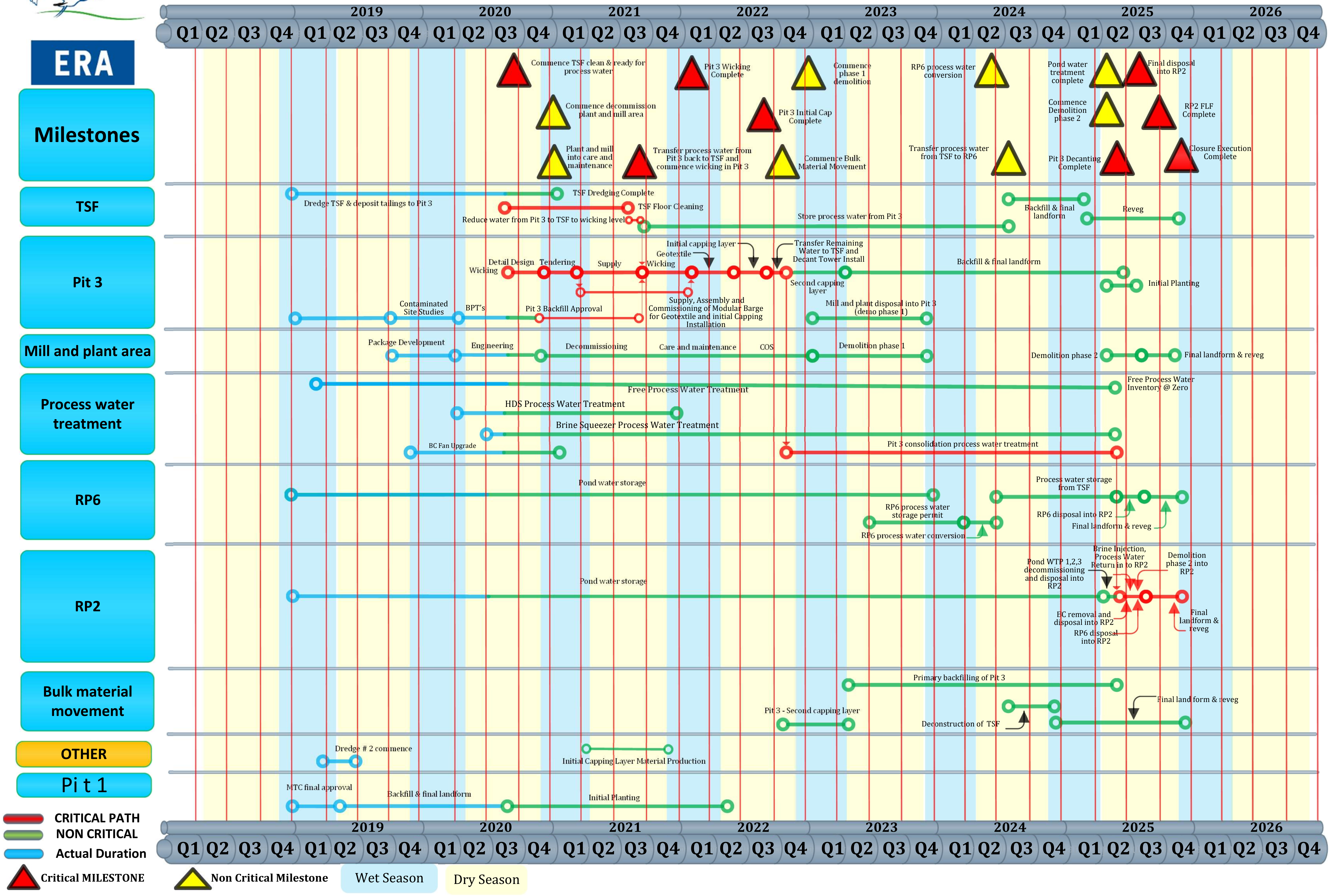
APPENDIX 9.1: SCHEDULE OF ACTIVITIES FOR CLOSURE

DOMAIN	ACTIVITY	TASK	STAGE	TIMELINE						
				2020	2021	2022	2023	2024	2025	2026
Pit 1	Wicks	Installation of prefabricated vertical drains (wicks) within previously transferred tailings	Complete							
	Geofab etc	Installation of geotextile and preload activities	Complete							
	Backfill	Pit 1 bulk backfill	Complete							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation activity commences on the perimeter of the pit	Commenced							
Pit 3	Underfill	Initial backfill of Pit 3 with waste rock for underfill	Complete							
	Drainage	Underfill drainage layer & installation of extraction pumping system	Complete							
	Piping	Piping etc. from process plant to pit for delivery of tailings installation	Complete							
	Tailings	Tailings from process plant and from TSF delivered to Pit 3	Ongoing							
	Wicks	Installation of prefabricated vertical drains (wicks) within previously transferred tailings	Scheduled							
	Geofabric	Installation of geotextile	Scheduled							
	Capping	Placement of initial rock layer (initial capping) sub aqueously	Scheduled							
		Placement of secondary capping layer using smaller equipment to get sufficient geotechnical strength.	Scheduled							
	Bulk Backfill	Bulk Backfill of rock into pit.	Scheduled							
	Demolition	Placement of deconstructed mill and other infrastructure	Scheduled							
	Demolition	Decommission tailings transfer infrastructure	Scheduled							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
TSF	Infrastructure	Construction of dredge to deliver tailings from TSF to Pit 3	Complete							
	Piping	Installation of tailings transfer piping and infrastructure	Complete							
	Tailings Transfer	Dredge tailings to Pit 3	Ongoing							
	Demolition	Decommission dredge and tailings transfer infrastructure	Scheduled							
	Tailings	Removal of remnant tailings and contaminated material from TSF	Ongoing							
	Process water	Conversion to water storage dam	Scheduled							
	Decommission	Decommission TSF	Scheduled							
	Remediation	TSF floor remediation – if required	Scheduled							
	Waste	Grade 1 (1s) waste coverage	Scheduled							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
LAAs	Assess	Assessment of contamination in soils	Ongoing							
	Demolition	Staged removal of infrastructure	Scheduled							
	Remediate	Remediation, as required	Scheduled							
	Revegetation	In fill revegetation, if required	Scheduled							
Processing plant, admin buildings and water	Services	Continuity of services	Ongoing							
	Decommissioning (make safe)	Decommission of processing plant infrastructure	Scheduled							

DOMAIN	ACTIVITY	TASK	STAGE	TIMELINE						
				2020	2021	2022	2023	2024	2025	2026
treatment infrastructure	Demolition	Demolition of processing plant and associated site infrastructure	Scheduled							
	Demolition	Demolition of water treatment infrastructure, including removal of pipelines and services	Scheduled							
	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
Stockpiles	Landform	Surface contoured to final landform shape	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
Water management areas	Decommission	Remove lining of RP6, and infrastructure of RP 2, 3 & 6	Scheduled							
	Landform	Surface contoured to final landform shape (RP 2, 3 & 6)	Scheduled							
	Erosion	Installation of erosion control features	Scheduled							
	Revegetation	Revegetation	Scheduled							
Linear infrastructure	Demolition	Remove any infrastructure in corridors (roads, tracks, service corridors, exploration lines)	Scheduled							
	Landform	Recontour and/or rip if required. Block access to tracks	Scheduled							
	Infrastructure	Install fencing and/or signs if agreed to by TOs	Scheduled							
Miscellaneous – borrow pits, landfill sites, magazine etc.	Demolition	Remove any infrastructure in/adjacent to borrow pits, lay down yards, nursery, coreyard, levy, landfill sites etc.	Scheduled							
	Landform	Recontour and/or rip if required. Block access to tracks	Scheduled							

Updated 31.8.2020

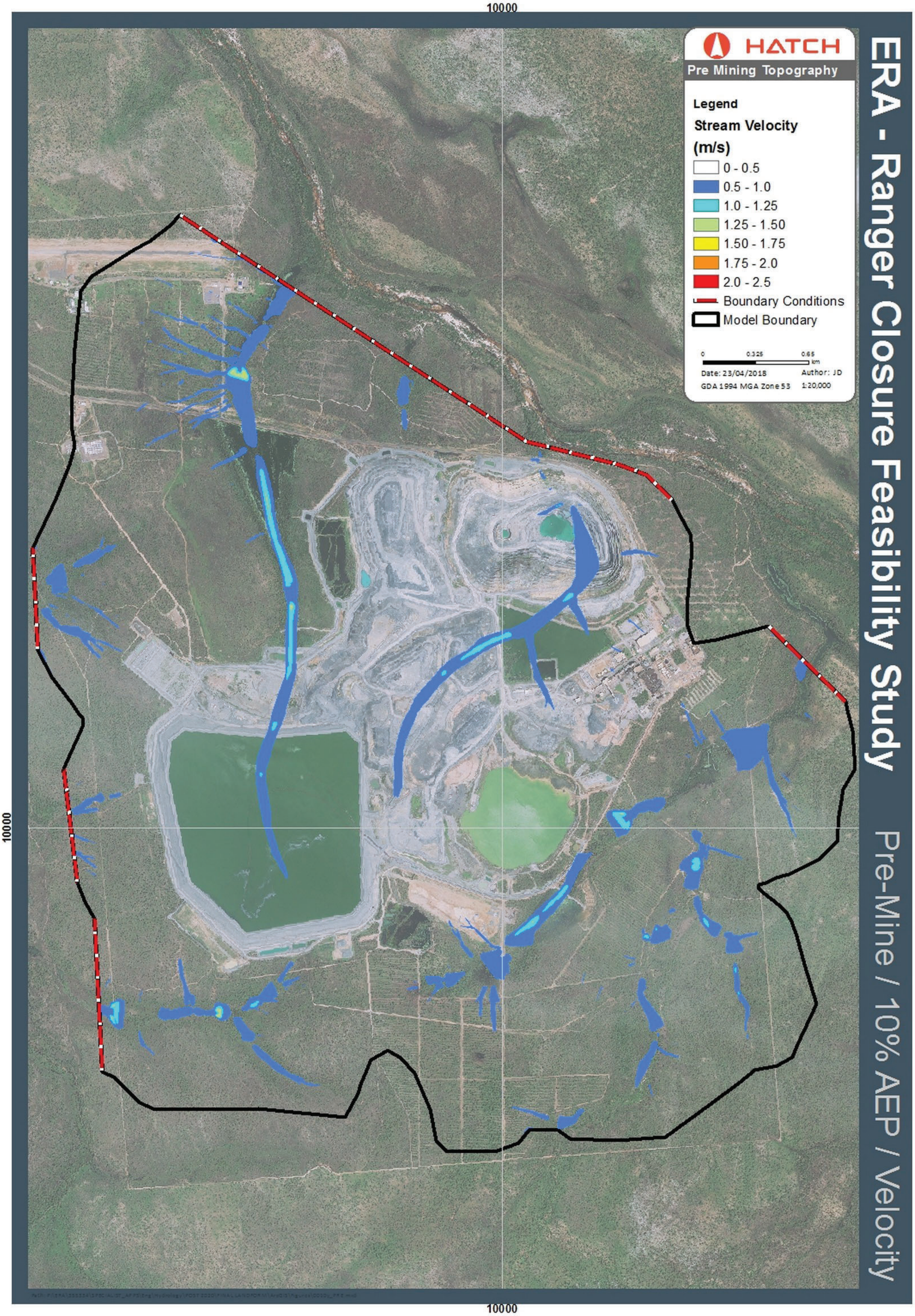
RANGER CLOSURE PROJECT LEVEL 1



APPENDIX 9.2: FLOOD MODELLING

ERA - Ranger Closure Feasibility Study

TUFLOW Model Setup



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Pre Mining Topography
Legend
Stream Velocity
(m/s)
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0.5 - 1.0
1.0 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.0
2.0 - 2.5
Boundary Conditions
Model Boundary
0 0.325 0.65 km
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Author: JD
GDA 1994 MGA Zone 53
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ERA - Ranger Closure Feasibility Study
Pre-Mine / 10% AEP / Velocity
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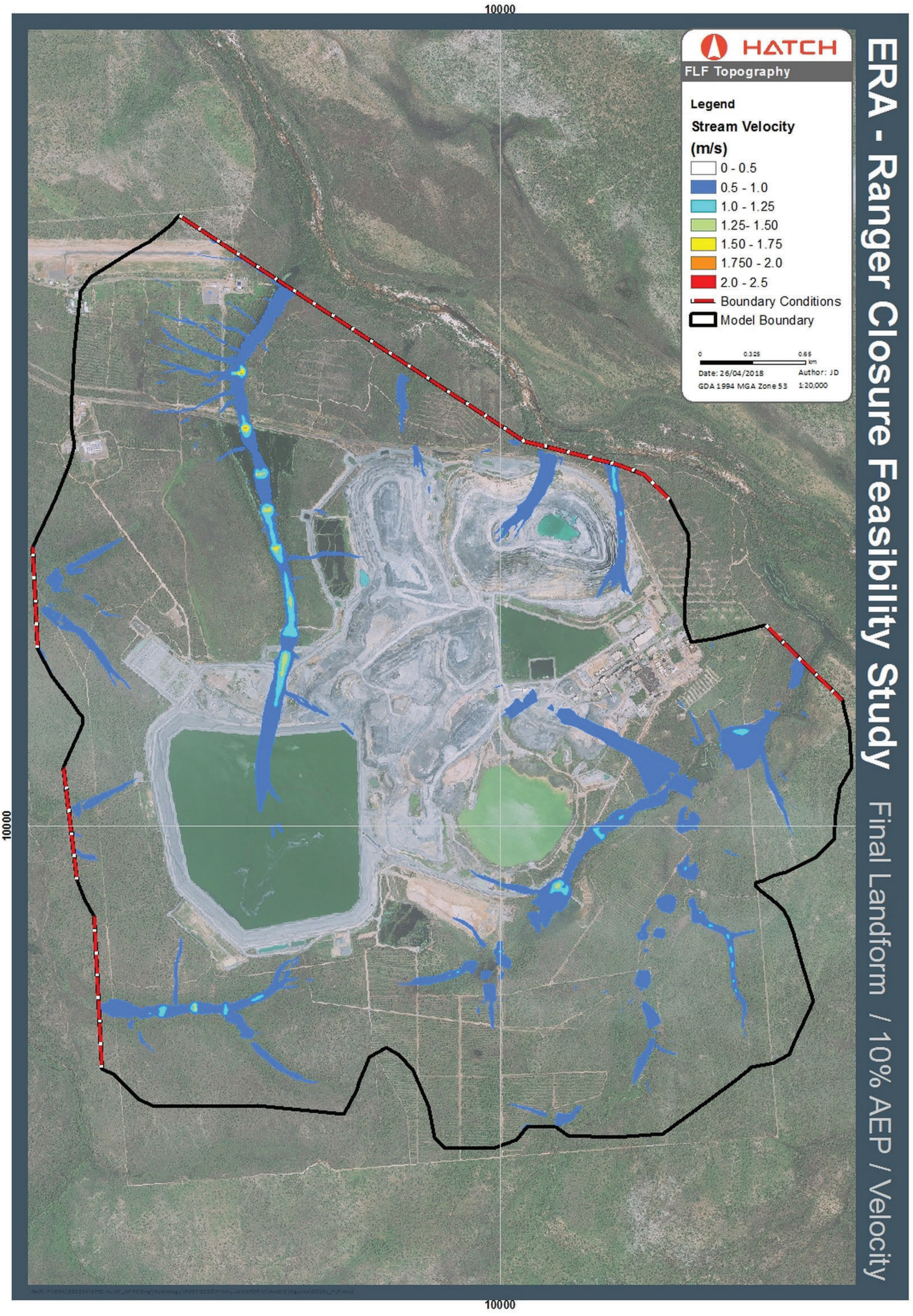
ERA - Ranger Closure Feasibility Study
Final Landform / 10% AEP / Velocity
HATCH
FLF Topography
Legend
Stream Velocity
(m/s)
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0.5 - 1.0
1.0 - 1.25
1.25- 1.50
1.50 - 1.75
1.750 - 2.0
2.0 - 2.5
Boundary Conditions
Model Boundary
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0.325
0.65
km
Date: 26/04/2018
Author: JD
GDA 1994 MGA Zone 53
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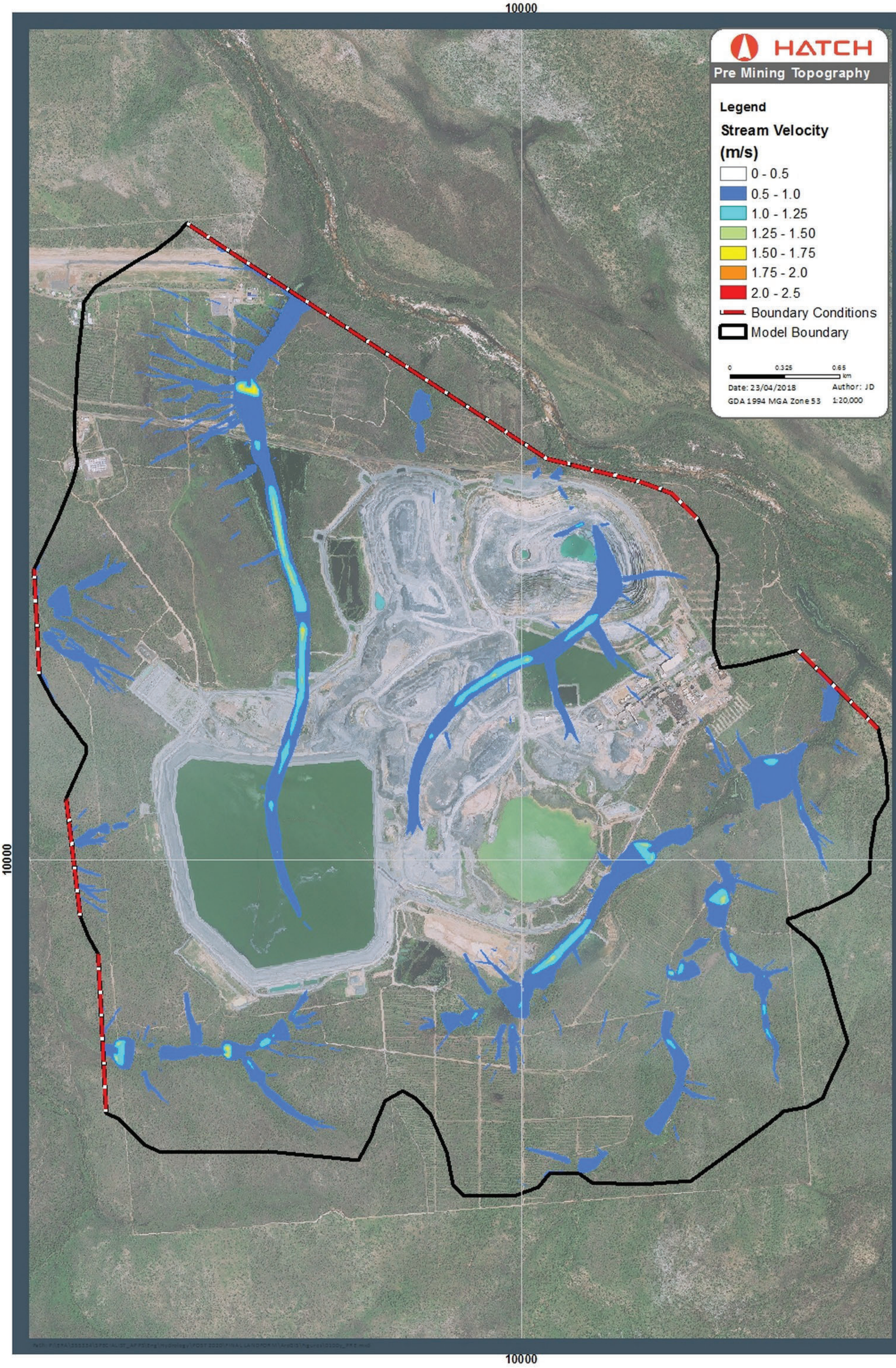
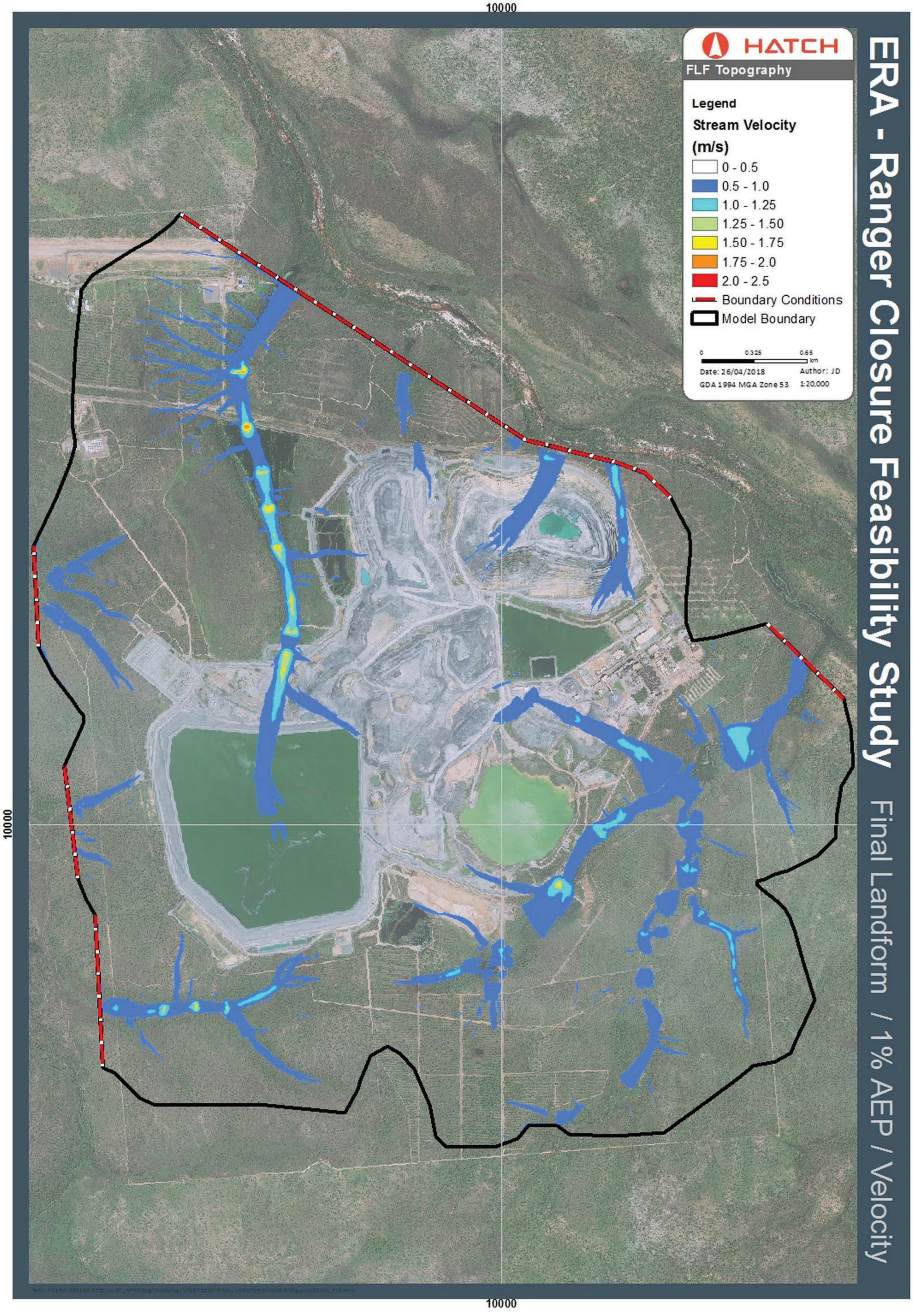
10000
10000



ERA - Ranger Closure Feasibility Study

Pre-Mine / 1% AEP / Velocity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HATCH
FLF Topography
Legend
Stream Velocity
(m/s)
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0.5 - 1.0
1.0 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.0
2.0 - 2.5
Boundary Conditions
Model Boundary
0
0.325
0.65
km
Date: 26/04/2018
Author: JD
GDA 1994 MGA Zone 53
1:20,000
ERA - Ranger Closure Feasibility Study
Final Landform / 1% AEP / Velocity
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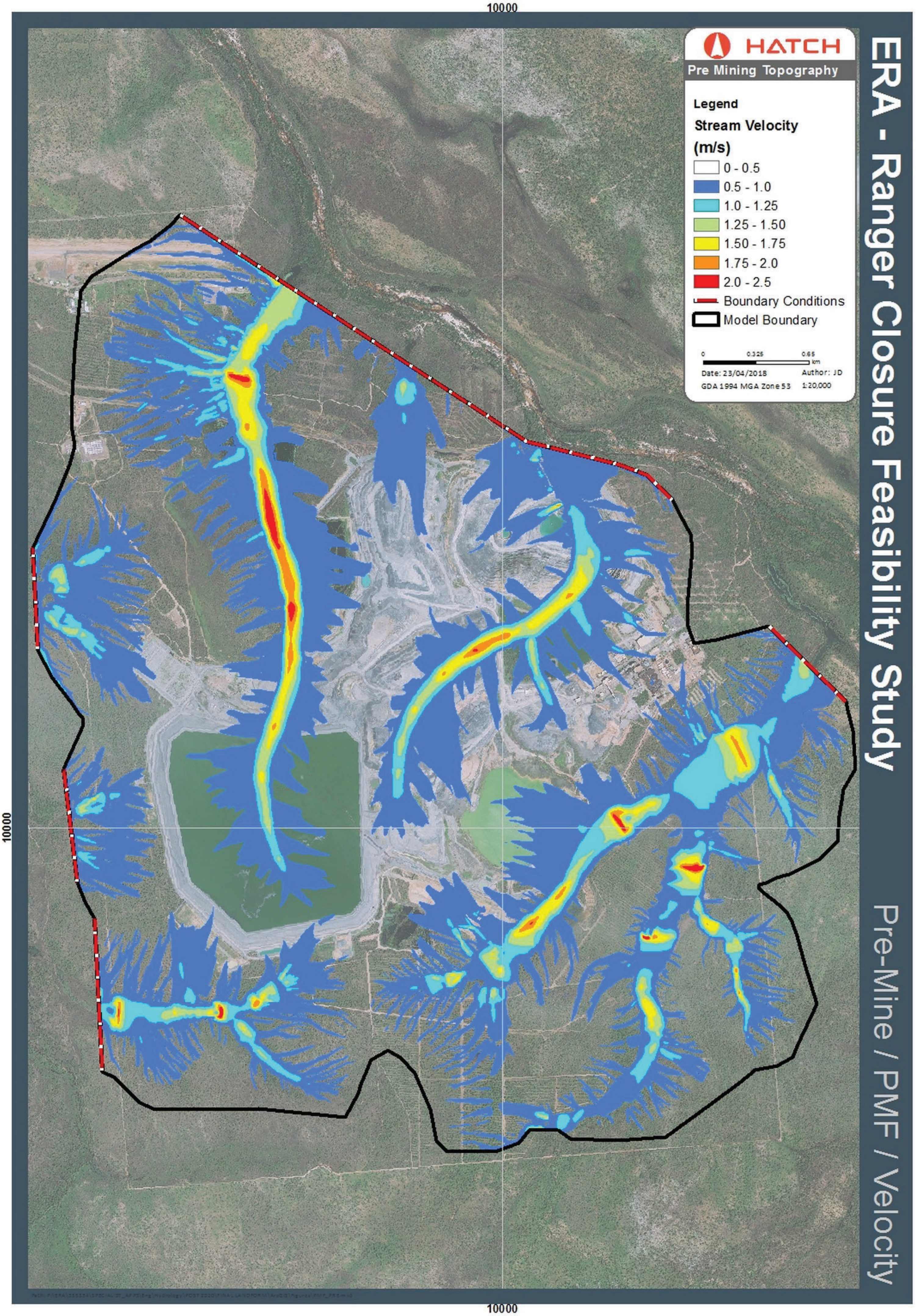
10000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Stream Velocity
(m/s)
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1.0 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.0
2.0 - 2.5
Boundary Conditions
Model Boundary
0
0.325
0.65
km
Date: 23/04/2018
Author: JD
GDA 1994 MGA Zone 53
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ERA - Ranger Closure Feasibility Study
Pre-Mine / PMF / Velocity
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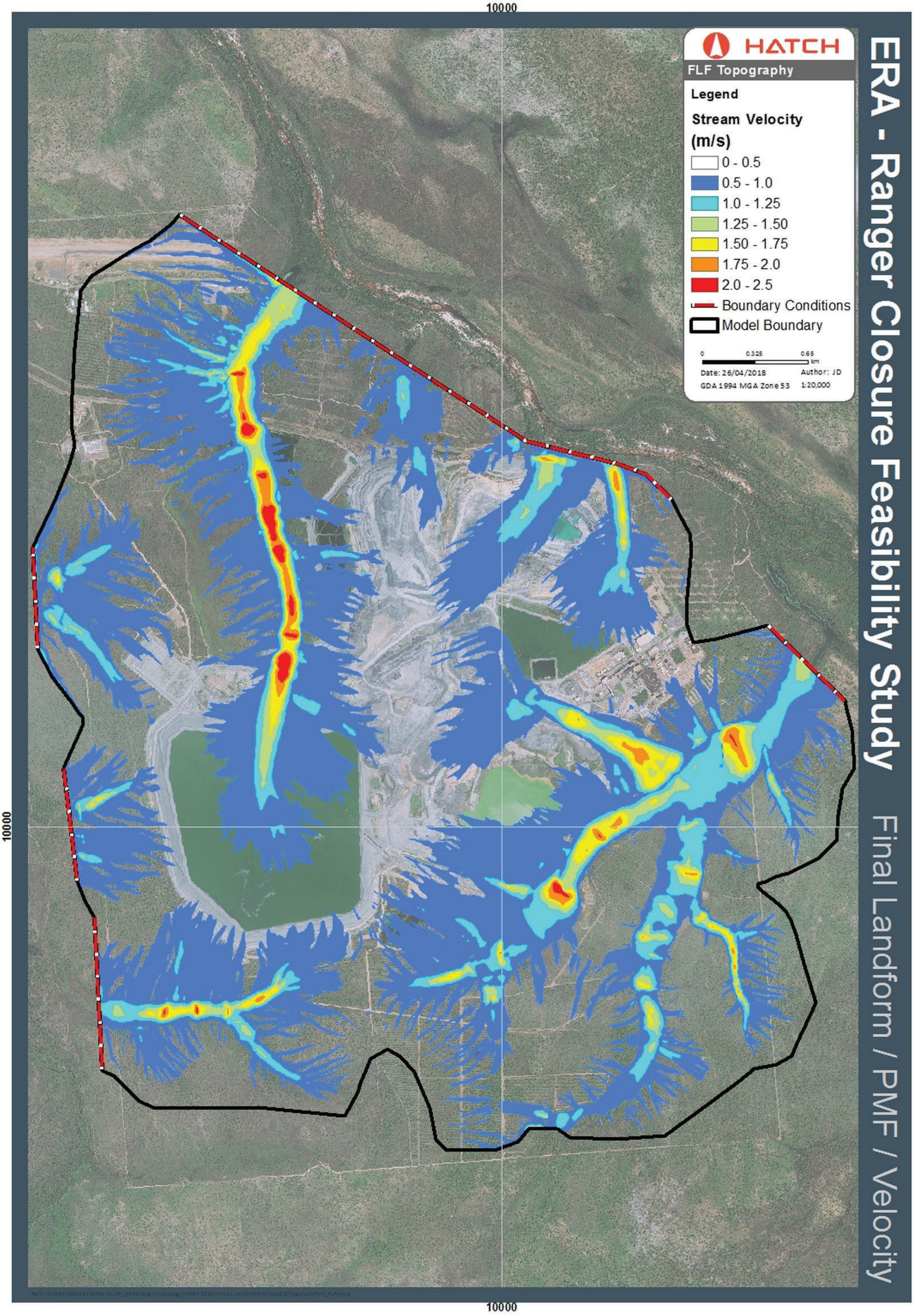
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HATCH
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Legend
Stream Velocity
(m/s)
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0.5 - 1.0
1.0 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.0
2.0 - 2.5
Boundary Conditions
Model Boundary
0
0.325
0.65
km
Date: 26/04/2018
Author: JD
GDA 1994 MGA Zone 53
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ERA - Ranger Closure Feasibility Study
Final Landform / PMF / Velocity
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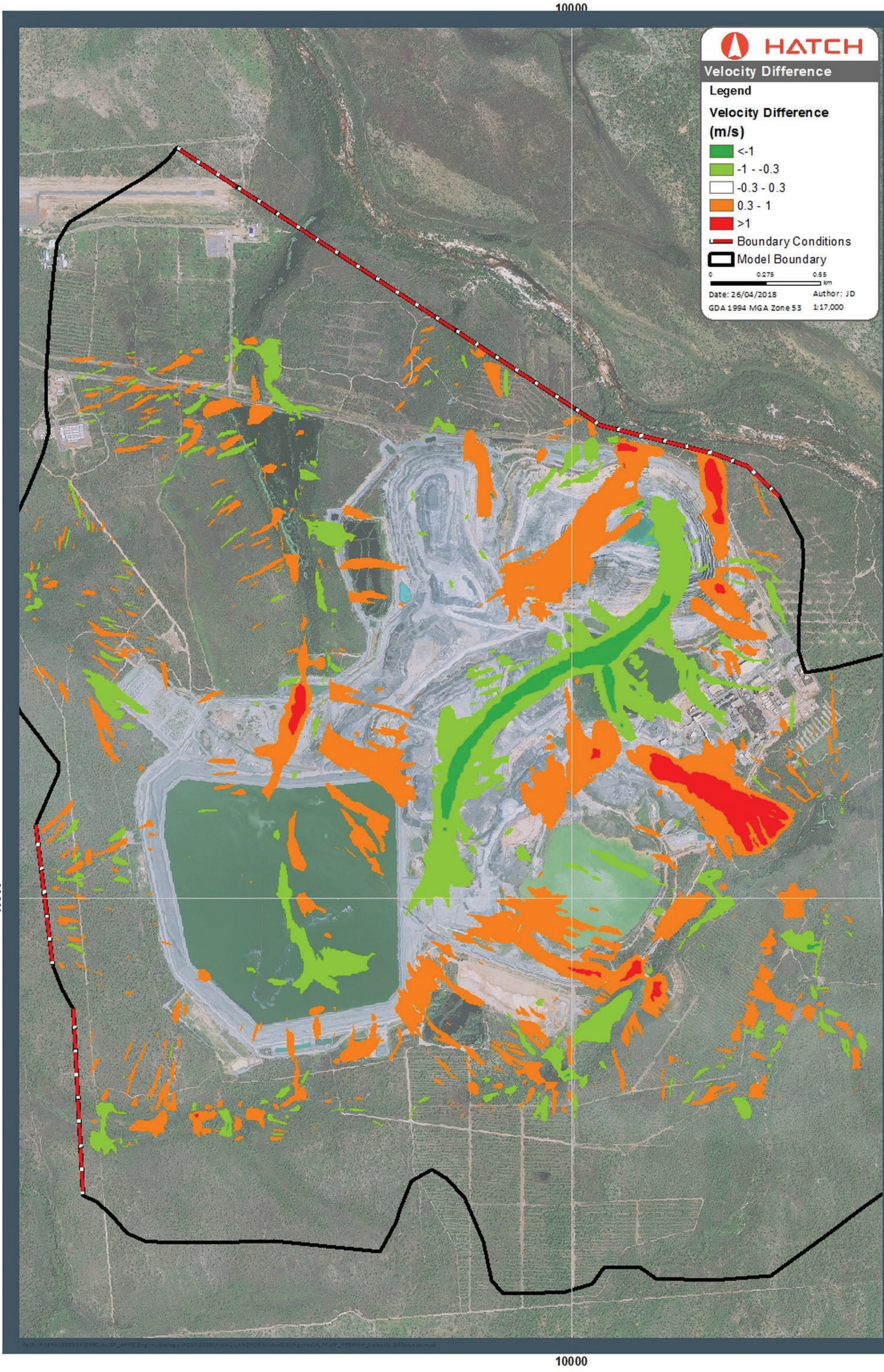
10000

ERA - Ranger Closure Feasibility Study

FLF to PRE / PMF / Velocity Difference



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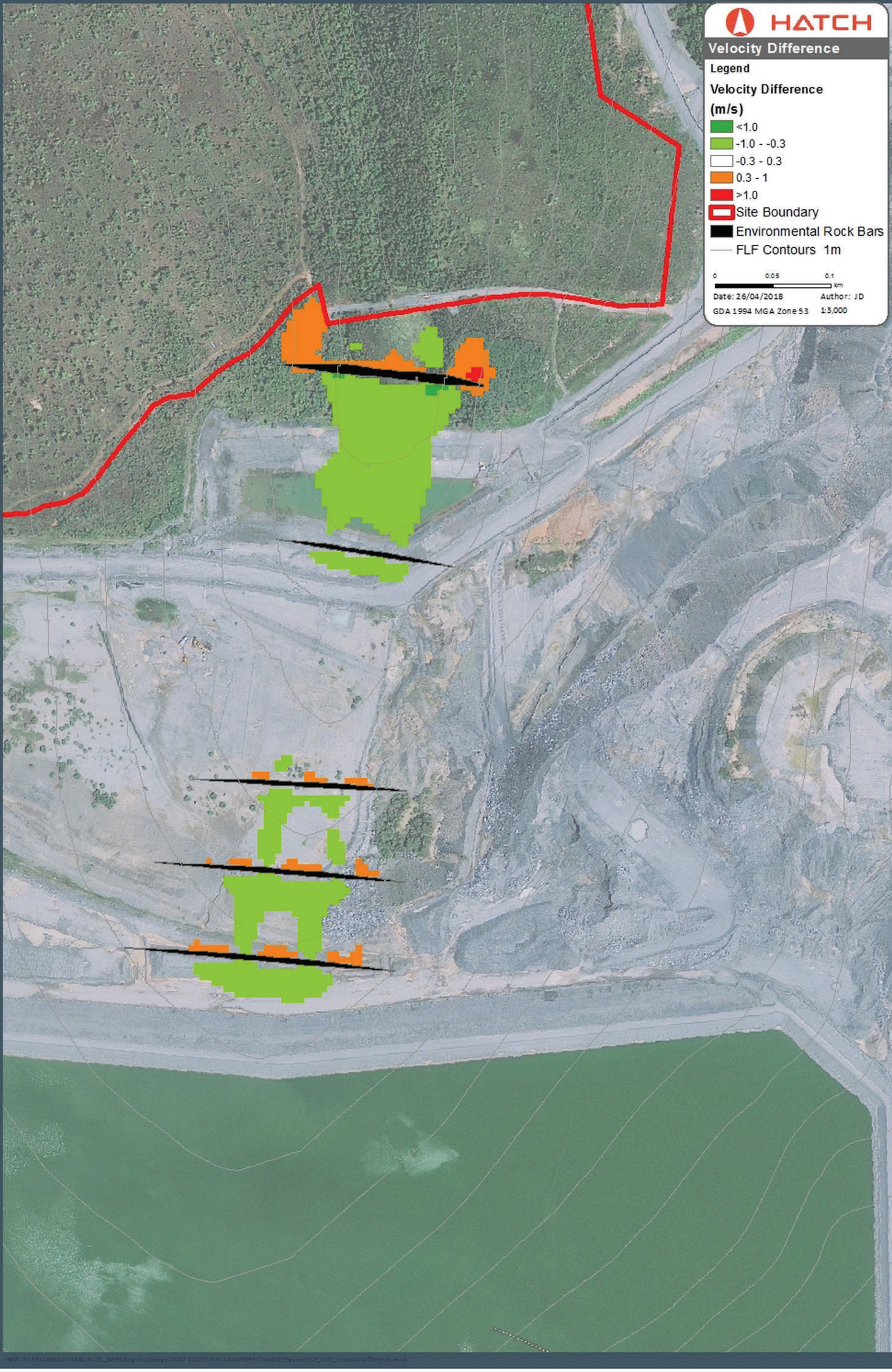
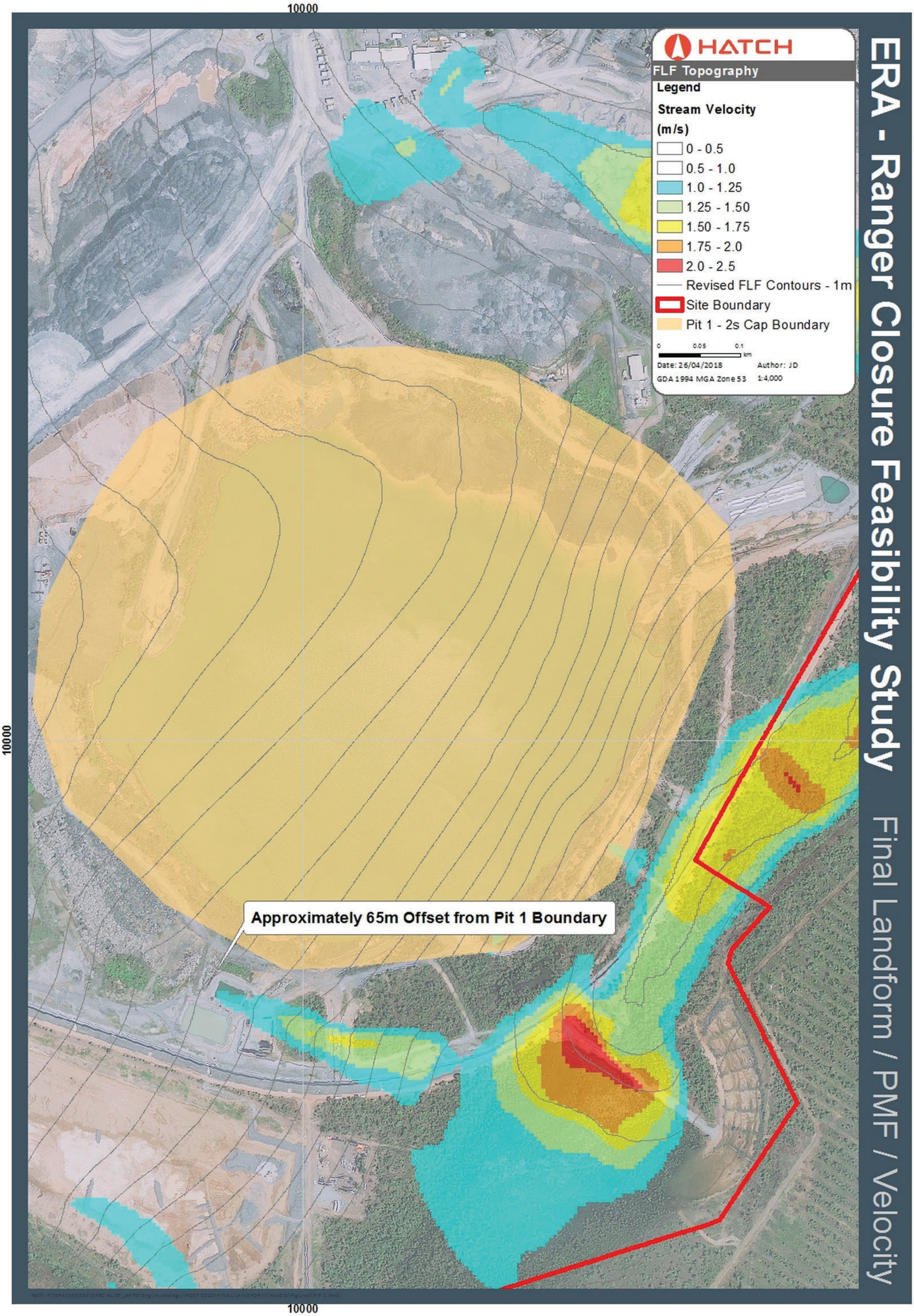
MIT to FLF / PMF / Velocity Difference



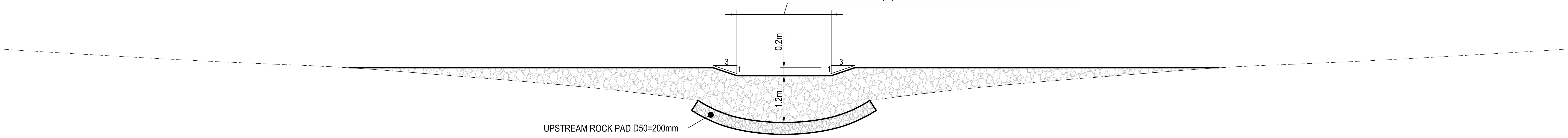


ERA - Ranger Closure Feasibility Study
Final Landform / PMF / Velocity
HATCH
FLF Topography
Legend
Stream Velocity
(m/s)
0 - 0.5
0.5 - 1.0
1.0 - 1.25
1.25 - 1.50
1.50 - 1.75
1.75 - 2.0
2.0 - 2.5
Revised FLF Contours - 1m
Site Boundary
Pit 1 - 2s Cap Boundary
0
0.05
0.1
km
Date: 26/04/2018
Author: JD
GDA 1994 MGA Zone 53
1:4,000
Approximately 65m Offset from Pit 1 Boundary
10000
10000
10000

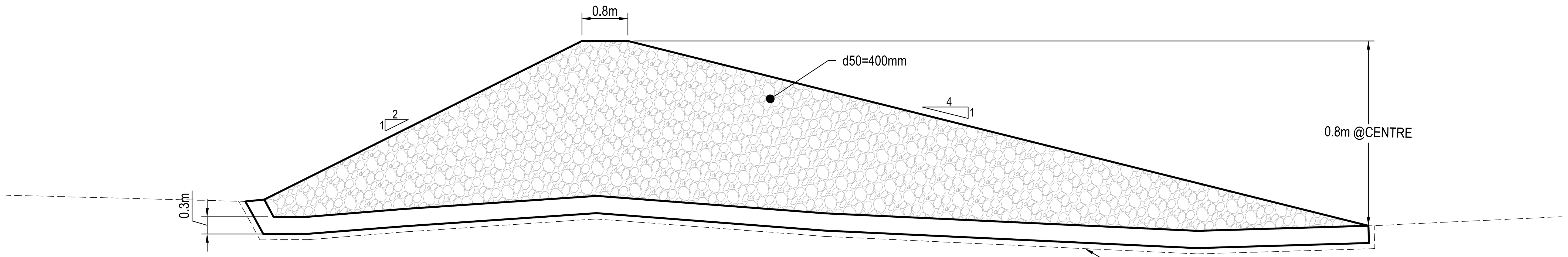
APPENDIX 9.3: FINAL LANDFORM DRAWINGS

IF IN DOUBT – ASK!   DO NOT SCALE   IF IN DOUBT – ASK!

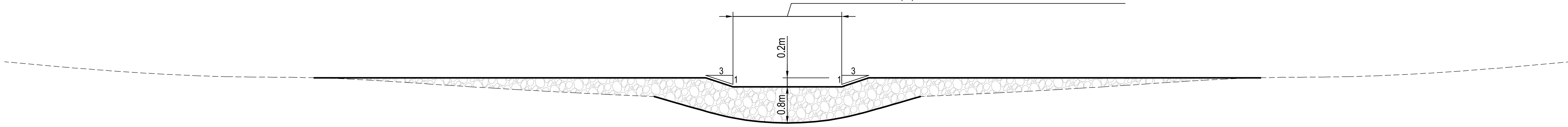
SEDIMENT BASINS
N.T.S



LONG SECTION - SEDIMENT BASINS
N.T.S



ENVIROMENTAL ROCK BARS - DJ, CJ AND CR
N.T.S



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.

APPROVED FOR USE

SUBJECT TO FINAL VERIFICATION AND APPROVAL   PRELIMINARY NOT FOR CONSTRUCTION

DRG. NO.	REFERENCE DRAWING DESCRIPTION

NOTES

HATCH

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	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

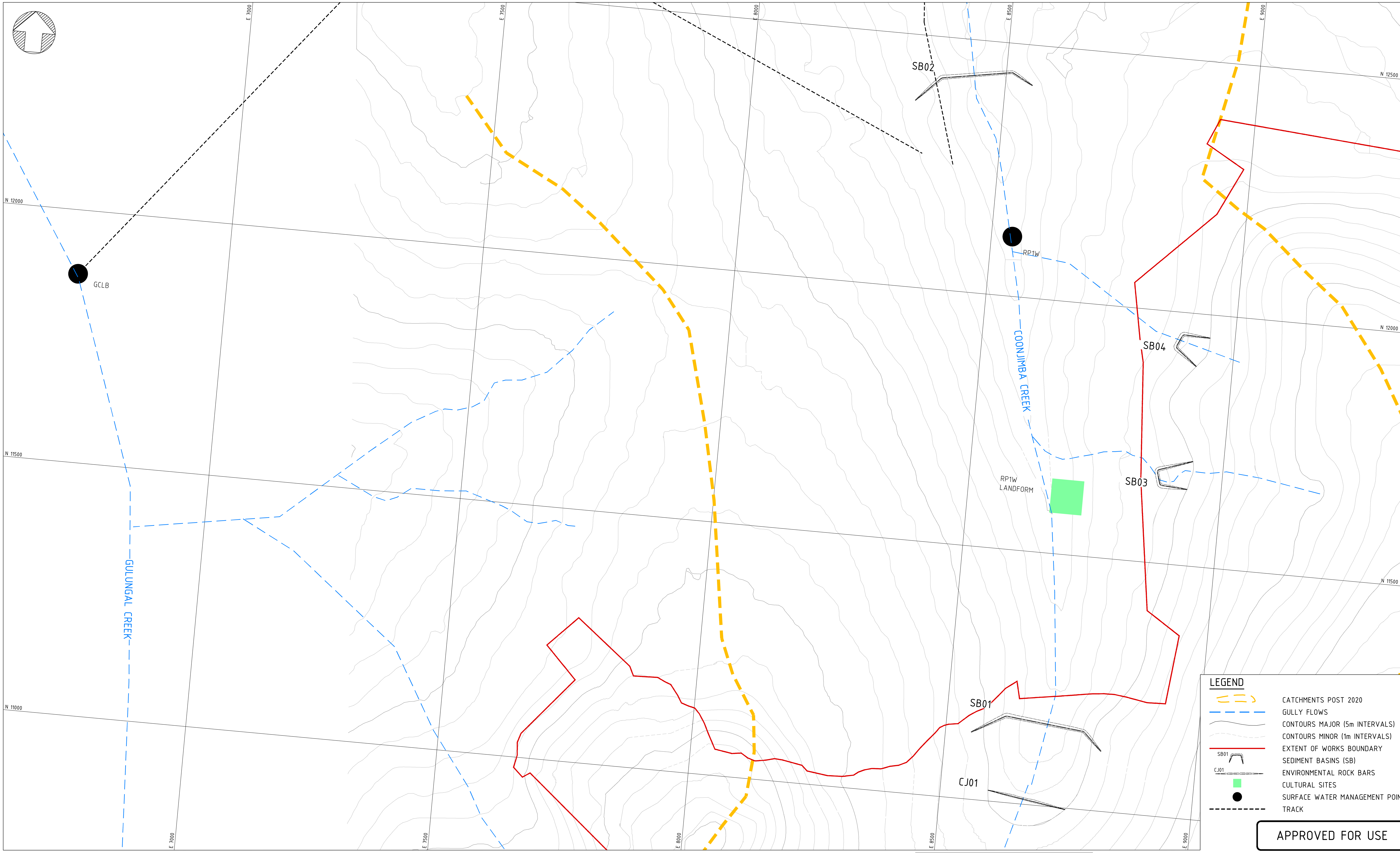
PLANT AREA: AREA 91 – CLOSURE STRATEGY

TITLE: ENVIROMENTAL ROCK BARS & INTREAM CHECK DAMS SECTION DETAILS

SHEET SIZE	PROJ/WORK ORDER NO.	AREA	DISC	DRAWING	REV
B1	.	91	C	0071	1

IF IN DOUBT – ASK! DO NOT SCALE IF IN DOUBT – ASK!

DWG No. H355334-00000-220-272-0001



0 75 150 225 300m
SCALE: 1:3000 @B1

APPROVED FOR USE

JOINS DRAWING 0021

FINAL CONTOUR PLAN 1

SCALE 1:3000

SUBJECT TO FINAL VERIFICATION AND APPROVAL

PRELIMINARY
NOT FOR CONSTRUCTION

DRG. NO.	REFERENCE DRAWING DESCRIPTION

NOTES

This drawing was prepared for the exclusive use of Energy Resources Australia Ltd. ABN 71 008 550 865 ("Client") and is issued pursuant to contracts between Client and Hatch Pty Ltd ABN 59 008 630 500 ("Hatch").

Unless otherwise agreed in writing with Client or specified in this drawing, (a) Hatch does not accept and disclaims any and all liability or responsibility arising from any use of or reliance on this drawing by any third party or any modification or misuse of this drawing by Client, and (b) this drawing is confidential and all intellectual property rights embodied or referenced in this drawing remain the property of Hatch.

REV.	DESCRIPTION	BY	CKD.	APP.	DATE
2	APPROVED FOR USE	PK	PDB	DB	06/02/19
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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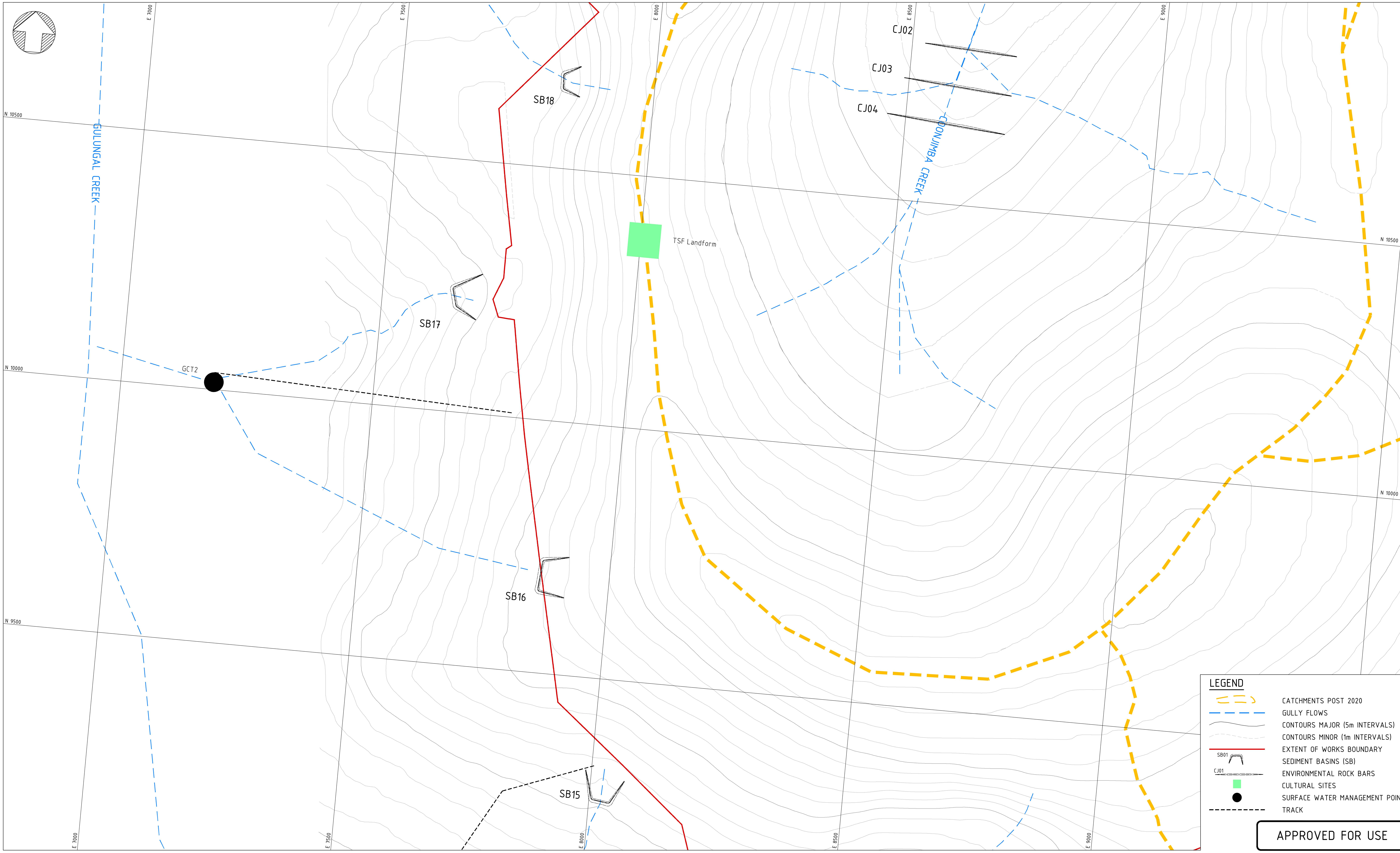
IF IN DOUBT – ASK!

DO NOT SCALE

JOINS DRAWING 0019

IF IN DOUBT – ASK!

DWG No. H355334-00000-220-272-0003



LEGEND

- CATCHMENTS POST 2020
- GULLY FLOWS
- CONTOURS MAJOR (5m INTERVALS)
- CONTOURS MINOR (1m INTERVALS)
- EXTENT OF WORKS BOUNDARY
- SEDIMENT BASINS (SB)
- ENVIRONMENTAL ROCK BARS
- CULTURAL SITES
- SURFACE WATER MANAGEMENT POINTS
- TRACK

APPROVED FOR USE

SCALE: 1:3000 @B1 (0 – 75 – 150 – 225 – 300m)

FINAL CONTOUR PLAN 3

SCALE 1:3000

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DRG. NO.	REFERENCE DRAWING DESCRIPTION

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REV.	DESCRIPTION	BY	CKD.	APP.	DATE
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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 H355334-00000-220-272-0003

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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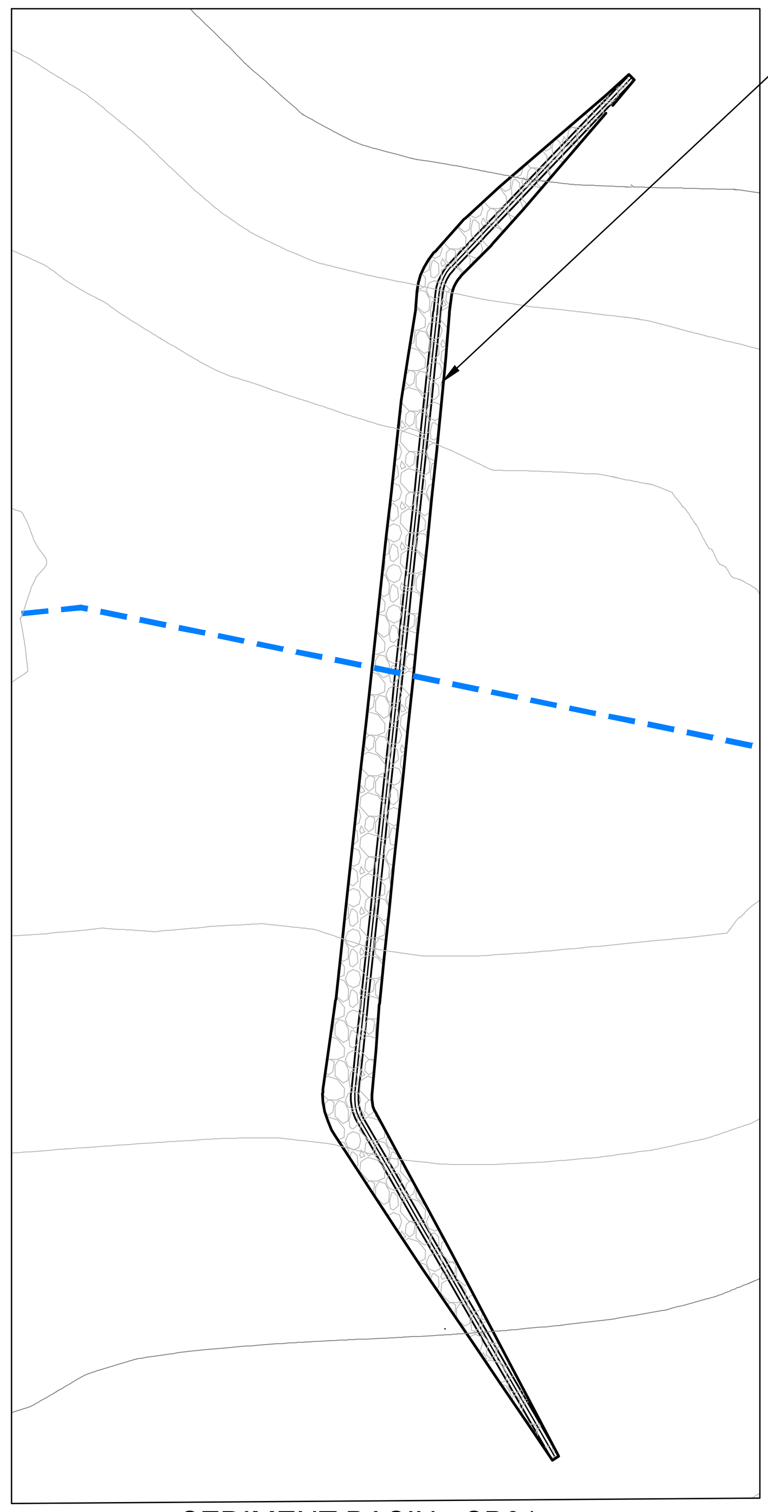
IF IN DOUBT – ASK! DO NOT SCALE IF IN DOUBT – ASK!

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.



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SCALE 1:1000

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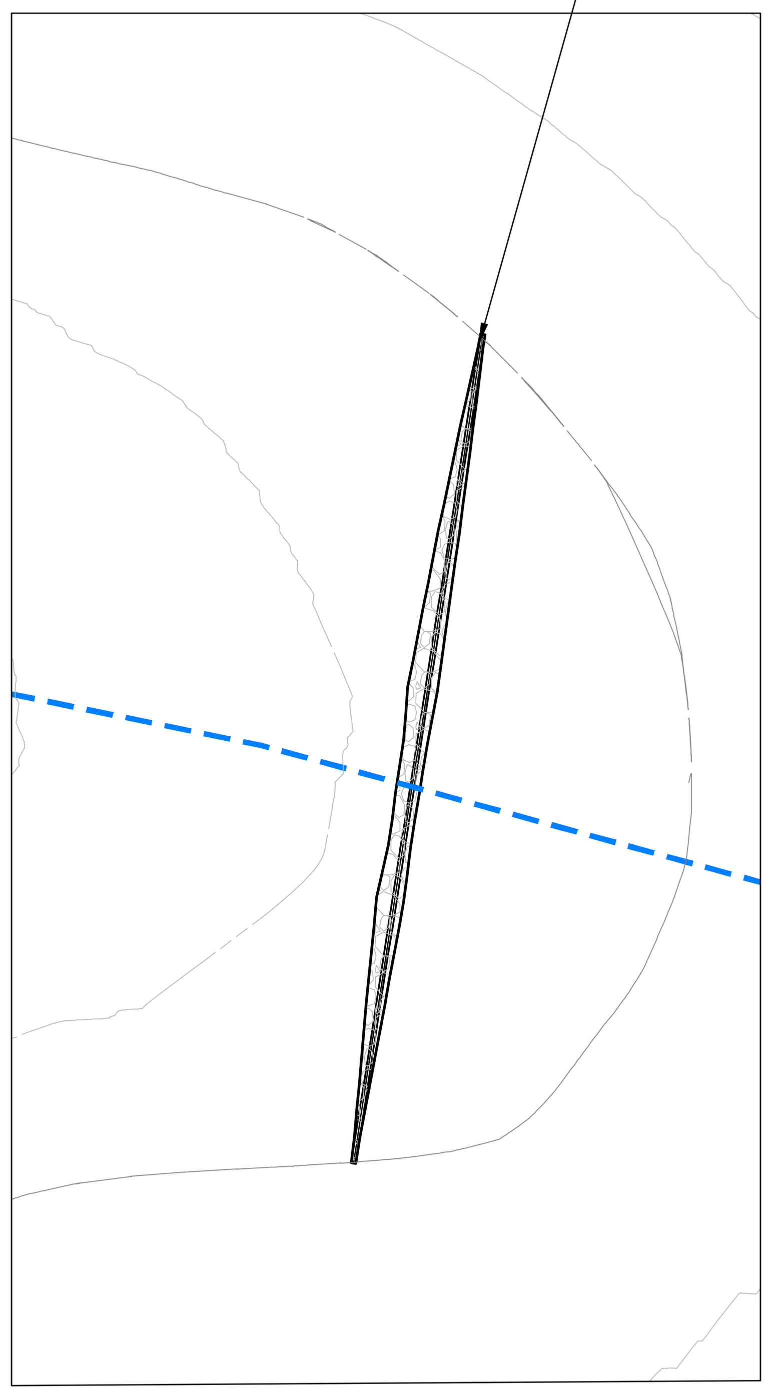
SCALE: 1:20 @B1



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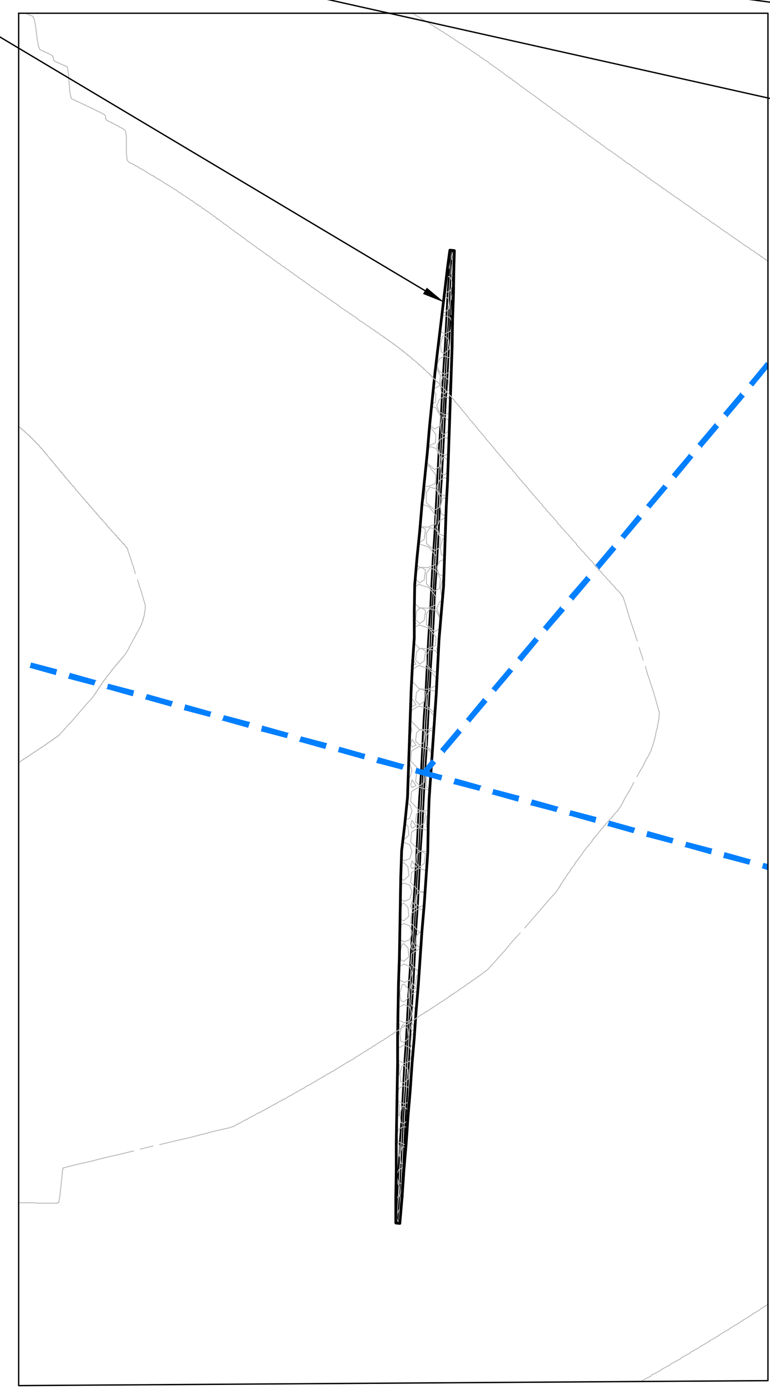
SCALE 1:1000



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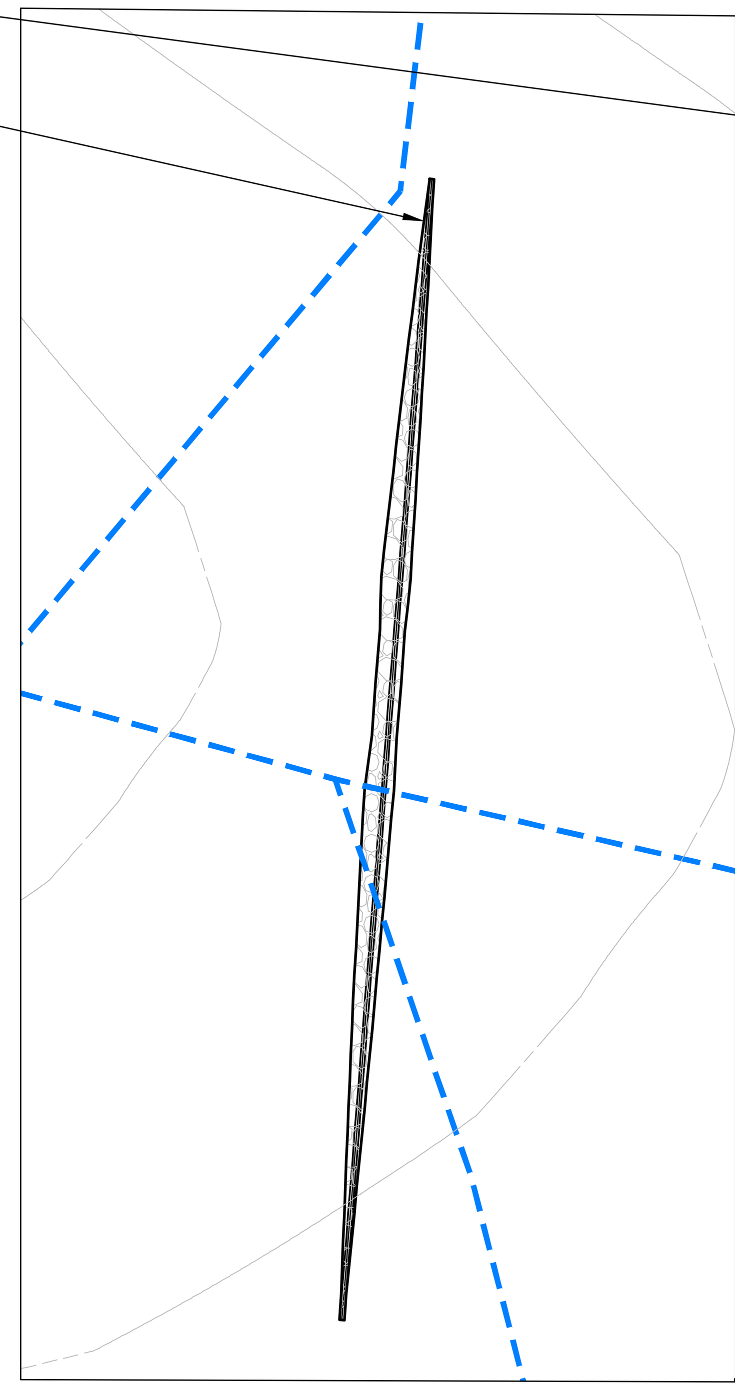

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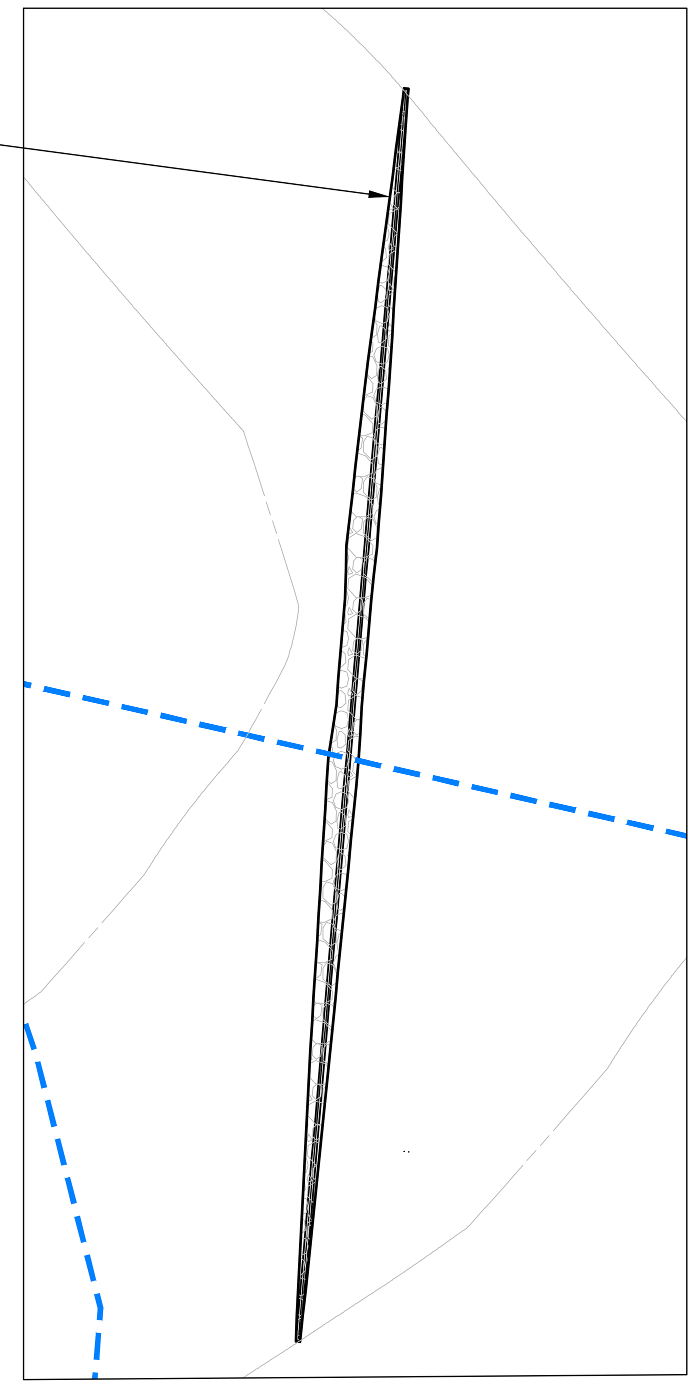
SCALE 1:1000



ENVIROMENTAL ROCK BAR CJ04
SCALE 1:1000

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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		
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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DWG No. H355334-00000-220-272-0002

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APPROVED FOR USE

JOINS DRAWING 0022

FINAL CONTOUR PLAN 2

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 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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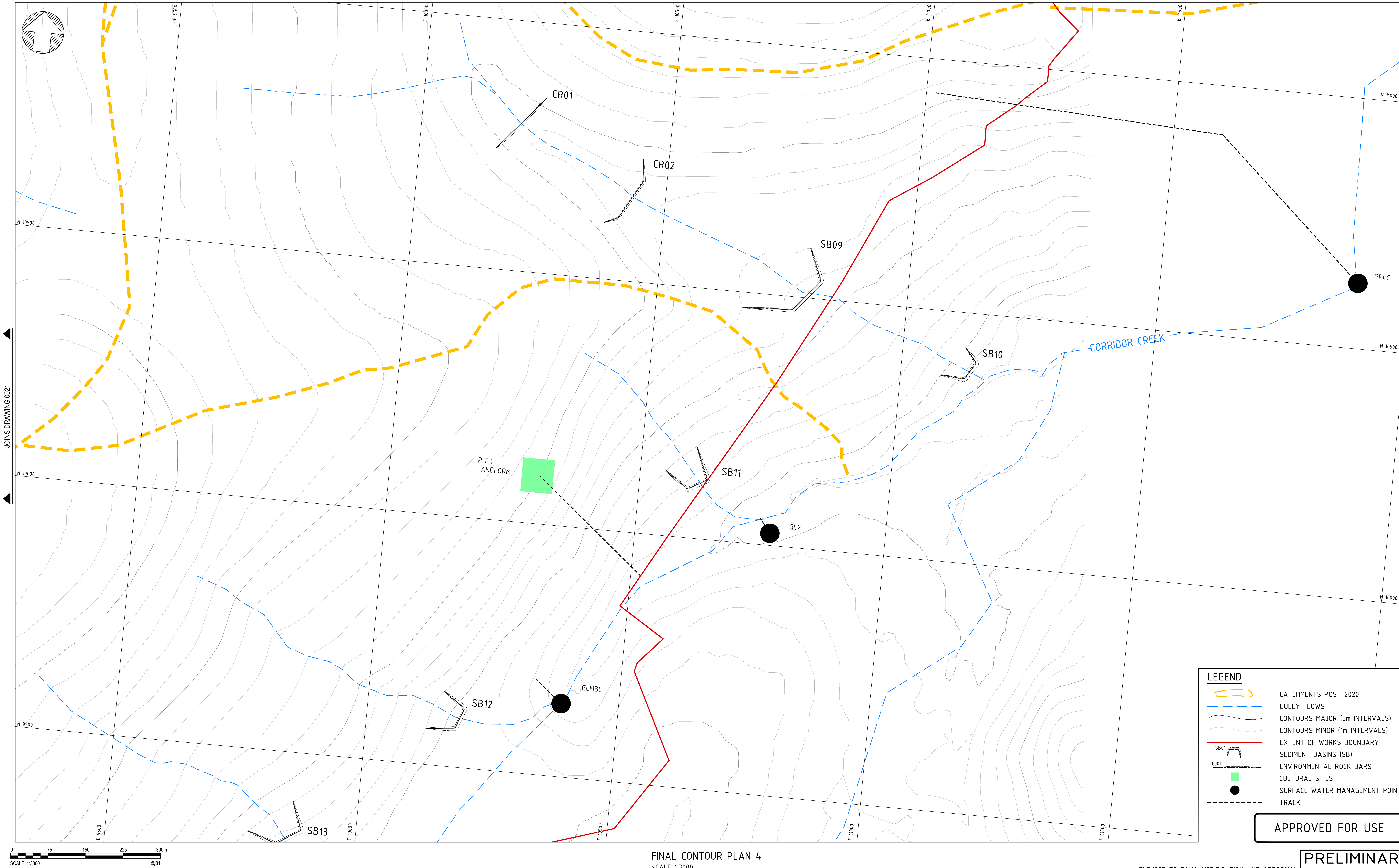
DWG No. H355334-00000-220-272-0004



APPROVED FOR USE

FINAL CONTOUR PLAN 4

SCALE 1:3000

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PRELIMINARY
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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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APPENDIX 9.4 HAZARDOUS MATERIAL AND CONTAMINATION CONTROL PLAN

ERA Energy Resources of Australia Ltd

Hazardous Material and Contamination Control Plan HMP001

Approvals

	Name	Position	Signed	Date
Originator	Anthony Cullen	Advisor Environment	A.Cullen	04/04/2019
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

Contents

Figures

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.

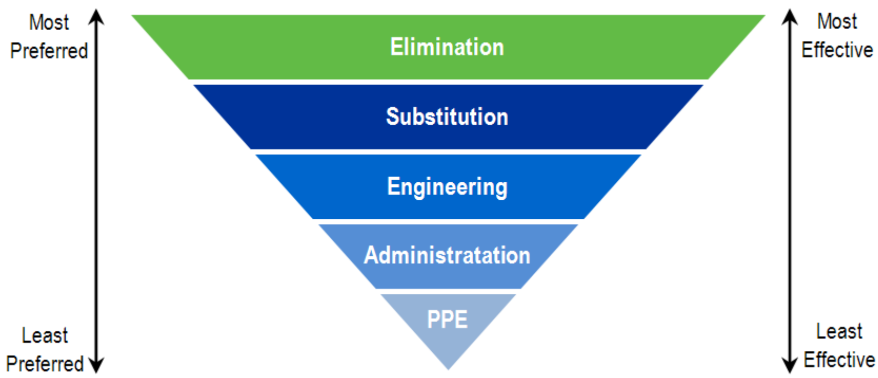

Figure 1: Hierarchy of Controls

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.

ERA Energy Resources of Australia Ltd

10 Closure monitoring and maintenance

Issued date: October 2020

Revision number: 1.20.0

TABLE OF CONTENTS

FIGURES

Cover photograph: Surface water monitoring station in Magela Creek

TABLES

APPENDICES

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 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 Modelling	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 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 Zones	Groupings of hydolithologic units based on similar geological and groundwater flow and transport characteristics.
Landscape denudation	Reduction in elevation and relief of the land surface due to various eroding processes
Landscape 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.

Key term	Definition
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	Period after 8 January 2026 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
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 μJ 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.

ABBREVIATIONS & ACRONYMS

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

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
ARRTC	Alligator Rivers Region Technical Committee
BACIP	Before-After Control-Impact Paired sampling
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
MERRG	Monitoring Evaluation Research Review Group
NLC	Northern Land Council
NP	National Park
PAEC	Potential Alpha Energy Concentration
RPA	Ranger Project Area
RWMP	Ranger Mine Water Management Plan
SSB	Supervising Scientist Branch
TARP	Trigger, Action, Response Plan
TPH	Total Petroleum Hydrocarbon
TSF	Tailings Storage Facility
WASWG	Water and Sediment Working Group

10 CLOSURE MONITORING

This section describes the monitoring programs developed for the Ranger mine to assess the trajectory of rehabilitation actions towards meeting the closure criteria (Section 8) and to address the requirements of the Ranger Authorisation. In accordance with clause 13.3 of the Ranger Authorisation: *"… 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"*.

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. The closure criteria have been developed to demonstrate achievement of the closure objectives and desirable outcomes (Section 8). The monitoring programs discussed within this section apply to the closure and monitoring and maintenance phases as defined in Section 1.3. The monitoring programs discussed below align with the six closure themes described in Section 8.3:

- landform
- radiation
- water and sediment
- soil
- ecosystem (revegetation & fauna), and
- cultural.

Within each closure theme is a description of the proposed monitoring as it will occur during the closure and monitoring and maintenance phases. The proposed closure monitoring programs build on the existing, extensive monitoring regimes established during mining operations at the Ranger Mine. The closure monitoring program is required to assess rehabilitation success, including determination of the protection of potentially impacted ecosystems and environmental values.

Both the monitoring programs and closure criteria are subject to review as the outcomes of studies and/or new information become available and stakeholder feedback is considered. As such, some aspects of post-closure monitoring require finalisation of the closure criteria to develop further. This is an adaptive management process designed to remove uncertainty and meet the closure objectives. Where necessary, amendments will be incorporated into future iterations of the Mine Closure Plan (MCP).

10.1 Closure monitoring program

Monitoring to evaluate performance against closure criteria begins as progressive rehabilitation activities are undertaken during operations and continue into closure. The closure monitoring program will enable an adaptive management approach to site rehabilitation to inform performance strategy. The monitoring program will provide ongoing feedback of the site rehabilitation performance allowing for the refinement of rehabilitation strategies before broad scale rehabilitation.

Operational monitoring programs will provide input into the closure monitoring programs, as required. Technical working groups, and programs that have taken place over recent years, have also informed the development of the monitoring programs outlined in this section. In recognition of the interrelationship between closure related studies undertaken by both Energy Resources of Australia Ltd (ERA) and Supervising Scientist Branch (SSB), the Monitoring Evaluation and Research Review Group was established in 2019. The group, represented by members of ERA and the SSB, as well as subject matter experts as required, is tasked with the ongoing development and refinement of research and monitoring programs during the progressive rehabilitation period.

Monitoring programs associated with closure studies will also continue throughout the operation and closure phases. The research related monitoring programs are captured within the summary of each research project in Section 5.

A Ranger Mine 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).

An overarching framework for the monitoring of Pit 1 was developed in mid-2019: *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1). The framework outlines the two phases of Pit 1 rehabilitation; construction and ecosystem rehabilitation. Monitoring plans will be developed for the two phases as rehabilitation of Pit 1 progresses. The monitoring plan for the construction phase (ERA 2020) was developed by the Monitoring Evaluation and Research Review Group (MERRG) and initiated in early 2020. The monitoring plan to be implemented during the ecosystem rehabilitation phase is currently under development. Success of the Pit 1 rehabilitation will be driven by adaptive management, research and monitoring to establish the overarching framework for ongoing rehabilitation across the Ranger Mine. A number of stakeholders, including the SSB and Alligator Rivers Region Technical Committee (ARRTC), have provided recommendations towards the Pit 1 monitoring objectives and requirements.

10.2 Monitoring and maintenance period program

The monitoring and maintenance program is initiated following the successful completion of decommissioning and rehabilitation. This monitoring phase will occur after January 2026 when the site is progressing towards the development of a long-term stable landform and self-sustaining ecosystem that meets the closure objectives. The adaptive management approach implemented during the transitional monitoring phase (from operations to closure to post-closure) will continue, whereby the monitoring program will provide ongoing feedback of the site rehabilitation performance, identify any issues and inform maintenance activities. However, under the current legislative framework, (*Atomic Energy Act* 1953 - section 41c (5) of the Authority (Nov 1999) (Section 3.1.2) the access of ERA to the Ranger Project Area (RPA) ceases on 8 January 2026. Discussions are currently underway with key stakeholders to enable ongoing access to the RPA after this date, to undertake monitoring and, if required, minor remedial or maintenance works (Section 3.1.5.1).

The monitoring program following the closure period will commence in 2026 and continue until results of the monitoring demonstrate that the site has met the required closure objectives and relinquishment of the RPA is achieved. As this length of time is unknown, ERA have currently assumed a 25 year period of monitoring and maintenance.

During this 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 Table 10-1.

Monitoring the rehabilitation progress of site access tracks and service corridors (the 'linear infrastructure' domain) will be assessed by aerial photography, as it will not be practical to undertake traditional monitoring in the field once tracks are removed. Remedial action will be undertaken, where necessary.

Table 10-1: Examples of maintenance work that may be required during the closure and/or post-closure phases

Action	Description
Minor earthworks	• Will be undertaken to repair any ongoing erosion or other stability issues, identified by landform monitoring. • May include localised maintenance of passive water management structures or sediment basins.
Infill planting	• Highest rates of plant mortality will most likely occur soon after initial planting and routine monitoring will allow for timely remediation through infill planting (timed to occur with annual wet seasons). Infill planting will be undertaken 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. • May also be required when an unplanned large-scale event such as a fire or cyclone causes significant additional mortality.
Weed control	• Weeds may out-compete and smother tubestock, or may increase the risk of fire, and thus increase mortality. • ERA will monitor and maintain a weed control buffer zone around the rehabilitated site. Targeted weed monitoring, as well as the routine revegetation monitoring will identify and record any weed infestations on the rehabilitated landform. • 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 or short acting chemicals, seed head cutting and burning, or fuel-load reduction by fire).

Action	Description
Fire management	• Fire is a part of the current land management of Kakadu NP but is a risk to the initial development of rehabilitation; and therefore, needs to be controlled. • In an effort to avoid fire in revegetated areas, only low-biomass native grasses and herbs will be introduced, along with trees and shrubs, at initial establishment. Fire will be excluded for the first 5-8 years until revegetated species have established a level of resilience (defined in the Ranger Mine Revegetation Strategy, (Section 5) and after which low intensity 'cool burns' will be promoted in the wet and early dry seasons.
Application of fertiliser	• Some of the growth media to be used in rehabilitation may be deficient in nutrients. 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).
Pest control	• High levels of insect damage can cause plant mortality; young plants may also be impacted by native and feral vertebrate fauna (e.g. wallabies or pigs). • Routine vegetation monitoring will identify impacts from the range of potential pest species. • Management of pests may involve spraying with insecticides, temporary fencing, or direct management of feral vertebrate fauna (carried out in accordance with the ERA Fauna Management Plan and in accordance with relevant licences and permits).
Water management	• Passive water and sediment management ponds may require maintenance. • Structures may also need to be decommissioned when no longer required.

10.3 Landform monitoring

A number of landform studies have been undertaken to address key closure issues and risks, and to inform the design parameters of the final landform. A 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 (Appendix 5.1). 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 begin during progressive rehabilitation and continue throughout the closure and monitoring and maintenance phases to assess the condition of the landform. Specific landform parameters are monitored during and after construction to assess stability and suitability for revegetation. The primary objective of monitoring during construction is to assess adherence to the planned landform design; including material transfer and placement. Following construction, parameters such as settlement and subsidence performance; surface topography; surface ripping; erosion and erosion controls; bedload and sediment control; and suspended sediment will be monitored. Further detail on these parameters are included in the Table 10-2.

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 (Supervising Scientist 2017). 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 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.

An important parameter for assessment of site-wide erosion is event load suspended sediment, tracked on a whole of wet season basis. Suspended sediment loads from the landform are expected to reduce over time, trending towards background suspended sediment loads. The SSB has demonstrated turbidity can be used as an indicator for suspended sediment (Moliere & Evans 2010). A comparison of turbidity levels upstream and downstream of the RPA will be applied as a measure of suspended sediment loads leaving the landform and entering Magela Creek or Gulungul Creek. As sediment loads are expected to decrease over time, achievement of the outcome criterion will be based on a trend towards background loads. Inspections for bedload in Magela Creek and Gulungul Creek will also be conducted following every wet season to assess the presence and extent of erosion and inform maintenance.

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. Settlement plates at the interface between the consolidating tailings and the overlying waste rock were installed during placement of the pre-load as part of the backfill of Pit 1. The monitoring plates enable regular verification and updating of the consolidation model. Ongoing measurements of tailings settlement have been undertaken on a monthly basis and confirm that the model is still valid. Use of Satellite based synthetic Aperture Radar is likely to be used to monitor tailings settlement in Pit 3. This will be confirmed in the Pit 3 closure application. Tailings will be monitored for excess pore water pressures via vibrating piezometers.

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. If the final landform varies significantly from the design, the topography will be used to rerun the 10,000 year landscape evolution model. 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 10-2 and Table 10-3, respectively.

10.3.1 Pit 1 landform monitoring

As discussed in Section 9.3, Pit 1 will be ready for revegetation early 2021. This provides an opportunity for a number of trials and monitoring programs to be implemented to develop and refine ERA's ecosystem re-establishment approach, thereby aligning with the *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1).

Pit 1 will be divided into four areas as shown in Figure 10-1. Each area will have a different ripping application applied which is intended to create a natural appearance of the surface topography whilst also providing an opportunity to trial revegetation options (refer Section 9.3.1.3).

Surface topography and micro-surface topography monitoring of each area will be undertaken. In summary, this will include:

- Undertaking an annual surface topography survey in various locations on Pit 1;
- Digital Elevation Model (DEM) surveys to be completed year-on-year; and
- Undertaking visual assessment surveys to monitor micro-topography change.

Post survey and modelling results will be compared with historical data to quantify landscape settlement. Micro-topography monitoring will inform landform closure criteria to determine whether the constructed landform meets the optimised landform design.

Landscape denudation and erosion monitoring will also be undertaken of each area. This will include:

- Telemetry stations at the topographical low of each area will be installed to measure turbidity and total suspended solids (TSS); and
- An estimate of discharge via flow measurements.

Opportunistic water grab samples will also be collected and analysed for key COPCs, including nutrients.

A number of vegetation trials will be undertaken on Area WM-1C. For further detail on these trials, see Section 9.3.1.3.

Table 10-2: Landform closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
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.	*Pit 1 Progressive Rehabilitation Monitoring Framework*
Subsidence or slumping, deformation and/or settlement	Geotechnical monitoring (as described in Section 10.4)	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.	L1
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.	L1
	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.	L1, L4
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.	L1, L3, L4
		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.	L1, L3
Surface ripping*	Map ripped areas	Mapping via GPS tracking, field survey or remote sensing.	Planned ripped areas.	Once, after landform creation.	Not applicable.	L4, L5

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
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.	L2, L3
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.	L2, L3
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.	L3
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.	L5
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.	L5

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	BACIP analysis (Moliere & Evans 2010) after end wet season. Inform assessment of site denudation rates. Turbidity trajectory transitioning to control environment levels after 5 years.	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.	L6

*Adapted from *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1)

Table 10-3: Landform monitoring and maintenance

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
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.	L3
Erosion (general)	Field inspection* of erosion, notes, photographs	General inspection for localised scouring and damage.	All disturbed areas	Biannually	2026-2031**	L3
				Annually	2031-2051**	L3
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	L5
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	2026-2029**	L5
				Biannually	2030-2051**	L5
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	BACIP analysis (Moliere and Evans 2010) after end wet season Inform assessment of site denudation rates. Turbidity trajectory transitioning to control environment levels after 5 years.	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	L6

*Erosion field study methodology to be developed prior to closure and being trialled as part of the Pit 1 Rehabilitation Monitoring Strategy.

**Assuming access to the landform is permitted after 2026

ERA

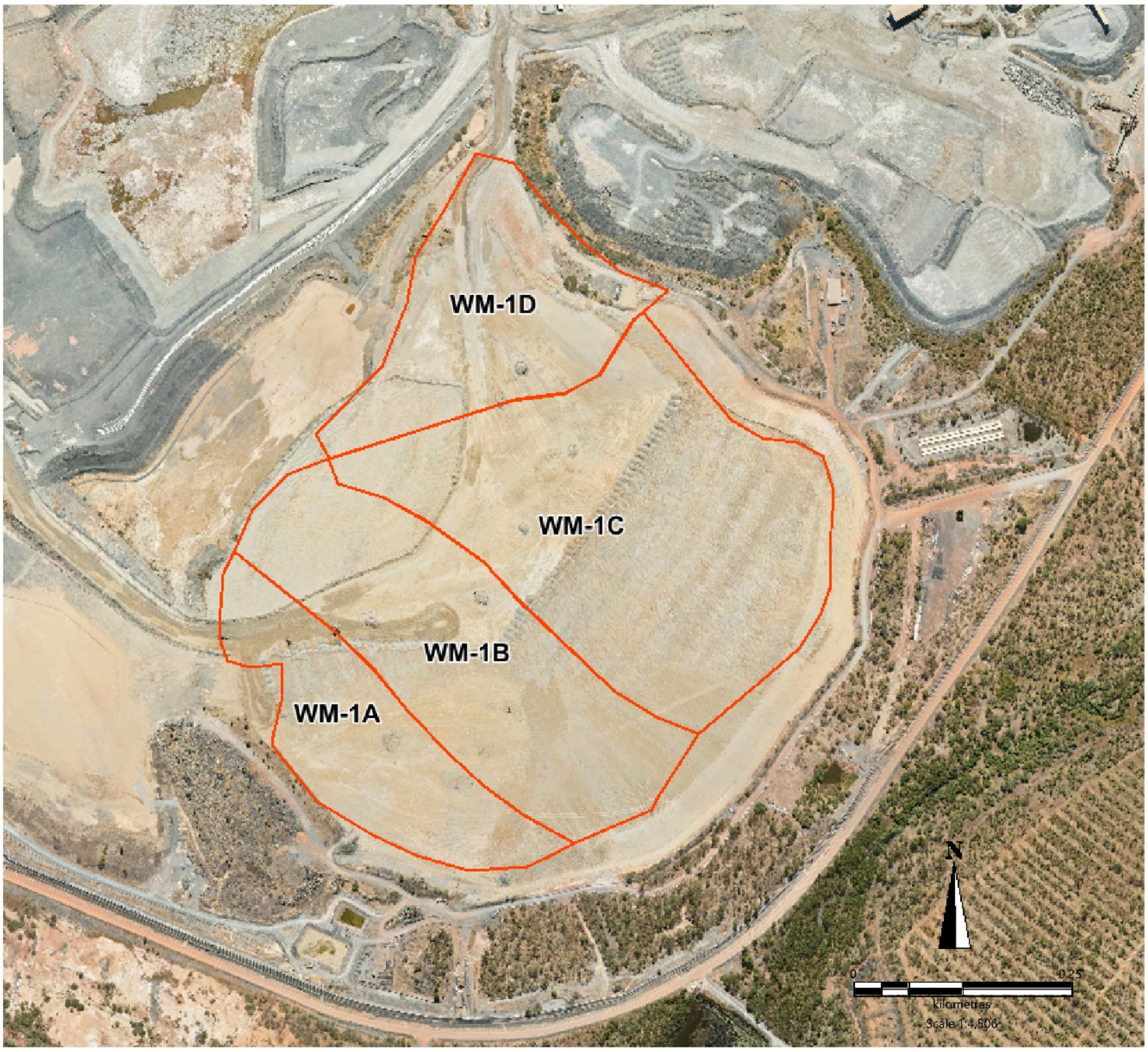

Figure 10-1: Pit 1 ecosystem reconstruction areas

10.4 Water and sediment monitoring

10.4.1 Surface water and sediments

10.4.1.1 Closure monitoring

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 Mine Water Management Plan (RWMP). The RWMP is 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 and 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 which 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 post-closure 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 criteria Table 10-4.

10.4.1.2 Monitoring and maintenance period

Monitoring in the post-2026 period is required to assess rehabilitation success including identifying any unexpected events or concentrations of constituents of potential concern (COPC) (compared to model predicted results), and assessing the protection of ecosystems, human health and environmental values by comparison of water quality against closure criteria.

Groundwater solute transport modelling has predicted long time lags between closure of the mine and delivery of peak solute loads to the creek system. The delivery time frames are dependent on the source of the contaminant, and transport pathway (Section 5).

Timeframes for the peak loads from the different source terms (INTERA 2016) and (INTERA 2020 – TSF modelling) are:

- waste rock runoff – < 20 years
- TSF contaminant plume - < 20 years
- waste rock seepage – ~ 270 years
- tailings and brines – ~10,000 years
- expressed process water (pit tailings flux) from Pit 1, removed and treated currently and throughout closure phase (i.e. prior to 2026).

The surface water model (Section 5) predicts concentrations of COPCs the creeks and billabongs will be exposed to as a result of these loads. Accumulation of uranium in sediments will be calculated based on predicted water quality results and the partition model being developed by the SSB.

Figure 10-2: GC2 monitoring station in the dry season

Figure 10-3: GC2 monitoring station in the wet season

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 post-2026 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.

[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

The proposed post-closure monitoring program, summarised in Table 10-4 provides a basis for determining if the environment and human health will continue to be protected in the post-closure phase, and if the surface water model predictions for that phase are being met.

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 in the post-closure period will be reviewed by the same group.

The locations and monitoring frequencies for current surface water monitoring forms the basis of the proposed initial post-closure monitoring strategy (Table 10-4). 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 within 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 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) (Section 6) will demonstrate acceptable levels of protection for ecosystems and land use on the RPA and
- Comparison of results against model predictions for all of the above sites will be undertaken for validation purposes.

As discussed above, 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.

The proposed initial monitoring program will evolve based on changes in methods and technology (some currently planned), feedback by WASWG and results collected in the initial years of the post-closure monitoring period. All discussions and improvements to this framework will likely be adapted into the broader site-wide closure monitoring programs as planning progresses. It is anticipated that the post-closure monitoring program could be carried out by a local service provider.

The results from the surface water monitoring program in the monitoring and maintenance period, and any triggered investigations and actions, will be provided to stakeholders with an interpretive report of all results at the end of each wet season. Investigation reports will be provided as completed, rather than at the end of the wet season. The need for more frequent reporting, and appropriate formats and levels of interpretation will be considered by WASWG.

The proposed surface water monitoring program details are summarised in Table 10-4 and is applicable to both the closure and monitoring and maintenance phases. Monitoring during the closure phase will identify the potential opportunity to decrease the monitoring scope during monitoring and maintenance.

ERA Ranger Mine	Surface water monitoring sites for the Ranger Mine		0 500 1,000 1,500 2,000 2,500 Metres GDA 1994 MGA Zone 53 Scale 1:30,000
	Authored: G Landwehr	Date: 13/08/2020	
	Prepared by: C Newland	Print Size: A3	
	Map Name: Ranger Mine Surface Water Monitoring V3.mxd		
	Spatial Data: "A5988_Ranger_50mm_RGB_MGA94z53_14-May-2019.ecw", ERA data , NT Government, ESRI Basemaps		

Figure 10-4: Statutory and operations surface water monitoring sites at the Ranger Mine

Table 10-4: Parameters and locations for post-closure surface water monitoring to assess compliance with closure criteria

Location	**Parameter**	**Frequency**	**Closure criteria** Tables 8-5 & 8-6
MG009, GCLB, MCUS, GCC	Turbidity	Continuous	W3,W5, W6, L6, C7
	EC (proxy for Mg)		W3, W5, C7
	Mn, U, SO_4	Monthly grab sampling during the wet season with frequency reduced over time based on performance and risk review.	W1, W2, W3, W5, C7
The parameter list for MCUS and GCC upstream sites may be reduced in future where criteria does not include comparison against natural distributions.	Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N		W3, W5, C7
	NO_3, NO_2		W1, W2, W5, C7
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.	W6, C7
Georgetown, Coonjimba and Gulungul Billabongs	Turbidity	Continuous	W3, W5,W6, C7
	EC		W5, C7
	U, Mn, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, SO_4	Monthly grab sampling during the wet season with frequency reduced over time based on performance and risk review.	W5, W1, W2, W3, C7
	NO_3, NO_2	Monthly (if recreational and drinking water identified as community value for these sites).	W1, W2, W5, C7
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.	W5, W6, C7
	Sediment concentrations and U	Accumulation in sediments limited by U in water criteria. Sediment sampling to demonstrate current[4] compliance via scheduled projects in closure phase.	W4, W5

[4] See footnote against sediment concentration for onsite billabongs.

Location	Parameter	Frequency	**Closure criteria** Tables 8-5 & 8-6
	Sedimentation	Event-based triggered by results of landform monitoring. TBC in consultation with Landform criteria and Water quality stakeholder groups.	W5, L5

10.4.2 Groundwater

10.4.2.1 Closure monitoring

Environmental Requirement (ER) 2.3 *"… provides for minimum restrictions on the use of the area."* However, it was agreed during the Closure Criteria Working Group meeting of 19 August 2008 that groundwater extraction for purposes other than monitoring would not be allowed on the RPA, post-closure. The minutes of the meeting state: *"… that a constraint on groundwater abstraction from Ranger operational area and some surrounds will be needed to prevent bores being sunk in areas where water may be unsuitable for use."*

In this context, the primary objective of the closure groundwater monitoring program will be to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and the regional groundwater environment remains protected. The results of solute transport modelling (INTERA 2014a, 2014b, 2018) 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. Therefore, it is not appropriate to set concentration-based groundwater closure criteria for these units. 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.

Groundwater on the RPA is generally described through discrete hydrolithologic units (HLU). These HLUs are defined based on similar geological and groundwater flow and transport characteristics. The HLUs are split into four typical zones and are summarised in Table 10-5.

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 is intended to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and that the receiving environment remains protected.

Table 10-5: Generally identified hydrolithologic units on the RPA

Hydrolithologic Zone	Geological Description and Typical Depth	Hydrological Description
Alluvial HLUs	The surficial alluvial HLUs include the alluvial sediments (sands, gravels and transported sediments). Alluvial HLUs are present in proximity to the creek channels across the RPA. Typical thickness of the alluvial HLUs are between 8 m and 12 m.	Ephemeral wetting in wet season. Hosts the water table in the wet season. Likely to behave as a porous medium with relatively higher permeability.
Shallow Weathered Rock HLUs	Weathered rock is the mantle of parent rock that has decomposed or altered to contain a large fraction of clay or sandy clay. In general, the thickness of weathered rock across the RPA is about 25 to 30 m but it can be thicker or thinner in local areas.	Ephemeral wetting in wet season. Hosts the water table in the wet season. Likely to behave as a porous medium with relatively moderate to high permeability.
Deep Bedrock HLUs	The deep HLUs are not exposed at the surface. The deep HLUs are those located in the fresh bedrock of the Cahill Formation and the Nanambu Complex. In general, these units start at base of the weathered rock HLUs and extend beyond the base of the groundwater model (700 m+ depth).	Fully saturated at all times (unless affected locally by dewatering associated with mine activities). Typically low permeability with the exception of several discrete zones that with moderate to high permeability. These higher permeability zones include the Deeps Water Producing Zone (DWPZ), MBL zone, depressurised upper mine sequence (D-UMS) and Zone C shallow bedrock. The DWPZ is a higher permeability region located below Pit 3 along a geological contact associated with the Deeps Fault Zone. The MBL zone is a higher permeability conceptualised strip of higher yielding rock. This was defined to explain high groundwater yields near the south-eastern edge of Pit 1. The D-UMS is a higher permeability zone that extends to the north of Pit 3. It is defined by an area where groundwater head responses were observed as a result of Pit 3 mining. Zone C is a relatively small zone of higher permeability shallow bedrock to the south of Pit 3. It is defined by an area where groundwater head responses were observed as a result of Pit 3 mining.
Mine Backfill HLUs	Mine backfill HLUs consist of the material used to backfill Pit 1, Pit 3 and the final landform. This material consists waste rock and tailings. The thickness of these HLUs varies greatly	The mine backfill HLUs consist of materials with both high permeability (waste rock) and lower permeability (tailings).

Hydrolithologic Zone	Geological Description and Typical Depth	Hydrological Description
	depending on location, the Pit 1 and Pit 3 backfill. HLUs extend from ground level to the base of the pit excavations whilst the final landform extends from the natural ground surface to the maximum height of the final landform.	

Groundwater monitoring programs for closure for Pit 3 (Djalkmarra catchment), Pit 1 (Corridor Creek), and R3D are included as components of the Ranger Water Management Plan (2020). The programs have been designed to target pathways for transport of solutes into the environment and the various hydrolithologic units defined in the groundwater conceptual model. New bores have been drilled and developed in the vicinity of Pit 1, Pit 3 and R3D as part of the 2019-2020 drilling program.

The Pit 1 groundwater monitoring program is intended to demonstrate that solute transport velocities and concentrations, within each hydrolithologic unit are consistent with modelling predictions, and that the receiving environment is being protected in this area. A number of opportunities and changes have been identified as a result of updated groundwater modelling information. The monitoring bore layout in the Pit 1 area was therefore changed as part of 2019-2020 Drilling Program. Figure 10-5 shows the location of all groundwater monitoring bores in Pit 1, including the new bores drilled in the 2019-2020 Drilling Program.

The Pit 3 groundwater monitoring program monitors changes in groundwater head and solute concentrations, within each hydrogeologic 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. Adjacent to Pit 3, 13 existing bores are monitored biannually to capture pre and post-wet season groundwater quality. Six new monitoring bores, nested with multiple HLUs and across three different locations were drilled as part of 2019-2020 Drilling Program as shown in Figure 10-5 and Table 10-6. These bores are monitored in accordance with the Ranger Water Management Plan (RWMP 2020). An additional seventh monitoring bore will be installed following completion of backfilling of Pit 3 to monitor head and solute concentration changes in the Pit 3 shallow waste rock backfill, which is expected to be a source for constituents of potential concern. The location and screening parameters of the Pit 1 and Pit 3 monitoring bores are provided in Table 10-6, and Figure 10-6

The site-wide post-closure groundwater monitoring network will be based on the existing network as outlined in the 2018/19 Annual Ranger Groundwater Report (ERM 2020). However, bores within the final landform will be decommissioned when no longer required. This program will also include the Pit 1 and Pit 3 monitoring bores identified below.

The R3Deeps groundwater monitoring program monitors changes in groundwater head and solute concentrations within hydrolithologic units adjacent the underground workings. Proximal to the R3Deeps workings, five existing monitoring bores are monitored biannually to capture pre and post-wet season groundwater quality. The location and screening parameters of the R3Deeps monitoring bores are provided in Table 10-6 and Figure 10-6.

Figure 10-5: Location of Pit 1 monitoring bores

Table 10-6: Parameters for monitoring bores for Pit 1,Pit 3 and R3D closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Monitoring
MB-A	Pit 1	274092	8596243	50	44 to 50	Quarterly WQ & SWL
MB-G	Pit 1	273681	8595812	50	44 to 50	Quarterly WQ & SWL
MB-L	Pit 1	273933	8595935	50	14 to 16	Quarterly WQ & SWL*
R1C3-1	Pit 1	273977	8595978	22.25	16.25 to 22.25	Quarterly WQ & SWL
P1_CL_01	Pit 1	273624	8595993	18	10 - 18	Quarterly SWL
P1_CL_02	Pit 1	273965	8595950	8	2 - 8	Quarterly WQ & SWL
P1_CL_03	Pit 1	274174	8596230	9	3 - 9	Quarterly WQ & SWL
P1_CL_04	Pit 1	274175	8596230	18	12 - 18	Quarterly WQ & SWL
P1_CL_05	Pit 1	274176	8596230	35	29 - 35	Quarterly WQ & SWL
P1_CL_06	Pit 1	274177	8596230	75	63 - 75	Quarterly WQ & SWL
P1_CL_07	Pit 1	273751	8595738	7	4 - 7	Quarterly WQ & SWL
P1_CL_08	Pit 1	273752	8595738	18	15 - 18	Quarterly WQ & SWL
P1_CL_09	Pit 1	273753	8595738	35	29 - 35	Quarterly WQ & SWL
MS4	Pit 3	274311	8598255	9.25	6 to 9.25	Biannual WQ & SWL
MS4-A	Pit 3	274311	8598255	5.25	1.45 to 5.25	Biannual WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Monitoring
P3-4B	Pit 3	273822	8598301	100	60 to 99.5	Biannual WQ & SWL
P3-8	Pit 3	274292	8598235	81	42 to 69	Biannual WQ & SWL
P3-11	Pit 3	274362	8598122	25.6	11 to 25.6	Biannual WQ & SWL
P3-12	Pit 3	273893	8598467	75.6	56 to 71	Biannual WQ & SWL
P3-13	Pit 3	274477	8597921	39	24.6 to 39	Biannual WQ & SWL
P3-15A	Pit 3	274651	8598250	57	39 to 54	Biannual WQ & SWL
P3-15B	Pit 3	274677	8598252	30	22 to 30	Biannual WQ & SWL
P3-16	Pit 3	274117	8598323	57.7	34.7 to 57.7	Biannual WQ & SWL
P3_CL_01	Pit 3	274283	8598187	10	4 - 10	Quarterly WQ & SWL
P3_CL_02	Pit 3	274287	8598183	25	19 - 25	Quarterly WQ & SWL
P3_CL_03	Pit 3	274290	8598181	60	48 - 60	Quarterly WQ & SWL
P3_CL_04	Pit 3	273608	8598337	70	46 – 70	Quarterly WQ & SWL
P3_CL_05	Pit 3	273820	8598300	20	8 - 20	Quarterly WQ & SWL
P3_CL_06	Pit 3	273823	8598299	45	33 - 45	Quarterly WQ & SWL
R3D49S	R3D	274800	8597799	294	263 – 284	Biannual WQ & SWL
R3D52D	R3D	274446	8598214	367	352 - 367	Biannual WQ & SWL
R3D52S	R3D	274446	8598214	284	263 - 284	Biannual WQ & SWL
R3D54	R3D	274562	8597836	397	351 – 393	Biannual WQ & SWL
R3D56A	R3D	274557	8598065	449	0 - 349	Biannual WQ & SWL

* Additional monitoring undertaken to support operational requirements

Figure 10-6: Location of Pit 3 monitoring bores

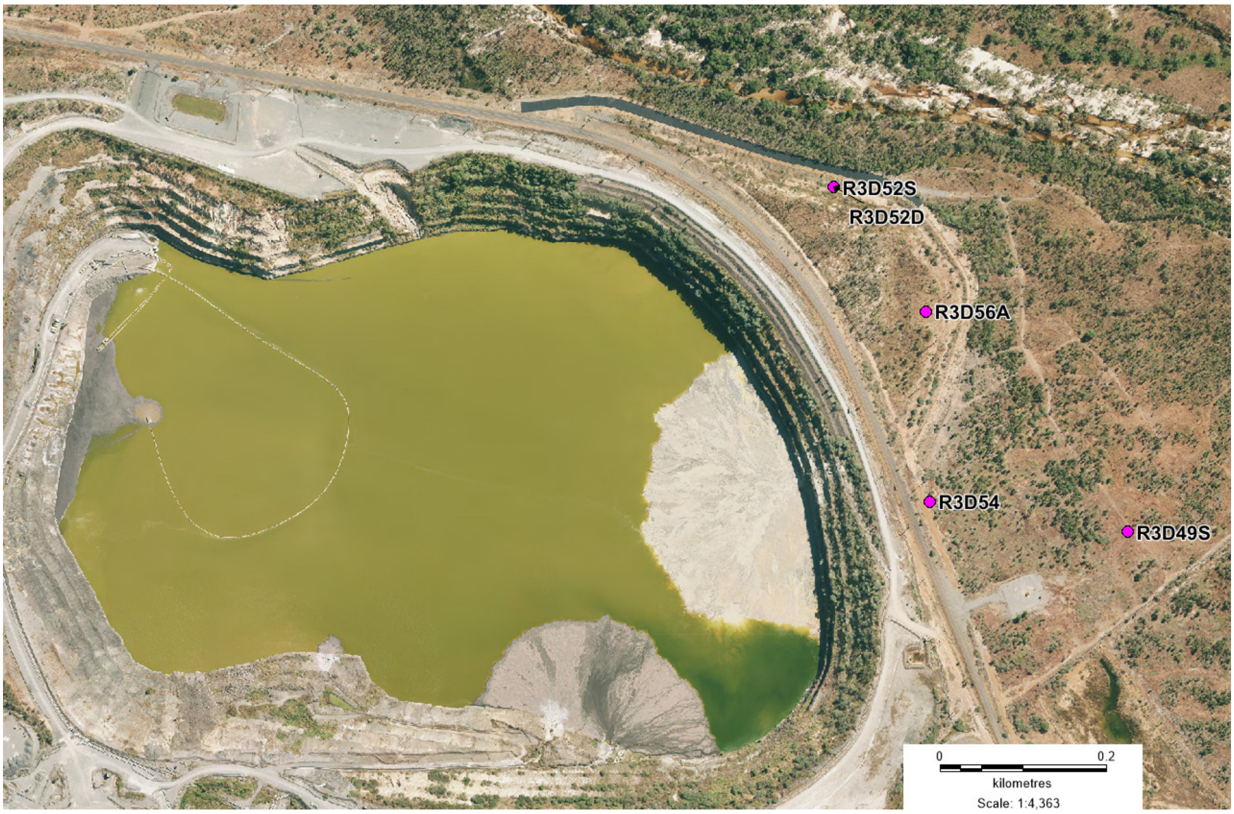

Figure 10-7: Location of R3D closure monitoring bores

A similar monitoring regime will be implemented across the other sub-catchments. This may be in the form of monitoring bores within hydrolithologic units, or in the form of primary, secondary and tertiary bores staged at various distances down-gradient of each potential contaminant source. These bores will provide background water quality data and enable expeditious verification of model predictions and detection of longer range effects of solute migration.

Monitoring of existing bores, as per Table 10-6, is underway. Results are presented in the annually in the Annual Ranger Groundwater Report. Assessment of this monitoring program will undergo continuous review to ensure it remains suitable for supporting closure studies and validating modelling results. Updates of the groundwater monitoring plan to support ongoing closure studies will be detailed in the annual RWMP and subsequent MCPs.

The proposed closure and post-closure monitoring will comprise monthly measurements of standing water level and quarterly or biannual sampling and chemical analysis (Table 10-8). The objective of the post-closure groundwater monitoring program, as with the closure groundwater management 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. 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.

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. These figures will be updated in the post-closure monitoring report as received. Weaver *et al.* (2010) provided a general review of background groundwater chemistry of the TSF. This review is intended as a guide below in Table 10-7. The proposed monitoring will comprise measurements of standing water level plus sampling and chemical analysis at defined frequencies of, for example, pH, EC, Ca, Cl, HCO_3^-, K, Mg, Mn, Na, SO_4^{2}-, ^{226}Ra and U. Updates of the groundwater monitoring plan to support closure will be detailed in the annual RWMP.

The final groundwater monitoring plan for post-closure will be developed with continued stakeholder engagement and advice from INTERA upon completion of the post-closure solute transport modelling. Development of the post-closure groundwater monitoring plan will be detailed in subsequent mine closure plans. The post-2026 groundwater monitoring plan will also incorporate refined background chemistry data as presented in Section 5. Groundwater monitoring currently proposed and executed for closure and monitoring and maintenance period is presented in Table 10-8.

Table 10-7: General background groundwater chemistry for 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		

Table 10-8: 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 10-6	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, Ranger Water Management Plan 2019/20
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 10-6	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			

10.5 Radiation monitoring

10.5.1 Closure monitoring period

The current operational radiation monitoring program will continue throughout the closure phase in accordance with the requirements of the Authorisation. The purpose of this monitoring is to confirm that radiation exposure to workers on the Ranger Mine site and members of the community is kept as low as reasonably achievable (known as ALARA) and below the relevant dose limits. Variations to the monitoring program will be necessary as rehabilitation progresses beyond the cessation of uranium processing.

Radiation monitoring, undertaken for the purposes of assessment of closure criteria, will be limited during the closure phase. Detail will be provided in future MCPs following the outcomes of the Monitoring Evaluation and Research Review Group.

10.5.2 Pit 1 radiological monitoring

ERA is currently finalising the scope of works to undertake radiological monitoring on the completed Pit 1 landform. The following monitoring will be undertaken:

- Surface gamma survey
- Radon 222 exhalation flux density
- Radium 226 substrate sampling
- Passive Radon 222 sampling

Further details on the scope of works is described in Section 5 and will be refined for review by stakeholders before execution.

10.5.3 Monitoring & maintenance period

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 outlined in Table 10-9. 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 Creek and Gulungal Creek 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.

Radiation monitoring for closure and monitoring and maintenance period is presented in Table 10-9.

Table 10-9: Radiation closure and post-closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
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 8 January 2026	R1, R2
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 8 January 2026	R1, R2
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	R1, R2
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	R1, R2

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
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-closure)	R1, R2,
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	Immediately post-closure	R1, R2

10.6 Soils monitoring

The *Contaminated Land Risk Register* has been developed and maintained by the site environment team at the Ranger Mine, in accordance with the operational *Hazardous material and contamination control plan* (ERA 2018). The *Contaminated Land Risk Register* identifies all sites where activities have occurred that have the potential to contaminate land. This register has been developed in conjunction with a number of targeted assessments undertaken at known contaminated sites on the RPA (Sections 5.5.2.5).

The key environmental receptors of the Ranger Mine are the surface water bodies adjacent to the mine site. These receptors are far away from contaminated sites. Groundwater velocities in the underlying formations are low, and the weathered rock underlying the site tends to retard most contaminants. Nevertheless, further characterisation of contaminants at some contaminated sites on the RPA may be required to determine vertical extent, lateral extent and/or mass of contamination.

It is intended that the degree of remediation required for each contaminated site will be remediated to a level where the environmental impact is ALARA to ensure the protection of the environment. Soil assessments, and additional investigations, will be used to undertake BPT assessments which will determine whether remediation action plans are required.

10.7 Ecosystem monitoring

Monitoring is an integral part of the ecosystem restoration process. It is used to determine the initial success of revegetation efforts in establishing the desired species density and composition and evaluate the progress of older revegetation in terms of growth rates, structural development, ecological function and tracking along a trajectory towards longer-term sustainability. 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 (Reddell & Meek 2004).

Ecosystem (revegetation and fauna) monitoring undertaken during the operation of Ranger Mine is presented in Section 5.

The current proposed program allows for potential improvements following a number of investigations proposed for the Pit 1 revegetation works, such as optimised species-specific establishment methods, the influence of substrate characteristics (and soil water availability) on plant success. Thus, the monitoring of Pit 1 will comprise a combination of research structured monitoring along with routine revegetation monitoring methods. The MERRG are currently developing the ecosystem rehabilitation monitoring plan for Pit 1 as part of the *Pit 1 Progressive Rehabilitation Monitoring Framework*. This plan will be completed in late 2020.

The ecosystem monitoring program presented in Table 10-10 represents the routine tasks anticipated for the overall revegetation program, regardless of additional research activities, which will be developed separately. Completion criteria relevant to ecosystem are in Table 8-10 and Table 10-10.

10.7.1 Ecosystem (revegetation) monitoring

The scope and frequency of monitoring is largely dependent upon the stage of development of the revegetation. An initial assessment soon after planting (one to three months) will capture any mortality caused by planting stress or other revegetation execution problems. The highest mortality is anticipated to occur in the first six to twelve months post-planting, due to drought conditions of the dry season. Thus, the determination of the requirement for infill planting will typically be made six to eight months after planting. 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. This initial monitoring will focus on survival rates for tubestock and germination rates for direct seeding, species composition, density, height, health and other opportunistic observations such as weeds, fauna, pests and erosion. Subsets of individual plants will be identified and recorded each year to allow assessment of individual species development.

Initial annual monitoring may involve recording every planted stem, though this will depend on the size of the area revegetated. Alternatively, belt transects, point centred quarter or other techniques may be used to sample a subset of the stems. Some permanent plots will be established and repeatedly measured to gather information on rates of change of various attributes over time. Fixed photo points will be used to provide a visual representation of revegetation progress. For the initial monitoring attributes, consistent methods will be used each year, to enable comparisons over time and between sites, and into the long-term monitoring program.

As the vegetation matures, monitoring of species composition and density will remain essential, whilst other aspects related to ecosystem structure and function will become increasingly important. Attributes to be measured as part of this long-term monitoring program may include occurrence of flowering and fruiting, presence of understorey (including weeds) and leaf litter, canopy cover, tree height and diameter at breast height. Monitoring will also include aspects other than vegetation, such as surveys for fauna, pests, weeds and erosion.

Monitoring of established, maturing ecosystems will focus on comparison with closure completion criteria attributes, and will gradually provide a developmental trajectory including predictive trends towards achieving the criteria.

As secondary introductions of additional plant species and plants occur, additional 'initial' monitoring of these plants will need to occur in addition to the routine vegetation monitoring of the already established vegetation.

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. As development stabilises, the frequency, intensity and potentially the scope of the monitoring program can be adjusted to allow more effective use of resources.

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.

Revegetation monitoring and maintenance will begin following initial planting. The majority of the infill planting and understorey planting activities will occur during this phase. Information provided by the monitoring of established reference sites and revegetation plots will be used to address ecosystem revegetation closure criteria.

The proposed survey frequency of revegetation across the final landform is: three, six and twelve months (year one); annually (years two to five, inclusive); one-off surveys every five years (e.g. at years 10, 15, etc). Some routine surveys, such as weed, will be annual, and every five years a more comprehensive monitoring will be required to demonstrate the trajectory. The details are presented in Table 10-10.

10.7.2 Weed monitoring

ERA has undertaken fine scale annual weed surveys and mapping across the RPA since 2003 (Section 5.3.3.2). This mapping provides data to assess the effectiveness of weed control measures and to inform the ongoing weed monitoring and subsequent corrective actions required to meet closure criteria, particularly within the first five years, whilst the revegetation is establishing.

Weeds may out-compete and/or smother tubestock, or may increase the risk of fire, and thus potentially increase tubestock mortality. ERA will monitor and maintain a weed control buffer zone around the rehabilitated site. Targeted weed monitoring, and routine revegetation monitoring will record if any weed infestations occur on the final landform.

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.

10.7.3 Exotic fauna monitoring

ERA currently undertakes exotic animal monitoring and culling to manage densities of particular species on the RPA, such as pigs. This practice will continue during the initial maintenance period after commencement of post-closure monitoring (e.g. years one to five). Exotic animals will be culled if densities become too high and other remedial actions will be taken if feral animals are adversely affecting physical works (e.g. damaging wetlands or revegetation on the final landform) or significantly compromising recolonisation by native fauna. As the landform develops, exotic animal monitoring and management will revert to that which is followed within Kakadu National Park (NP).

10.7.4 Native fauna recolonisation

Fauna recolonisation closure criteria have been included in the 2020 MCP (Section 8). The fauna criteria is in draft and will require further studies and stakeholder consultation. Once closure criteria is finalised, appropriate monitoring plans will be developed.

Monitoring of fauna recolonisation may be more suitable on a campaign (e.g. five-year) basis in the mature revegetation (along with similar surveys of the reference sites). Some details are presented in Table 10-10.

Figure 10-8: Water quality sampling

Table 10-10: Flora and fauna closure & maintenance period monitoring

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
Initial Establishment Monitoring.	Species composition, total species richness, density and species relative abundance	Use standard NT vegetation survey methods such as plots and transects.	In specific plots to provide representative samples within the RPA. Also to be used following infill planting and remediation that involves the introduction of new plants.	3, 6 and 12 months after planting, and then annually each post-wet / early dry season.	To transition to 'long-term' vegetation monitoring program once rates of attrition reduce and structural and functional attributes begin to develop, e.g. 3-5 years.	E1-4, C10-12
	Survival rates (incl. height and health) for tubestock and germination rates for direct seeding	Rapid assessment of broadscale plant survival using tubestock planting data (location / species). Permanent plots, individual plants assessed over repeat monitoring events. % of planted (or sown) plants.				N/A
	Opportunistic observations such as weeds, fauna, pests and erosion	Opportunistic observations as part of flora monitoring program. Aerial / LiDAR assessment of erosion and/or weeds.				N/A
Long-term Revegetation Monitoring.	Species composition and relative abundance, Stems per hectare	Use standard NT vegetation survey methods such as plots and transects. Bray-Curtis similarity index.	In specific plots to provide representative samples within the RPA.	Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any	Until closure criteria achieved	E1-E7, C10, C12

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
				requirement for active management intervention.		
	Canopy architecture	Presence of multi-strata. Presence of understorey shrubs and grasses developed appropriate to the substrate.		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria achieved	E8-E11, C9-C10
	Canopy cover index, ground cover index	Use standard NT vegetation survey methods. Comparable to appropriate reference sites.		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria achieved	E8-E10, C9-C10
	Tree distribution	Trees are planted in a manner to appear 'natural'. Traditional owners inspection and assessment		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria E11 achieved	E11C4

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
	Reproduction (flowering and seeding)	Evidence of flowering and fruiting		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E12, C10
	Recruitment & regeneration	Presence of seedlings and/or suckers		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E13, C9, C11
	Nutrient cycling	Chemical and biological indicators, e.g., Soil nutrient analysis, Accumulation of litter and organic matter. Evidence of decomposition of litter. Presence of soil, animals and saprophytic fungi.		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E14
	Fire resilience	Vegetation plots/transects Following a recent fire (within the previous five years), all other closure criteria must be shown to have been met, demonstrating recovery.	RPA where required according to fire events	Event-based	Until closure criteria achieved	E15
	Wind & drought resilience	Woodland ecosystem demonstrates survival under natural condition,	In specific plots to provide representative	Event-based	Until closure criteria E16 achieved	E16

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
		similar to appropriate reference sites.	samples within the RPA.			
	Weed composition and abundance	Spatial mapping and density scoring Survey for Class A weeds and Class B weeds and other introduced species.	Spatial mapping: priority species Density scoring: across the RPA	Annual	Until closure criteria E17-19 achieved	E17-E19, C11
Fauna Monitoring	Fauna habitat connectivity: lack of physical barriers (e.g. fences)	Visual assessment	RPA	Annual	Until closure criteria E21 achieved	Draft criteria E21 C3
	Native fauna species richness and diversity: Number of vertebrate Evenness of bird species across sites	Survey plots and transects Pielou's evenness	RPA	Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites). One-off surveys every 5 years (ongoing).	Until closure criteria achieved	Draft criteria E22-E23
	Functional diversity of native fauna: Species richness for each of four Key Functional Groups of ants	Survey plots and transects		Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites).	Until closure criteria achieved	Draft criteria E22-E23

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
	Species richness of nectivorous and frugivorous species			One-off surveys every 5 years (ongoing).		
	Target native fauna species: culturally significant fauna Activity, diversity, and functional diversity of subterranean active termites Number of threatened species	Survey plots and transects		Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites). One-off surveys every 5 years (ongoing).	Until closure criteria achieved	Draft criteria E22-E23
	Exotic fauna Density of buffalo, horses and pigs	Survey plots/transects Density of buffalo, horses and pigs	RPA		Until closure criteria achieved	E20, C12

10.8 Cultural monitoring

Alongside the development of the cultural closure criteria (Section 8.3.6), 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 10-11). 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 10-11: Suggested indicators of cultural health of rehabilitated site (Garde 2015)

Landscape surface	Vegetation	Riparian zone	Biodiversity
Size of rocks	Growth rate	Presence or absence of artificial water bodies	Natural species numbers and diversity
Presence/absence of erosion	Botanical diversity	Visual impressions of water quality, sedimentation, silting of rehabilitated water courses	Impressions of hunting potential
Accessibility	Correct species for ecological zone	Condition of water course margins, creek banks	Impressions of vegetable food availability
General aesthetic (does it look 'natural')	Presence/absence of weeds		

Garde (2015) states that there are very few established models or methodologies to inform programs that assess cultural health. 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.

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 10-12).

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:

1. TSF rehabilitated landform
2. Pit 3 rehabilitated landform

3. Retention Pond 2 (RP2) rehabilitated landform
4. Pit 1 rehabilitated landform
5. Retention Pond 1 (RP1)
6. Kundjinba Billabong (Coonjimba Billabong)
7. Georgetown Billabong (Madjawulu)
8. Brockman irrigation area (i.e. Corridor Creek LAA)
9. Karnbowh Djang (Tree Snake Dreaming), and
10. Ranger Mine 34 archaeological site (quartz outcrop with grinding holes).

Table 10-12: 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. The GAC and the NLC have been working with Traditional Owners and Murray Garde to build on previous work completed. Once GAC and NLC have finalised the proposed process, it will be reviewed by ERA and incorporated into future revisions of the MCP.

10.9 Trigger, action, response plan (TARP)

The monitoring program described in Sections 10.3 to 10.8 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 10-13.

Table 10-13: Trigger, action, response plan

Aspect	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: 18 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: BACIP analysis (Moliere & Evans, 2010) 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)
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)	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	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
	Analysis: Chemical analysis of samples and continuous EC Frequency: Ongoing monitoring for EC (Mg), scheduled grab sampling			Review model assumptions and outputs	
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 a	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)orm.	To confirm radiation doses 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). Bushfoods to be collected from the RPA. Analysis: Gamma spec analysis 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: Aplha spec analysis and ICP-MS Frequency: Field campaigns with traditional owners and park rangers	As above	As above	As above	Radiation Safety Officer (or delegate)
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)

Aspect	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
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	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 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[5] weeds. Class B[2] weeds similar to surrounding Kakadu NP (defined by monitoring). Presence of other introduced species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	Site Environmental Officer (or delegate)
Cultural					
Cultural values	To be determined (see Section 10.8)	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)

[5] Class A Weeds are to be eradicated. Class B weeds growth and spread to be controlled

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Soils					
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)

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APPENDIX 10.1: PIT 1 PROGRESSIVE REHABILITATION MONITORING FRAMEWORK

ERA Energy Resources of Australia Ltd

2rog

Pit 1 Progressive Rehabilitation Monitoring Framework

April 2019

Author(s): Dr Paul Frazier (2rog)

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V1b	4/02/19	Final	PF	EF	PF
V2	9/04/19	Following SSB review	PF	EF	PF

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FIGURES

TABLES

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.

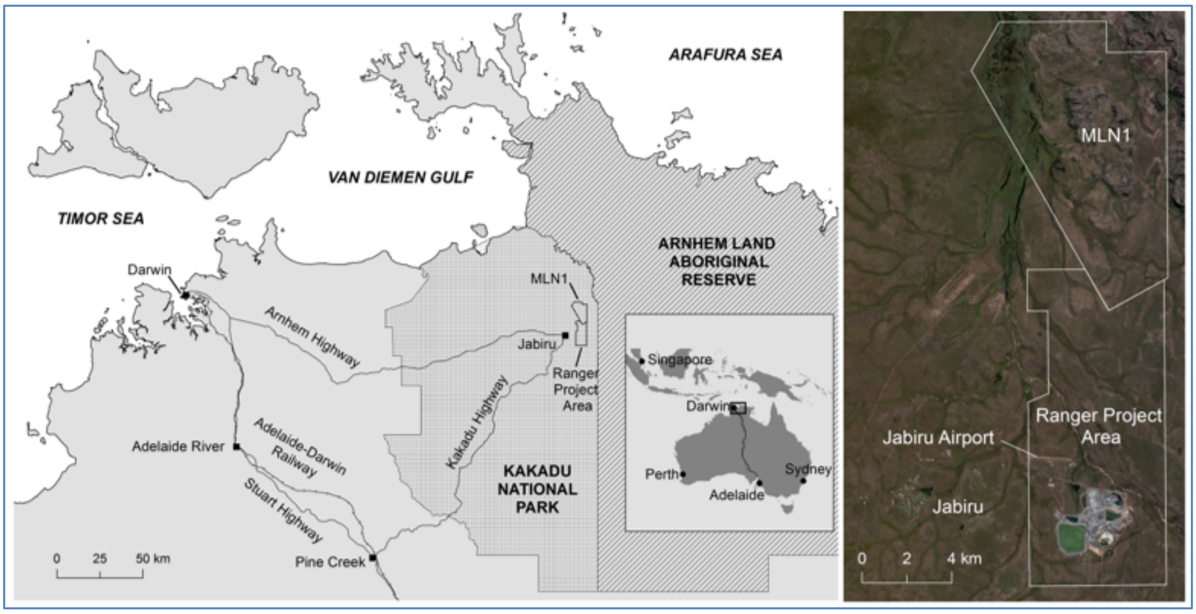

Figure 1 Ranger uranium mine location

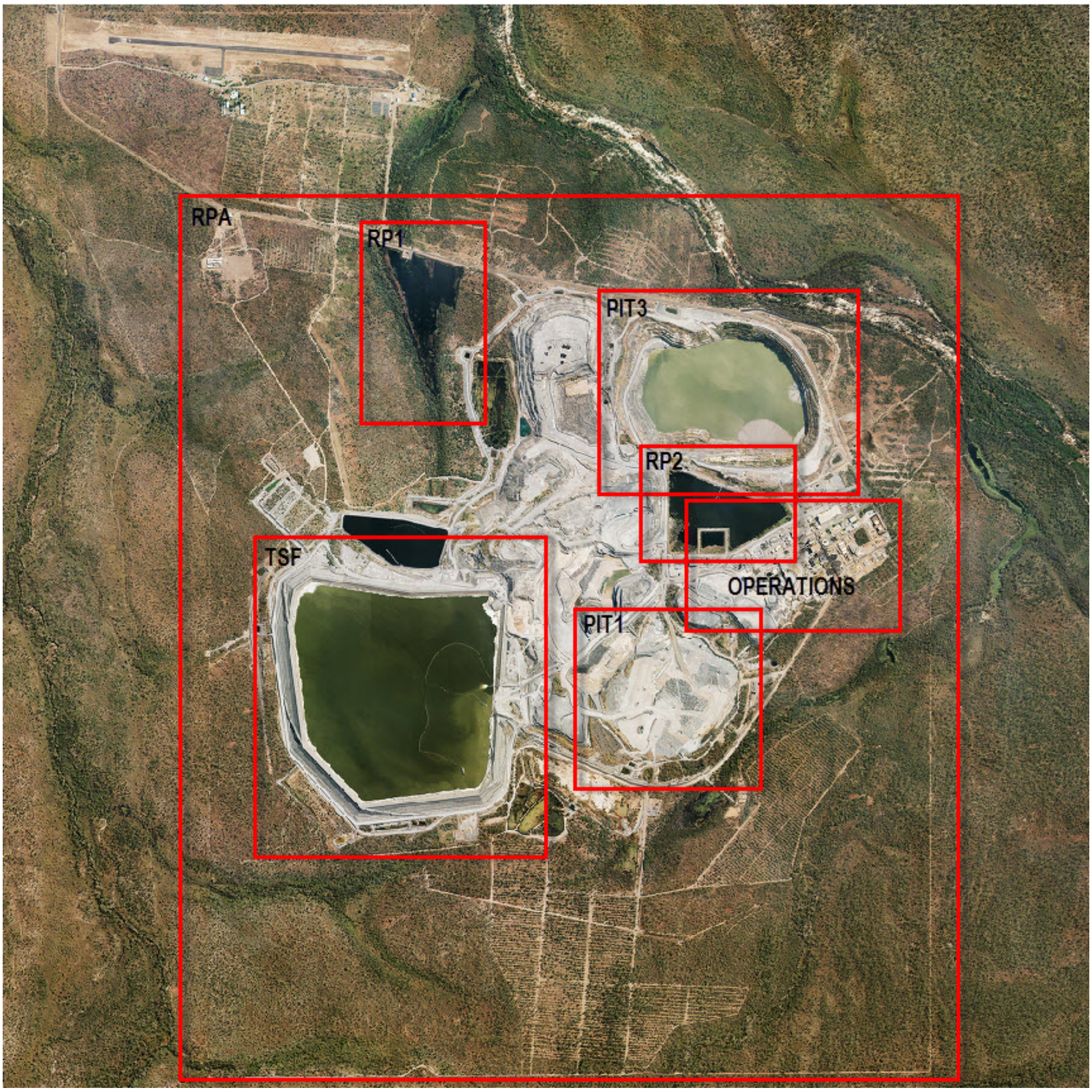

Figure 2 Aerial imagery of Ranger Mine layout with Pit 1 identified (Photo capture June 2018)

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 [illegible]
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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ERA Energy Resources of Australia Ltd

11 Financial provision for closure

Issued Date: October 2020

Revision #: 1.20.0

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Cover photograph: Cluster Fig (*Ficus racemosa*) recruit on the trial landform (2020)

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
BC	Brine Concentrator
ERA	Energy Resources of Australia Ltd
HDS	High Density Sludge
MCP	Mine Closure Plan
PFS	Prefeasibility Study
RPA	Ranger Project Area
TSF	Tailings Storage Facility
WTP	Water Treatment Plant

11 FINANCIAL PROVISION FOR CLOSURE

11.1 Rehabilitation provision

The Energy Resources of Australia Ltd (ERA) rehabilitation provision as at 30 June 2020 was $744 million.[2] The calculation of the rehabilitation provision relies on estimates of costs and their timing to rehabilitate disturbed land to a condition similar to the surrounding environment. It should be noted that the rehabilitation provision also includes costs which are outside the scope of the Ranger Mine Closure Plan (MCP), such as Jabiru head-lease expiry related costs, staff redundancies and various corporate costs.

The Ranger rehabilitation costs are estimated on the basis of this MCP and the closure model, taking into account considerations of the technical closure options available to meet all ERA obligations. The provision for rehabilitation represents the net present cost at 30 June 2020 of the preferred plan within the requirements of the Ranger Authority.

The closure model is based on the closure feasibility study, completed in February 2019, which expanded on the previous prefeasibility study (PFS) completed in 2011. Key packages of work completed since 2012 include preliminary Pit 3 backfill, Pit 1 capping and design, construction and commissioning of the tailings dredging system. The feasibility study has increased the level of certainty regarding forecast rehabilitation expenditure.

Major activities to complete the rehabilitation plan include: material movements, water treatment, tailings transfer, demolition and revegetation. Major cost sensitivities include material movements, water treatment and tailings transfer costs.

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. It is reasonably possible that outcomes from within the next financial year that are different from the current cost estimate could require material adjustment to the rehabilitation provision for the Ranger Project Area (RPA).

Selected downside sensitivities on the Ranger rehabilitation provision are detailed below.

[2] The 30 June 2020 provision discounted at 2 per cent and presented in real terms ($785 million undiscounted in real terms).

11.1.1 Process water

In order to increase process water treatment capacity, ERA has progressed the recommissioning activity of the High Density Sludge (HDS) plant, the commissioning of the Brine Squeezer (including preparing for process water treatment trials) and the Brine Concentrator Expansion Project. The recommissioning of the HDS plant has been impacted by both the timing of external consents and a number of technical commissioning issues. Subject to future process water inventory volumes, this may necessitate the HDS operating for longer than previously planned. The Brine Squeezer commissioning has progressed, albeit with production limited due to low pond water volumes at present. Trials to evaluate the potential for the Brine Squeezer to treat process water are planned for the second half of 2020. The Brine Concentrator Expansion Project is progressing with commissioning expected in quarter 1, 2021.

Additional process water volumes are sensitive to many factors and any additional water would require treatment through the ERA process water treatment infrastructure, primarily the Brine Concentrator (BC). Water volumes can vary due to:

- additional rainfall above an average wet season
- the performance of water treatment plants (WTPs), including new smaller scale plants that are yet to be commissioned
- the timing of closure of which water catchments occurs, and
- the volume of water expressed from tailings.

If water treatment volumes exceed the available capacity, it may be necessary to expand treatment capacity. This may involve the construction of an additional BC plant or other alternate technology. This has not been allowed for in the estimate and would come at significant additional cost. Furthermore, any significant delay may further compress the schedule requiring alteration to other closure activities.

11.1.2 Bulk material movement

Pit 3 bulk material movements are sensitive to the volume of material which is to be moved and the schedule of movement.

11.1.3 Tailings transfer

Tailings transferred from the Tailings Storage Facility (TSF) to Pit 3 are sensitive to the characteristics of the tailings being moved. During the first half of 2020, the productivity of the dredging operations was constrained due to ongoing interstate travel restrictions in place as a result of the COVID-19 pandemic and lower free process water volumes. ERA has now implemented a revised dredge plan which reduces the potential impacts of lower free process water volumes through the remainder of the year.

11.1.4 Tailings consolidation

Following the completion of transfer of tailings to Pit 3, the final capping of Pit 3 will commence. During the capping process the tailings in Pit 3 will consolidate and express process water that 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 tailings. The consolidation model accuracy and 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.

ERA continues to monitor the rate of tailings consolidation in Pit 3 compared to the consolidation model assumed for the purposes of the closure feasibility study. It is becoming apparent that a greater proportion of process water is being retained within the tailings than planned.

11.1.5 Other factors

In addition to the factors identified above, the estimate is sensitive to many additional items, including: evaporation rates, stakeholder requirements, brine salt disposal, TSF conditions, engineering studies, 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 2020, the real discount rate was 2.00 per cent.

ERA considers further specifics of the closure cost estimate to be commercially sensitive information.

11.2 Government agreement

Separate to this MCP, each year ERA prepares and submits an Annual Plan of Rehabilitation (APR) to the responsible Commonwealth Minister for assessment and approval in accordance with the Ranger Uranium Project Agreement between ERA and the Commonwealth Government (Government Agreement). The specific purpose of the APR is to determine the securities amount to be held by the Commonwealth Government for Ranger rehabilitation obligations; these funds are held in the Ranger Rehabilitation Trust Fund. Once the APR is accepted by the Commonwealth Government, the APR is independently assessed and costed and the amount to be provided by ERA into the Ranger Rehabilitation Trust Fund is determined.

ERA Energy Resources of Australia Ltd

12 Management of information and data

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Cover photograph: Caterpillar on *Eucalyptus tintinnans* on 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
ANRDR	Australian National Radiation Dose Register
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ARRTC	Alligator Rivers Region Technical Committee
ERA	Energy Resources of Australia Ltd
LIMS	Laboratory Information Management System
MCP	Mine Closure Plan
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.

The retention and management of this information is important to demonstrate the appropriateness of, and adherence to, the closure strategy, drive change where required and provide a history with which to inform any future issues. Ultimately, this information will be utilised for the preparation of the Completed Works Final Report due for submission in 2026.

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 such stakeholders as 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, and provides stability in relation to retention of knowledge should key staff leave.

To support the transition from operations to closure, and beyond, a program of works is in development to ensure critical information is available. In accordance with the prescribed legal requirements, the program will ensure that the Information Systems can be maintained and, where necessary, relocated efficiently and effectively without disrupting the activities of the

[2] AS4801 has been superseded by ISO 45001. ERA will move to ISO 45001 in 2021.

Business Unit, Operations and the Project 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
- development of a handover specification detailing data source, nominating handover recipient, detailing data type, reason for handover and indicative timelines.

Data shall be adequately collected and recorded for the purpose of communicating information either internally or externally, as required. Long term obligations towards data and information management are represented in various legislative requirements. A specific example of this is;

> Schedule 7.5 of the Authorisation 108 (2018) requires 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 Authorisation 0108, determines that the company must make data and reports available to the major stakeholders (Schedule 13.2a) and make reports, other than commercial-in-confidence matters, available to members of the Advisory Committee established under the *Environment Protection (Alligators Rivers Region) Act 1978* (Schedule 13.2b). In accordance with Appendix D of the Authorisation 0108, provision of monitoring data, including routine water quality reports is to be submitted weekly during flow events and monthly at all other times. With regard to research undertaken, plans and results must be provided to the technical committee established under the *Environment Protection (Alligators Rivers Region) Act 1978,* as per Schedule 15.1 of the Authorisation 0108, to enable the Technical 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, hazardous substances (asbestos, carcinogens etc.) exposure records are to 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 indicative types of data collection at ERA, and the internal/external departments and groups responsible for the 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. ERA maintains these datasets within its various document management systems.

Table 12-1: Indicative data collection types

Type	Storage/software	Reporting	Objective(s)
As built records (drawings)	• Data viewer • ERA server and centralised data storage systems (including 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	• To record project decisions • To manage change in strategy documents
Ecological surveys	• TIMS Trimagic Enterprise Library • ERA server and centralised data storage systems	• Periodical reports (developed internally and externally) • Ranger MCP • ARRTC	• To record and demonstrate progressive remediation and rehabilitation • To inform closure criteria • To inform revegetation strategy
Geochemical QA/QC	• LIMS • TIMS Trimagic Enterprise Library • ERA server and centralised data storage systems	• Mining Management Plan • 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	• Vulcan 3D Geomodelling • ERA server and centralised data storage systems • TIMS Trimagic Enterprise Library	• Mining Management Plan • Ranger MCP Annual Report	• To record and demonstrate progressive remediation and rehabilitation • To inform closure criteria • To input into modelling
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

Type	Storage/software	Reporting	Objective(s)
			• To validate groundwater models
Materials movement tracking	• Hexagon MineEnterprise/ MineOperate	• Mining Management Plan • 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	• Labware LIMS Radiation • ERA server and centralised data storage systems	• 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	• TIMS Trimagic Enterprise Library • ERA server and centralised data storage systems	• Mining Management Plan • 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 • To maintain construction standards
Surface water and groundwater monitoring (including spatial data)	• Laboratory Information Management System (LIMS) Water • Hydstra • LoggerNet Water Telementry • OPSIM • ERA server and centralised data storage systems (Map info files)	• Mining Management Plan, subject to periodical review, assessment and approval via the Minesite Technical Committee (MTC) • Ranger Annual Groundwater Report • Annual Ranger Wet Season Report • Routine water quality reports • Ranger Mine Closure Plan (MCP), subject to periodical review, assessment and approval via the MTC • Alligator Rivers Regional Technical Committee (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	• Mining Management Plan • 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	• Mining Management Pan	• To record and demonstrate progressive remediation and rehabilitation • To meet regulatory compliance requirements
Incident notification	• RTBS	• Mining Management Plan • Ranger MCP • Annual Report • Periodical reports (developed internally and externally) • ARRTC	• To maintain and record incident related information

GLOSSARY

Below are terms used throughout the Ranger Mine Closure Plan

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.
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.

Key term	Definition
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.
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	Period between 8 January 2021 & 8 January 2026 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.
Conceptual Reference Ecosystem	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.
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.

Key term	Definition
Gamma Radiation	Ionizing electromagnetic radiation emitted by a radionuclide during radioactive decay
Georgetown Billabong	The statutory surface water monitoring point for Georgetown Billaboing, 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.
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.

Key term	Definition
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 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	Period after 8 January 2026 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	Period prior to 8 January 2021 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.

Key term	Definition
	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.
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.
Ranger Mine 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 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

Key term	Definition
	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).
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.

Key term	Definition
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. 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.

Key term	Definition
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.
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
XPAC	A mine scheduling software.

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 2020 Ranger Mine Closure Plan either directly or indirectly via workshops, studies, consultation and advice.

Energy Resources of Australia Ltd

APPENDIX A: Stakeholder feedback

Issued Date: October 2020

Revision #: 1.20.0

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
1	3.1 Risk assessment	To justify the assignment and ranking of risks, risk classes, controls and control effectiveness, the risk assessment should include: • evidence to justify the likelihood and consequence rankings, including key assumptions and the level of certainty associated with the information informing this evaluation • a clear distinction between existing and proposed controls, and evidence to support control effectiveness rankings including consideration of control applicability or availability during the three closure phases (i.e. decommissioning, stabilisation and monitoring and post-closure) • a clear plan to obtain additional information to inform the assessment of each risk, to improve the control effectiveness, or to identify new risks as further information is obtained, where required.	The 2019 MCP includes further information to justify the assignment and ranking of risks, risk classes and controls. It is acknowledged that further development and refinement will be achieved in the 2020 risk assessment update, and these continual improvements will be included within each MCP update.	*Acknowledged* Noted that the 2019 MCP does not appear to include further information to justify assignment and ranking of risks, classes and controls.	The 2020 MCP has included more details on the closure risks. This is now in Section 7. The risk register provided in Appendix 7.1 has been updated to provide additional clarity.	7
2	3.1 Risk assessment	Terms and definitions should be simplified and standardised	[SSB - No response]	*Not addressed*	Terms and definition have been added at the beginning of the Section 7	7
3	3.1 Risk assessment	The likelihood classifications may need to be reconsidered given the long timeframe for the life of the project (10,000 years).	[SSB - No response]	*Acknowledged* Timeframes have been added to the likelihood classifications, although it is not clear how these were considered in the risk assessment scoring.	It is noted that some risks have the 10,000 year timeframe. The likelihood rankings used by ERA do not span this timeframe; however, it is the consequence of the risk occurring any time within the 10,000 years that is assessed. Based on this the likelihood descriptors are considered appropriate.	7
4	3.1 Risk assessment	Additional discussion around control effectiveness and contingencies should be provided for existing controls that: • might be removed during decommissioning • are known to be ineffective at the time of reporting.	[SSB - No response]	*Not addressed*	See response to comment 1 above. Additional information on contingencies for each of the closure execution activities is provided in Section 9.	9
5	3.1 Risk assessment	Table 9-6 should include: • reference to the existing controls • the phase of closure for which the risk is being assessed	[SSB - No response]	*Not addressed* Table 10-5 includes reference to controls noting that there is no distinction between	The risk assessment section in the MCP has been updated to distinguish between controls and actions. Actions, when implemented and realised becomes controls.	7

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
		• risk TC4-03: Delays to rehabilitation and/or closure activities extending beyond 2026 in the Aquatic Ecosystem risk category (TA), as well as the People risk category (TC).		existing/potential controls, or the relevant closure phase.		
6	5.10 Landform. Detailed activity description	Provide additional information, including: • detailed construction plans and timelines • engineering designs, construction tolerances and a digital elevation model • material movement and balances (including reference to consolidation models) • assumed availability rates/capacities of key equipment • mapped locations of material grades • quality control procedures to be employed during construction • a schedule showing material movements as the landform is constructed.	This additional information will be provided within the MTC application (final landform and revegetation) due for submission in 2022.	*Acknowledged* In addition to the previously-listed information, the following should also be provided: • plans/designs for the distribution/extent of the different surface materials (waste rock, rock armour, ripping, natural surfaces) on the final landform • engineering designs and long-term management plans for proposed sediment and erosion control structures on the final landform • up to date flood modelling	Section 11 of the 2019 MCP and the associated appendices provided all of the feasibility study engineering drawings for the final landform, ripping, erosion controls and the latest flood modelling ready for execution. It is not clear what additional information is required.	9
7	5.10 Landform: Landform Stability	Provide the following information on the proposed flow and sediment control structures, including: • the design • a program of maintenance • the volume of bedload requiring disposal • potential impacts and planned mitigation measures that the structures are ineffective	Design features are provided in Section 11. The maintenance is included within Section 12 - Monitoring and maintenance.	*Acknowledged* Most information has been provided, except volumes of sediment requiring disposal.	It is not possible to determine the volumes of sediment that will require removal from the sediment traps each year as this will be highly dependent upon the final rock placed on the surface and the rainfall for that year. As such ERA's maintenance program will be adapted each year as required.	9
8	5.10 Landform: Landform Stability	Provide information on the background bedload yields, to assess the potential impacts associated with bedload transport to Magela and Gulungul creeks (should this occur).	This KKN is planned to be completed in 2020, and the results will be incorporated into the next MCP update, and will supply the details requested in the comment.	*Acknowledged* Note that the primary relevant KKN is LAN1B.	KKN LAN1B is now a SSB KKN. SSB have allocated new projects to address the knowledge need (RES-2019-022).	N/A
9	5.10 Landform: Landform Stability	Assess the potential risks of extreme events and landscape-scale processes on landform stability.	These risks were considered under Category B, C & D of the August 2019 Risk Assessment. This also included consideration of greater than expected rainfall events, variation of predicted Pit 1 & 3 consolidation, excessive erosion impacting landform stability and the potential effects of large scale fire or cyclone events.	*Acknowledged* This will be addressed with completion of relevant ERA/SSB projects allocated to KKN LAN2.	No further action required	N/A
10	5.10 Landform: Landform Stability	Use synthetic rainfall datasets in flood modelling.	The LEM (landform evolution model) does utilise a synthetic rainfall data set for 10,000	*Not addressed*	The flood modelling completed for ERA assesses the early year sediment and erosion controls and does not require the	5

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
			years, and also considers climate change scenarios.	The comment was in relation to use of synthetic rainfall data in flood modelling, not LEM modelling.	long term data set. The LEM modelling requires the synthetic long term data set. ERA is currently evaluating the final landform and completing sensitivity testing of key LEM model parameters including climate sequences, rainfall losses, particle size distribution and vegetation cover. In these evaluations, the synthetic rainfall data set of the SSB has been used. See also comment 35.	
12	5.10 Landform: Infrastructure Disposal	Section 7.5.1 states that all material with the potential for environmental impact will be placed at the bottom of the mined-out pits. It is suggested this statement is removed from the plan as it is not readily achievable given grade 1 waste rock has the potential for environmental impact.	[SSB - No response]	*Not addressed* It is noted that this comment was in the text but not specifically included in the relevant summary table of comments/recommendations in SSB's 2018 Assessment Report.	The statement was removed from this Section. Waste and hazardous material management are now discussed in Section 9.4.2	9
13	6.8 Water and Sediment: Water Management	A schedule should also be included for water treatment, indicating the planned options for process water treatment and demonstrating that these options will be sufficient to treat the predicted process water volumes.	A schedule for water treatment has been included. Three active process water treatment routes are planned: • Treatment using the existing Brine Concentrator. The Brine Concentrator will be the principal path for active process water treatment, with its feed water stream drawn from the bulk process water inventory – which is typically the highest. A feasibility study is underway to incrementally expand the distillate production capacity of the Brine Concentrator through an upgrade of the vapour recompression fan in unit three. Under the median forecast, the Brine Concentrator will be decommissioned in June 2025 – after all sources of process water have ceased. • Treatment using the HDS plant. This plant will treat an intermediate range of process water in terms of salt concentration, to minimise treatment cost and maximise plant throughput. HDS plant operation is planned from 2019 through to the end of 2021. • Treatment using reverse osmosis technology, of similar nature to (and perhaps using) the Brine Squeezer. This treatment process will target sources of process water with lower salt concentration, and is expected to run through to the middle of 2025.The contributions of the three active process water treatment routes are shown in Figure 11-29.	Acknowledged. Given the uncertainty associated with the predicted process water volumes up to 2025, it is critical that ERA is able to fulfil its identified contingency to continue water treatment and disposal of all process water (including expressed tailings pore water) for as long as necessary. As the process water treatment predictions are further refined, this may also have implications for the disposal of brine in Pit 3. Additional information should be provided in the RMCP, including: • results of investigations undertaken in order to reinstate the Pit 3 underdrain extraction bore • evidence to demonstrate the longevity of the brine injection wells and factors that may affect this.	ERA has acknowledged for some time that there are scenarios in which water treatment may need to be extended, such as if significantly above average rainfall occurs in one of the later wet seasons within the rehabilitation period before catchment areas are sufficiently progressed through planned transitions to pond and ultimately release water designations. ERA will maintain such water treatment infrastructure as is necessary to complete water treatment and the disposal of waste streams. It should be 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. In regard to the underdrain bore, the bore casing and annulus was surveyed 3 times by full-wave sonic cement bond logging to identify potential failures in the cement bond in the annular cavity. The casing was perforated at a specific point and pressure-injected ~2,200litres of grout to seal the annulus. This was again wireline surveyed to confirm the cement bond. A low-mobility grout was placed below the intersecting lateral to seal that zone. This work is completed to minimise the potential for groundwater infiltrating the	9

ERA

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
					borehole and will be validated during commissioning and performance testing. As a further contingency plan, a new design has been sourced for a vertical decant well. In regard to the brine injection wells, early operation was significantly impacted by the on/off nature of the brine concentrator operation due to a range of factors. This intermittent operation contributed to blockages within the brine injection wells through scaling / and crystallisation of salts out of the highly concentrated brine. This was known at the time of the Closure Feasibility Study and as such provision was made for the construction of additional brine injection wells. Engineering and design activities for these additional wells is occurring through 2020. Since 2017 the performance of the brine concentrator has improved significantly such that unplanned outages have been effectively eliminated. The risk to the integrity of brine injection wells is consequently also significantly reduced. Ultimately the longevity of individual wells, whilst impacting costs, is not a risk to closure schedule or environmental outcomes, as additional wells can be constructed as required. In addition to the option for additional wells as required, ERA is investigating the use of higher injection pressures and different maintenance options and contingency options for two brine injection failure scenarios. This is summarised in Section 9.3.2.4. However, as these investigations are continuing, detail cannot be provided in the 2020 MCP.	
14	6.8 Water and Sediment: Water Management	Clarify why tailings pore water expression during deposition has increased by more than 30% in consolidation modelling results between 2014 and 2016.	Further explanation has been included within Section 7.1.3.	Not addressed In 7.1.3 it is stated that: 'The increase in expressed water (for the 2016 case) during deposition is due to thickening after Year 1 in the 2014 case.' However, the latest 2018 modelling shows that expression is now more consistent with the 2014 case (rather than 2016), which assumed thickened tailings.	The 2014 modelling considered tailings thickening which allows more water to be freed from the tailings at the process plant and recycled into the process circuit. As a result, the ex-mill tailings have less water available for expression during deposition into the Pit. The 2016 modelling on the other hand did not consider tailings thickening. Consequently, the ex-mill tailings have more water available for expression during deposition, into the Pit, than the case of the thickened tailings. At the end of deposition, the thickened	5

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A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
					tailings achieved a dry density of 1.42t/m^3 while a dry density of 1.39t/m^3 was attained by the non-thickened tailings.	
15	6.8 Water and Sediment: Site Conceptual Models	The RMCP should detail future hydrogeological work that will be undertaken to refine the Ranger Conceptual Model, and explain how this will further inform rehabilitation planning, particularly with regard to: • further refinement and characterisation of key hydrolithilogical units, aquifers and groundwater flows in high-risk areas for contaminant transport (around Pit1, Pit 3 and the Tailings Storage Facility) • further information on surface water/groundwater interactions improved characterisation of existing contaminated groundwater (e.g. under the Tailings Storage Facility) and contaminated sites (e.g. Land Application Areas).	Work has been undertaken by ERA and INTERA in the last 12 months to update the Ranger Conceptual Model. Groundwater monitoring, specifically to support closure criteria, is detailed within Section 12.5.2. This monitoring has been designed to support further refinement of key hydrolithological units, and groundwater / surface water interaction via collection of groundwater quality and high resolution water level data via dataloggers. All monitoring data collected for both operational requirements and specific studies is used to support ongoing updates to the Ranger Conceptual Model. The updated Ranger Conceptual Model (INTERA 2019) details all refinements made to the characterisation of all hydrolithological units within the model domain, which includes all high risk areas. Project planning and scoping is underway to support future studies specifically to quantify the contamination below the Tailings Storage Facility and Processing Area. These studies will support the development of the remediation plan. The Tailings Storage Facility contaminated materials application will specifically address contamination as a result of operation of the Tailings Storage Facility. KKN WS2 and WS3 are to address surface water and groundwater interactions.	Acknowledged The conceptual model will need to be updated as this information becomes available and the RMCP should detail future hydrogeological work that will be undertaken to refine the model and explain how this will feed into the contaminant transport modelling and rehabilitation planning. Additional comments are provided in the 2019 RMCP Assessment Report.	Acknowledged. Details on studies to support and inform updates to the Ranger Conceptual Model have been included in the 2020 MCP, Section 5.	5
16	6.8 Water and Sediment: Contaminant Source Terms	Further work is required to quantify contaminant source terms and factors that influence their mobilisation on a whole-of-site basis, including existing groundwater contamination and contaminants predicted to arise from the waste rock landform, the buried tailings and contaminated soils and sediments disturbed during rehabilitation.	ERA has numerous projects underway to address this. Refer to the summary of activities against KKN WS1A What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?	*Acknowledged* Additional information should be presented in the Pit 3 Closure application to demonstrate that all contaminant sources onsite, including contaminated groundwater and material associated with the Tailings Storage Facility and processing area, has been well characterised, is adequately represented in contaminant transport modelling and will not result in environmental impacts.	An update to the Ranger source term model has been undertaken during 2020 in order to inform the solute transport model and uncertainty analysis. The work completed to June 2020 has been included in the 2020 MCP (Section 5) and the completed works will be included in the Pit 3 closure application.	5
17	6.8 Water and Sediment: Contaminant Transport Modelling	A robust analysis of model uncertainty will need to be undertaken to quantify and understand the level of uncertainty associated with the modelled outputs.	The Ranger Mine sitewide modelling process complies with the guiding principles from the Australian Groundwater Modelling Guidelines. The Ranger Mine groundwater calibrated model will meet all indicators for	*Acknowledged* It is noted that uncertainty analysis will also need to be undertaken for the surface water model.	The preliminary surface water model as described in Section 5 provides probabilistic predictions of concentrations of COPCs in surface waters downstream of the mine site.	5

ERA

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
			the Level 3 confidence level (highest confidence level) after completion of the planned peer review by an independent hydrogeologist with modelling experience. Furthermore, ERA have made a commitment to have INTERA update minor Sections of the report to address comments made by SSB. The outstanding concerns relate to development of a formal uncertainty analysis which ERA has committed to undertake (and will be included in future MCP when complete).		The surface water modelling update will assess a range of solute transport loading predictions identified through the uncertainty analysis completed as part of the groundwater solute transport modelling by INTERA. Key parameters within the surface water model will also be examined and tested to assess model prediction sensitivity as part of the surface water modelling update. The completed surface water modelling update will be included in the Pit 3 closure application.	
18	6.8 Water and Sediment: Closure Criteria	Define the process for ALARA in the context of closure criteria and provide examples of water and sediment criteria that are ALARA.	The MCP has been updated to clarify use of ALARA, as a process, in respect to closure criteria. ANZG (2018) supports the use of narrative statements for guideline values and water quality objectives. Several examples of narrative draft water quality objectives are used in Table 6-3, eg demonstrating what water quality is ALARA, and for aesthetic water values.	*Acknowledged* It is noted that there don't appear to be any examples, or a Table 6-3.	The closure criteria chapter changed from chapter 6 in the 2018 MCP to chapter 8 in the 2019 MCP. The table reference should have been to Table 8.2 where there are examples of narrative criteria. The stakeholder Water and Sediment Working Group has been discussing how ALARA can be assessed using the BPT and risk management frameworks. ERA have finalised a report on this and the information included in the 2020 MCP as Appendix 6.2.	
19	6.8 Water and Sediment: Closure Criteria	Assess the potential for offsite impacts associated with mobilisation and accumulation of contaminants via transport of suspended sediments.	Sediment transport and accumulation will be predicted by the surface water model. ERA has several projects assessing the risk associated with sediment contamination. Refer to projects listed against KKN WS5A. Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?	*Acknowledged* Noted that the current surface water modelling being undertaken by ERA may not predict concentrations of suspended sediments.	The surface water model (OPSIM) will provide suspended sediment concentrations at defined nodes (receptors). Sediment accumulation will not be modelled, on the basis that the majority of sediment generated from runoff is in the early phase of closure, where erosion and sediment controls will ensure sediment is largely managed and retained on the premises. The results of Landform Evolution Modelling completed by SSB suggest denudation rates off the final landform will be on a trajectory towards background and, as such, accumulation of sediments will be consistent with natural/background conditions. The surface water model predicts suspended sediment concentrations but not accumulation. CAESAR modelling undertaken by the SSB predicts sediment movement from the mine but not accumulation. ARRTC and stakeholder working groups discussed issues with modelling sediment	8

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
					accumulation and the associated risks and agreed (i) modelling of sediment accumulation is not required, (ii) turbidity criteria address the risk associated with suspended sediment, and (iii) the risk from bedload sediment will be managed by erosion control and monitoring plans.	
20	6.8 Water and Sediment: Monitoring	The surface water monitoring program should include: • acknowledgment that additional contaminants that have not been previously identified as a risk may need to be considered in future (e.g. findings from contaminated site investigations) and include provision in the post-closure monitoring program for periodic review of contaminants • key sites on the Ranger Project Area (e.g. Georgetown Billabong, Coonjimba Billabong, RP1 and other onsite waterbodies, while they are present) for demonstration that concentrations of contaminants are as low as reasonably achievable • acknowledgment that grab sampling may need to be conducted more frequently than monthly in the initial period after completion of rehabilitation works • sampling for Ra-226.	These sites are included in the revised monitoring program and the potential use of event triggered monitoring is discussed in addition to monthly grab sampling. The CoPC list is currently being reviewed and a project to review again following contaminated sites sampling is scheduled. Project 1221-07 *Acid Sulfate Sediments Conceptual Model* is underway to address this. Previous studies have also addressed this.	*Acknowledged* The monitoring program should be refined and agreed between ERA and the Supervising Scientist via the Water and Sediment Quality Working Group.	Noted. All monitoring commitments will be updated and reviewed via the Water and Sediment Working Group (WASWG) or MERRG as the Ranger Mine transitions to closure. The WASWG has recognised this as one of their objectives.	10
21	7.8 Radiation Rehabilitation monitoring	Include groundwater radionuclide monitoring within the radiation monitoring program.	Post-closure monitoring of radionuclides in groundwater is now included in Table 12-9. Radionuclides are also included in Table 12-7 of the groundwater monitoring program discussed in Section 12. Monitoring during the closure and post-closure phases will continue to be refined as relevant studies are completed. Changes and additional detail regarding groundwater radionuclide monitoring will be incorporated into future iterations of the MCP and the Annual Ranger Water Management Plan.	*Not addressed* Post-closure monitoring of radionuclides in groundwater is not included in Table 12-9. Also noted that radionuclides specified in Table 12-7 are background data, not proposed monitoring.	All monitoring commitments, in the transition to closure, will be updated and reviewed via the WASWG or MERRG. The most updated agreed monitoring program has been included in the 2020 MCP Section 10 and includes Ra-226 analysis in Groundwater.	10
22	8.6 Soils Closure Criteria	Assess the risk of contaminated soils within the Ranger Project Area impacting the environment outside the Ranger Project Area.	A risk review was held as part of the Feasibility study to identify further work required to scope and assess potentially contaminated sites to the correct level to satisfy the closure objectives and relevant	*Not addressed* It is not clear how the contaminated sites assessment will inform off-site risks, or demonstrate that on-site risks are ALARA.	Noted. Appendix 12.2 of the 2019 MCP details the proposed process for contaminated sites assessment, including data quality objectives. Results from the 2019 contaminated sites drilling program	5

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
			legislation. The Contaminated Site Register was updated throughout 2018 and has been reviewed to identify contamination volume, clean up requirements, and the potential impact of the contamination outside of the Ranger Project Area. (Refer to Section 7.10.9)	Information on contamination volumes, clean up requirements and potential off-site impacts should be included in the RMCP – the Section referenced in ERA's response does not exist in the document.	will be interpreted with informed relevant guideline levels to better understand the risk associated with each contaminated site. This will inform the BPT assessment to select an appropriate management option. The ALARA framework in Section 6 will assist in informing the BPT assessment. Details on the contaminated sites assessment completed in the past 12 months are provided in the 2020 MCP (Refer to Section 5). As assessments are completed they will continue to be provided in the annual MCP updates.	
23	9.7 Ecosystem Restoration: Detailed Activity Description	Expand the Revegetation Strategy to an ecosystem restoration strategy.	The rehabilitation of the RPA will consider ecosystem establishment, and not simply the revegetation of the site. An ecosystem rehabilitation strategy will be developed, incorporating relevant KKN information, when complete, and be included within future MCP updates.	*Not addressed*	Draft fauna closure criteria have been developed for the 2020 MCP. Following review and incorporation of comments from stakeholders this will form the basis of a faunal recolonisation strategy. Once complete the Revegetation Strategy can be updated to an 'Ecosystem Rehabilitation Strategy'.	8
24	9.7 Ecosystem Restoration: Ecosystem Restoration	Provide uncertainty analysis for all modelling undertaken in relation to demonstrating that there will be sufficient plant available water in the final landform.	Information on PSD and PAW modelling, plant rooting depth, subsurface consolidated layer, and more has been added to the 2019 MCP. Consistent with information previously provided as part of 2019 App. 3 to Pit 1 Application. Supporting information available within the reference Lu P, Meek I, Skinner R. 2019. Supporting Information on Revegetation Growth Substrates at Ranger for Pit 1 Application. Energy Resources of Australia Ltd report, Feb. 2019	*Not addressed* No additional uncertainty analysis has been provided in the 2019 RMCP.	The key uncertainty in the PAW risk assessment associates with the following factors: • Fines % of the growth medium (ie. Potential water holding capacity); • Growth media thickness (assuming it is also accessible by root system); • Type of vegetation supported by the growth media; and • Weather conditions. To make it more explicit, the 2020 MCP PAW studies has been updated and revised, including a sub-section to describe the uncertainty analysis (Appendix 5.1).	5
25	9.7 Ecosystem Restoration: Ecosystem Restoration	Provide evidence to demonstrate that compaction layers: • will improve the water-holding capacity of the waste rock • will not lead to other issues affecting plant growth (e.g. physical restriction of roots, formation of perched water tables)	The results of the completed KKN are summarised within Section 7.3.5 of the updated MCP. Demonstrated that 4-6 m of waste rock landform with various levels of rock contents can maintain a positive PAW water balance while supporting a vegetation similar to one of the reference sites.	*Acknowledged* Any reference to compaction layers appears to have been removed from the 2019 RMCP, with no explanation provided for this.	ERA has clarified that there is no purposely compacted layer proposed and, following subsequent stakeholder discussions, it was agreed that the term 'compaction' would be avoided in order misinterpretation. The term 'consolidated layer' replaces 'compaction'.	
26	9.7 Ecosystem Restoration:	The lack of a seasonal trend in radon exhalation rates on the waste rock-only Section of the trial landform should be	*Bollhöfer, A., Doering, C., 2016. Long-term temporal variability of the radon-222 exhalation flux from a landform covered by*	*Not addressed*	Volumetric soil moisture content in the Trial Landform substrate is described in	5

A.1 2018 MCP feedback from SSB requiring further comment

Comment #	2018 SSB Assessment report Section	SSB comment in 2018 assessment report	ERA response in 2019 MCP	SSB response in 2019 assessment report	ERA response	2020 MCP Section
	Ecosystem Restoration	investigated in the context of the ability of the waste rock substrate to retain water.	*low uranium grade waste rock. J. Environ. Radioact. 151, 593–600.* has discussed the effect of the soil moisture on the radon emission.	The cited reference reports on seasonal trends in radon exhalation flux from waste rock. However, ERA has not integrated this information (in particular that seasonal variations in radon exhalation from waste rock begin to occur 2+ years after landform construction) into Section 7.3.3 of the MCP.	Appendix 5.1 (which includes the seasonal variation) is the same data in the published paper by *Bollhöfer, A., Doering, C., 2016* ERA has not used direct measurement data for soil moisture and not the relationship of seasonal trends in Rn-222 exhalation flux and soil moisture to date.	
27	9.7 Ecosystem Restoration: Ecosystem Restoration Risks Not Assessed	Provide information to assess how vegetation community development may be affected by landform stability, including re-contouring the landform surface.	Landform stability is considered in the final landform design, and follow up monitoring. Refer to updated MCP relevant Sections (7.5). The predicted date for completion of KKN LAN3 - will be the end of 2020, and thus results will be discussed in the 2021 updated MCP.	*Acknowledged* 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.	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	10
28	9.7 Ecosystem Restoration: Closure Criteria	Clearly justify why some closure criteria would be more important than others, in relation to the Environmental Requirements.	Some criteria, such as canopy architecture and ground cover index, are not independent of each other and should be considered collectively, or within the context of meeting the overall closure objective as a whole. This approach was recommended by DPIR as part of their initial assessment of the Ranger Mine closure criteria and ERA agrees with this recommendation.	*Acknowledged* SSB will seek clarification from ERA on this response.	It is acknowledged that the wording provided in the 2018 MCP was not clear. During 2020 the descriptive closure criteria for flora and fauna have been finalised. The closure criteria sections have been updated and this wording was removed. See Section 8.	8
29	9.7 Ecosystem Restoration: Closure Criteria	Ensure that the closure criteria for ecosystem restoration use consistent and clearly defined terminology.	Updating the content within the Closure Criteria and Supporting Studies Sections has addressed these inconsistencies.	*Acknowledged* SSB will seek clarification from ERA on this response.	Refer above response to comment 28.	8
30	9.7 Ecosystem Restoration: Closure Criteria	Provide information to justify the proposed plant reproduction closure criterion of evidence of flowering and fruiting in 80% of species, including consideration of the amount and periodicity of flower, fruit and seed resources provided in the revegetated site.	Information to justify this criteria is pending further studies and finalisation of the reference sites. This will be updated when suitable information is available. At present, woody species are being assessed and of these evidence has demonstrated that only a single species has not reproduced on site trials.	*Acknowledged* Criteria will need to take into account that there is a key difference between flowering/fruiting and successful reproduction (i.e. new individuals established and surviving).	Refer above response to comment 28.	8
31	9.7 Ecosystem Restoration: Closure Criteria	Criterion F13 should be reworded to; feral animal densities 'not greater than' those in surrounding areas, as opposed to similar to those in surrounding areas.	This criterion has been reworded in terms of weeds and feral animals to "not greater than" the surrounding areas. Note - Previous wording was used to align with the KKN. Work on fauna return strategies (including criteria / monitoring approaches) is ongoing and updates may be expected in 2020 MCP.	Not addressed Criterion F13 in Table 8-5 of the RMCP has not been reworded as per the ERA response.	This was an editing error and has been corrected in the 2020 MCP	8

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
32	Section 7.5 Landform design and performance	This Section includes information on model development being undertaken by the Supervising Scientist that is either out of date or incorrect. For example, the Supervising Scientist is not integrating a dynamic vegetation model linking soil moisture to biomass growth.	Ensure that information on landform modelling being undertaken by the Supervising Scientist is correct and up to date.	Noted. Section 5 has been updated with up to date information.	5
33	Section 7.5 Landform design and performance	There is insufficient information on planning/ monitoring of material movements and proposed surface structures.	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.	A mine plan has been developed for material movement over the closure period. This model uses a full suite of parameters as is standard in the mining industry to plan material movement by a truck and shovel fleet and includes parameters such as truck and shovel hours, Fleet Availability and Effective Utilisations plus a suite of standard mine planning parameters. The output of this mine plan is a detailed execution plan for material movement from the various stockpiles on site to their ultimate destination across site. This plan is updated at least every year. Material movement is tracked on a shift by shift basis against plan by the mine team against plan. There is also a weekly material movement tracking metric that is discussed at the Manager/GM level against the weekly plan. Refer to Section 9 in the MCP.	9
34			Provide more detailed information to justify the proposed surface structures, including up to date flood modelling, engineering designs and long-term management plans.	Provided in Section 9 of the MCP	9
35	Section 7.5.2 Landform flood study	The landform flood study does not take into consideration the impacts of major flood events on long-term landform stability and could be improved by incorporating the synthetic rainfall datasets that have been supplied to ERA by the Supervising Scientist.	Consider the impacts of major flood events on long-term landform stability and incorporate the synthetic rainfall datasets in landform flood modelling.	The landform flood studies are completed in order to appropriately design the short term erosion and sediment controls structures. These structures are required to manage the higher sediment loads expected in the first few years post landform construction. It is expected that many of these structures will not be required after the first 10 years. Once they are no longer required plans for either their infilling or removal will be agreed with stakeholders. The landform flood studies, being a short term focus, do not require the use of a synthetic rainfall data set. The assessment of long term landform stability can only be completed with a landform evolution model (e.g. CAESER or SIBARIA). Landform evolution modelling has historically been completed by the Supervising Scientist and the results reported in the MCP. ERA, supported by RioTinto are completing sensitivity testing of key LEM model parameters including climate sequences, rainfall losses, particle size distribution and vegetation cover.	5
36	Section 8.2 Table 8-1 Closure criteria landform	Closure criteria related to the physical isolation of tailings for 10,000 years that were proposed in the 2018 RMCP (i.e. previously L3 and L4) have been removed in the 2019 RMCP, without justification.	Reinstate the closure criteria to demonstrate that tailings will be isolated for at least 10,000 years, or provide justification for their removal.	The 2019 Landform closure criteria were reviewed and updated by ERA to match the Supervising Scientist Standard for Landform. Updated Closure Criteria are described in Section 8.	8

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A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
37	Section 8.2, Table 8-1 (L4) Closure criteria	While the closure criterion related to denudation rate (L4) has been proposed in accordance with the Landform Rehabilitation Standard, it is noted that the clarifying text *averaged over the entire landform* that was proposed in the 2018 RMCP (i.e. previously L5) has been removed in the 2019 RMCP. The previous text allowed for some degree of variation across the landform.	Reconsider the requirements for denudation rate.	Noted. The Landform closure criteria submitted were reviewed and updated by ERA to match the Supervising Scientist Standard for Landform.	8
38	Section 11.4.1.6 Dredgers removal and disposal	*This will, in turn, mean that remnant tailings on the floor under beached equipment would not be able to be removed.* This is not in accordance with the environmental requirement ER11.2	Consult with stakeholders regarding the proposal for some remnant tailings, which is not in accordance with the environmental requirements.	ERA is currently completing work on the plan for cleaning of the floor and walls of the Tailings Dam at the completion of dredging, prior to its longer term use as a process water storage facility. This plan will form the basis of how ERA will demonstrate to stakeholders how it intends to comply with ER11.2. The outcomes of this will be included in the 2021 MCP.	9
39	Section 11.16.6 Erosion & sediment controls	Although denudation rates on the landform are unlikely to reach background denudation rates for at least 1000 years, under higher rainfall scenarios and on different areas of the final landform, it may take significantly longer for the denudation rate to reflect background rates (i.e. >10,000 years).	Acknowledge the uncertainty in the erosion modelling and ensure that plausible worst-case scenarios are considered in the design of the final landform and surface erosion control structures.	Noted. The synthetic rainfall data set already considers higher rainfall scenarios. Note that all existing/current LEM modelling is being undertaken by SSB. ERA is continuing to work on an optimised landform design to present for modelling of scenarios. ERA is currently working on a sensitivity analysis on some of the parameters used in the modelling completed as described in Section 5.	5
40	Section 12.4 Landform monitoring	The RMCP mentions the use of vibrating piezometers to monitor excess pore pressures within tailings but it is not clear whether or how they may be used to inform tailings consolidation in the final landform. It is understood from consultation with ERA that it may not be possible to utilise the settlement plate method (i.e. as used in Pit 1) in Pit 3.	Provide further information on tailings consolidation monitoring, including Pit 3 and during the post-closure phase.	The Pit 3 tailings monitoring instruments will provided information on tailings pore pressure and hence settlement. The measured data for tailings settlement versus time will be utilised to track the predicted data obtained from the consolidation model. The settlement and corresponding time for a given degree of consolidation (for example 95%) can be determined. The appropriate type of monitoring instruments based on the tailings in Pit 3 will be provided as part of the Pit 3 closure application and summarised in the 2021 MCP.	10
41	Section 11.16.6.1 Appendix 11.4 Revegetation strategy	*…ripping to 0.5 m deep along the contour at four metre intervals, creating rough contour banks which will slow runoff and encourage infiltration in areas of identified higher erosion potential…* Further consultation with Traditional Owners and assessment or ripping benefits versus impacts will be undertaken prior to finalising the ripping design for the remainder of the landform. The ripping design in the feasibility study was to minimise erosion only… Surface ripping has been identified as critical to early erosion control and subsequent vegetation establishment and soil development (Saynor *et al*. 2019). Rip lines of 0.5 m depth will be installed at 4 m intervals across the entire surface of the waste rock landform. It is unclear how the areas of higher erosion potential have been identified and on what basis have been used to determine areas that require ripping.	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.	In order to assess the various aspects affected by ripping and obtain input from all stakeholders, ERA has planned a ripping trial for the Pit 1 final landform. Details of this trial have been provided in Section 9 and discussions with stakeholders are ongoing.	9

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
42	Section 12.6.2 Table 12-9 Radiation closure and post-closure monitoring	In addition to Ra-226, studies by SSB suggest that Po-210 and Pb-210 are important dose-forming radionuclides in terrestrial bushfoods.	Consider including Po-210 and Pb-210 in the post-closure monitoring of radionuclides in terrestrial bushfoods.	Noted and included.	10
43		The gamma spectrometry method specified is unlikely to have the requisite sensitivity for measuring radionuclides in terrestrial bushfoods.	Consider alpha spectrometry as the analysis method for Ra-226, Po-210 and Pb-210 (via Po-210 ingrowth) and ICP-MS as the analysis method for U.	Noted and included.	10
44		Information currently provided in Table 12-9 suggests that the only terrestrial bushfood group to be monitored for radionuclides is fruit. There are several other terrestrial bushfood groups in the model diet (e.g. buffalo, pig, wallaby, goanna and yam) through which radionuclides can be ingested.	Provide a list of the terrestrial bushfood groups to be targeted for post-closure monitoring of radionuclides or if fruit is the only group to be targeted, then justification for this needs to be provided.	ERA will be undertaking a terrestrial and aquatic bushfood sampling program which is described in Section 5. ERA's permits and approvals for collection of bushfoods expire in 2025 and therefore terrestrial bushfood will be collected prior to expiry.	5
45		Table 12-9 indicates that there will be no post-closure monitoring of radionuclides in aquatic bushfoods (i.e. only water).	Consider the inclusion of monitoring of radionuclides in aquatic bushfood, especially for on-site waterbodies potentially contaminated by mining operations (e.g. Georgetown Billabong), to confirm dose estimates based on water radionuclide measurements.	ERA will be undertaking a terrestrial and aquatic bushfood sampling program which is described in Section 5. ERA's permits and approvals for collection of bushfoods expire in 2025 and therefore terrestrial bushfood will be collected prior to expiry.	5
46		Po-210, in addition to Ra-226, is an important dose-forming radionuclide in aquatic bushfoods.	Consider including Po-210 in the post-closure monitoring of radionuclides in water for the purpose of estimating ingestion doses from aquatic bushfoods.	Noted. Po-210 is now included in the radiation closure and post-closure monitoring program provided in Section 10.	10
47		The gamma spectrometry method specified is unlikely to have the requisite sensitivity for measuring radionuclides in water.	Consider alpha spectrometry as the analysis method for Ra-226 and Po-210 in water and ICP-MS as the analysis method for U in water.	Noted. The monitoring program has been updated to remove the specific method for analysis of radionuclides in water. This can be determined closer to the 2026 and the best available method at the time used.	10
48	Section 7.3.3 Radon exhalation	*…there was no obvious seasonal trend observed for radon exhalation fluxes from waste rock only.* The most up-to-date information on radon exhalation characteristics for waste rock has not been referenced. A study by SSB indicates that seasonal variations in radon exhalation fluxes from waste rock begin about 2+ years after landform construction: Bollhöfer, A., Doering, C., 2016. Long-term temporal variability of the radon-222 exhalation flux from a landform covered by low uranium grade waste rock. J. Environ. Radioact. 151, 593–600.	Reference the most up-to-date studies and their findings for radon exhalation characteristics from waste rock.	Noted. ERA has updated the Trial landform knowledge base section (Section 5.3.5.1) with reference to the 2016 paper on radon exhalation by Bollhöfer and Doering.	5
49	Section 7.4.1.3 (including Table 7-16) Bushfood radiation baseline	The most up-to-date information on radionuclide activity concentrations and concentration ratios in bushfoods has not been referenced. The most up-to-date information is available in: Doering and Bollhöfer, 2016. A database of radionuclide and metal concentrations for the Alligator Rivers Region uranium province. Journal of Environmental radioactivity 162-163, 154-159. Doering et al., 2017. Estimating doses from Aboriginal bush foods post-remediation of a uranium mine. Journal of Environmental Radioactivity 172, 74-80.	Consider revising this Section with the most up-to-date information on radionuclides in bushfoods.	Reference to this new data has been provided in Section 5.2.9.3. This data will be used for any future radiation dose assessments undertaken	5
50	Section 2.2.9.7	The summary of the site water model is based on August 2018 results. Given that it is such an integral aspect of the	Present results of the most up to date site water model and assumptions and ensure the approval status of	The model presented in the 2019 RCMP was the model current at the time of preparation of that RCMP.	9

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A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
	Site water model Section 11.5.1 Water treatment closure activities	site closure planning, the most up to date results and assumptions should be presented in the RMCP (e.g. as an Appendix). The approval status of assumptions for future water treatment processes is unclear, as some strategies are yet to receive regulatory approval.	potential or proposed future water treatment processes is clearly stated.	The model described in the 2020 RCMP is the current approved model dated February 2020. Section 9 The approval status of future water treatment options have been included in the RCMP text. Section 9.4.3	
51		This modelling includes a number of significant assumptions, such as seasonal rainfall, water treatment capacity and efficiency over time and volume of contaminated water generated by the process of tailings consolidation in Pit 1 and Pit 3. However, there is no indication of model uncertainty based on the likely variability in these assumptions over time.	Provide information on surface water model uncertainty relating to variability in model assumptions over time, to enable a detailed assessment of likely success of the proposed water treatment strategies.	ERA assumes the word "surface" was mistakenly written instead of "site". The site water model provides forecasts of possible outcomes given variation in rainfall, with that variation being based on historical rainfall observations. Closure planning is completed on a median or 50th percentile basis, with contingencies identified to deal with higher rainfall scenarios. Any contingencies or strategy changes are all cost based and have no impact on the environmental outcome.	9
52	Section 7.1.2 Pit 1 Tailings consolidation	The solute balance indicates that the measured mass of solute recovered through the decant towers matches the mass of solute estimated to have been expressed from tailings (Figure 7-6). The volume balance indicates that the decant structures are recovering additional volume from the waste rock cap. Figure 7-6 actually shows the solute expression profiles are similar but in fact the predicted mass of solute is consistently underestimated by the model by up to 20% and is fairly consistent	Provide evidence or discussion to support the assumption this consistent difference is simply attributed to waste rock as a source term and not an inherent underestimation from the source term assessment or consolidation model outputs.	Note that in the 2019 MCP, Figure 7-6 shows cumulative solute (magnesium) flow. The variation between the two curves occurs mostly in the first five months, when only a single sample of decant water was available (see chevron markers on x axis). This five month period corresponds to the wet season, when rainfall inflows can significantly influence concentration and a single sample is unlikely to be representative of the average concentration over the time. After the initial four months the curves are mostly parallel – the instantaneous rate of solute flow (given by the slope of the curves) is similar. If there was a consistent difference, the curves would continue to diverge. See the reference (Harvey, 2019) in the text for more information.	9
53	Section 10.3 Closure risk assessment	*Process water treatment required beyond closure date to treat process water to achieve 95% consolidation for Pit 3.* No details have been provided to describe how consolidation of tailings in Pit 3 will be measured over time, nor how achievement of the 95% consolidation target will be verified.	Detail how consolidation of tailings in Pit 3 will be measured over time and how achievement of the 95% consolidation target will be verified.	The Pit 3 tailings monitoring instruments will provided information on tailings pore pressure and hence settlement. The measured data for tailings settlement versus time will be utilised to track the predicted data obtained from the consolidation model. The settlement and corresponding time for a given degree of consolidation (for example 95%) can be determined. The appropriate type of monitoring instruments based on the tailings in Pit 3 will be provided as part of the Pit 3 closure application and summarised in the 2021 MCP.	9
54	Section 7.4.3.6 Prediction of existing groundwater contamination	Further information is required to support the approach to remediating contaminated groundwater and soils across the site.	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	Detailed contaminated sites investigations were completed in late 2019 and results are being analysed. Studies into contamination in soils and groundwater are captured within KKN WS1 with multiple studies currently underway. Updates on studies completed to date have been provided in Section 5.	5

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
			where necessary, compared against the risk of remediation and disposal of the material in the upper levels 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)		
55	Section 7.9.9.1 Contaminated sites - plumes	*This lack of impact to nearby downgradient bores suggests that migration of contaminants from the processing plant area is extremely slow….* *…The contaminant plume that is present in the processing plant area has migrated to the south and south east, towards Corridor Creek, consistent with local groundwater flow directions.* *However, the lack of recent water quality data throughout much of the processing plant area leaves uncertainty about current groundwater conditions.* These statements appear to be inconsistent and there has been impact identified in downgradient bores, as identified through recent groundwater reports.	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.	Inconsistencies have been revised and updated. The work completed to June 2020 has been included in the 2020 MCP (Section 5.4.3) and the completed works will be included in the Pit 3 closure application.	5
56	Section 7.9.9 Contaminated sites	(Table 7-39) *Once tailings are removed, assumption that no remediation is required* (p 7-210) *Natural attenuation is assumed to allow for plume remediation* These statements appear to be out of date, when INTERA's current body of work is already assessing what to do with contaminated materials below the Tailings Storage Facility.	Ensure statements in relation to remediation of Tailings Storage Facility contaminated groundwater are consistent with current knowledge and planned work.	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.	9
57	Section 7.9.9.1 Contaminated sites - plumes	*Reclamation is expected to remove much of the CoPC sources in the shallow soil, so groundwater concentrations are expected to decrease over time* While it is agreed that source removal will eventually result in lower concentrations in groundwater, it is unclear over what period of time this might occur, or the fate and transport of the CoPC that remain in the soil and groundwater.	Provide further information to demonstrate how removal of soil contamination in the processing area will address groundwater long term contamination (i.e. predicted concentrations, timeframe, fate of residual soil/groundwater contamination).	Detailed contaminated sites field investigations were completed in late 2019 and results are being analysed. Studies into contamination in groundwater are captured within KKN WS1 with multiple studies currently underway. An update to the Ranger source term model has been undertaken during 2020 in order to inform the solute transport model and uncertainty analysis. The work completed to June 2020 has been included in the 2020 MCP (Section 5) and the completed works will be included in the Pit 3 closure application. Results from the 2019 contaminated sites drilling program will be interpreted against known knowledge gaps identified during the Feasibility Study. These results will then inform BPT assessments to select an appropriate management option, based on what impact is ALARA. Updates on studies completed to date have been provided in Section 5. As assessments are completed, they will continue to be provided in the annual MCP updates.	5
58	Section 11.9.1.2 Catchment management - LAAs	Although it is acknowledged in the RMCP that further assessment is required to demonstrate there are sufficient disposal options for treated pond water throughout rehabilitation, further consideration is needed of the future capacity of the remnant Land Application Areas, and	Provide further information on the future capacity of the remnant Land Application Areas, and whether or not there will be an increase in associated environmental risks (e.g. waterlogging, unseasonal runoff, and alteration to groundwater levels).	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	9

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A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
		whether or not there will be an increase in associated environmental risks (e.g. waterlogging, unseasonal runoff, and alteration to groundwater levels).		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.	
59	Section 11.9 Water management	During progressive rehabilitation and construction of the final landform, there may be an increase in suspended sediment concentration in surface runoff from the site, which may increase the risk of sediment-related impacts to the offsite environment.	Surface water modelling being conducted to predict the concentrations of suspended sediment in the creeks surrounding the Ranger Project Area should consider the deposition of sediment throughout surrounding catchments, particularly to assess the risk of infilling of nearby billabongs.	During rehabilitation works and the construction of the final landform sediment will be actively managed according to the Ranger Water Management Plan. Post closure sediment and erosion control structures will be installed to actively manage sediment runoff. This negates the requirement of sedimentation modelling. Details of the design of these structure have been provided in Section 7.4.5. The surface water model predicts suspended sediment concentrations but not accumulation. CAESAR modelling done by SSB predicts sediment movement from the mine but not accumulation. ARRTC and stakeholder working groups discussed issues with modelling sediment accumulation and the associated risks and agreed (i) modelling of sediment accumulation is not required, (ii) turbidity criteria address the risk associated with suspended sediment, and (iii) the risk from bedload sediment will be managed by erosion control and monitoring plans. The surface water model (OPSIM) will provide suspended sediment concentrations at defined nodes (receptors). Sediment accumulation will not be modelled, on the basis that the majority of sediment generated from runoff is in the early phase of closure, where erosion and sediment controls will ensure sediment is largely managed and retained on the premises. The results of Landform Evolution Modelling completed by SSB suggest denudation rates off the final landform will be equivalent to or below background and as such accumulation of sediments will be consistent with natural/background conditions.	9
60	Section 11.10 Waste and hazardous material management	The current works schedule states that the Tailings Storage Facility will be required for process water storage until late 2024, and that backfill of Pit 3 will be completed by 2025. This does not allow for the possible disposal of contaminated material from the Tailings Storage Facility in the lower levels of Pit 3, given that the pit backfill would be close to completion.	Backfill of Pit 3 should not commence until it has been demonstrated that the placement of material from the TSF into Pit 3 is not required.	A TSF contaminated material trade-off study has been completed, demonstrating better outcomes to leaving material *in situ* rather than placement in Pit 3. Refer to the TSF subfloor contaminated material management application (approved by stakeholder on 6 August 2020). A summary of this application has been provided in Section 9.3.3.3.3.	9
61		Insufficient information is provided on the disposal of contaminated soils, site infrastructure and other materials to enable assessment of the planned waste disposal.	Provide further information on the disposal of contaminated soils, site infrastructure and other materials, including the effect that in-pit disposal may have on tailings consolidation, and an assessment of the potential environmental risks and information on how they will be mitigated.	Detailed contaminated sites field investigations were completed in late 2019 and results are being analysed. A summary of work completed to June 2020 has been provided in the 2020 MCP, Section 5. As this work continues it will be provided in subsequent MCPs. Also see Section 9.4.2.	9
62	Section 8.3.2	The rationale for proposed metals and sulfate in sediments closure criteria is not detailed.	Provide the rationale for proposed metals and sulfate in sediments closure criteria.	The criteria proposed for metals in sediment in the MCP were the ANZG (2018) guideline values. A hazard	8

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
	Water and sediment – Management objectives and outcomes Table 8-2 Closure criteria – water and sediment			assessment has shown that these are not contaminants of environmental concern for the Ranger site. Updated water and sediment closure criteria is provided in Section 8.	
63	Section 7.8.3 – Surface water modelling Model results	*Based on the predicted downstream solute concentrations, and the magnesium-calcium ratios, the post-closure final landform does not pose a risk to the downstream environment.* There is currently insufficient information to support this statement and ERA is currently updating the surface water modelling to assess the risk of downstream impacts associated with contaminants from the post-closure landform.	Until it can be demonstrated otherwise, remove any statements within the RMCP suggesting that the post-closure final landform does not pose a risk to the downstream environment.	Updated. ERA is in the process of undertaking further updates to the surface water model. This updated information will be included in the next iteration of the MCP. More information is provided in Section 5.	5
64	Section 12.5.1 – Water & sediment monitoring Surface water and sediment	The proposed surface water quality monitoring program includes sulfate as a parameter at key monitoring sites on Magela and Gulungul Creeks. Given the risk of acid sulfate soil development on the Ranger Project Area and the Supervising Scientist's rehabilitation standard for this parameter, it should also be monitored at RP1 (and other onsite waterbodies, while they are present) and Georgetown and Gulungul Billabongs.	Include sulfate as a water quality monitoring parameter at RP1 (and other onsite waterbodies, while they are present) and Georgetown and Gulungul Billabongs.	The post-closure monitoring program is updated and includes sulfate as a water quality monitoring parameter at MG009, GCLB, MCUS, GCC, and Coonjimba and Gulungul Billabongs.	10
65	Section 12.5.2 Water and sediment monitoring Groundwater	The proposed groundwater monitoring program does not clearly demonstrate that it will facilitate validation of groundwater models, or detect significant increases in contaminant concentrations in aquifers surrounding Pit 1, Pit 3 and the Tailing Storage Facility.	Revise the groundwater monitoring program to clearly demonstrate that monitoring will be undertaken at an appropriate spatial and temporal scale to: observe trends in groundwater level recovery and contaminant transport post-closure that can be used to validate groundwater models, and recalibrate if necessary detect significant increases in contaminant concentrations in aquifers surrounding Pit 1, Pit 3 and the Tailing Storage Facility, to enable downstream mitigation of impacts if required (i.e. groundwater interception or abstraction). Additional information obtained from ongoing post-closure solute transport modelling or new monitoring bores (including those planned to be installed in vicinity of Pit 1 and Pit 3 during 2019), should be used to refine and optimise the long-term groundwater monitoring plan.	The groundwater monitoring program has evolved over time to address operational and environmental concerns and risks at the Ranger Mine site. The post-closure monitoring plan has also evolved as the closure planning and modelling has progressed with the closure studies. Additional information informing the rationale for the post closure groundwater monitoring plan is detailed in Section 10.	10
66	Section 7.3.5.3 Plant available water studies Modelled plant available water	The transpiration rate input to the WAVES modelling is based on a subset of key overstorey tree species but does not capture the midstorey species that may account for a moderate to high proportion of the total cover.	Provide an estimation of the contribution of midstorey species (including evergreen species) to transpiration rates in the WAVES modelling.	The transpiration in midstorey species was not omitted in the modelling, rather it was overestimated. Stand transpiration of the reference sites in the Georgetown area was estimated based on the measurement of the average sap flux density (SFD) multiplied by the stand's total sapwood area. The SFDs were measured in mostly overstorey (OS) species though some midstorey (MS) were also measured. Within scientific literature, it has been shown that overstorey SFD	5

ERA

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
				is usually higher than MS. Therefore, the average SFD calculated from OS trees will overestimate the true average SFD of the stand. As the stand sapwood area is the sum of each tree's sapwood area in the stand including every OS and MS trees, the estimated stand transpiration used for modelling is indeed conservative.	
67	Section 11 Implementation	**Pit 1** (11.2.3) – states that *no contingency plans are required* i.e. missing contingencies for potential issues such as differential tailings consolidation, revegetation success, higher seepage rates, etc. **Pit 3** (11.3.3) - only includes contingencies for the risk of tailings rising above -15 mRL i.e. missing contingencies for potential issues such as tailings consolidation taking longer than expected (e.g. extended water treatment as identified in BPT Section 9.2.7.4), differential tailings consolidation, revegetation success, higher seepage rates, etc. **Tailings Storage Facility** (11.4.3) - only includes contingencies for the risk of dredge disposal i.e. missing contingencies for risks for potential issues such as Tailings Storage Facility wall breach while still in use, management of contaminated materials (i.e. residual tailings on inside walls, floor, clay core, rip rap), and the contaminated groundwater plume. **Water treatment** (11.5.4) and **Water management** (11.9.3) - only includes contingencies for treatment of process water i.e. missing contingencies for treatment of pond water and risks associated with water quality closure criteria not being met (i.e. ongoing treatment). **Waste and hazardous material** (no Section) and **Contaminated sites** (11.5.3) - no contingencies included, noting it is acknowledged in 11.5.3 that contingencies for contaminated sites will be identified by future BPT assessments. **Ecosystem restoration** (no Section) – no contingencies included for the potential failure of the rehabilitated landform to become a self-sustaining ecosystem, which are also not included in the RMCP risk assessment.	Ensure that all contingencies associated with risks listed in the Ranger Closure Risk Assessment (Appendix 10.1) are included or referenced within the relevant areas within Section 11. Further detail should be provided for each contingency, including: level of confidence in its likely effectiveness timing of implementation impact on the overall closure schedule, including consequential effects on other related activities Include contingencies for the potential failure of ecosystem restoration (i.e. rehabilitated landform does not become a self-sustaining ecosystem).	Additional information has been included on contingencies within each domain of the implementations Section of the MCP (Section 9). Where possible the details requested have been provided, however in most cases this level of detail is not available and ERA believe not required. Contingency plans are developed to order of magnitude level and then are parked pending need. If need develops the various options are then assessed and progressed to engineering.	9
68	Section 10.3 Closure risk assessment	The ongoing review process for the closure-related risks is not clear in terms of frequency, scope and how it informs future iterations of the RMCP.	Detail the ongoing risk assessment review process, including a plan to obtain additional information to update the risk assessment over time, and what would trigger an update of the risk assessment.	Details of ERAs closure risk management processes have been included in Section 7	7
69	Appendix 10.1 Risk assessment	To obtain the risk ranking, the controls are considered but those listed are a combination of existing controls, planned controls and contingencies (potential controls). If all of these elements are considered together, this may result in an artificial reduction in risk level by considering controls that aren't necessarily in place, or have a low level of effectiveness.	Clearly distinguish between the existing and proposed controls for the planned closure scenario, along with evidence to support control adequacy and effectiveness, including consideration of control applicability or availability during the three closure phases (i.e. decommissioning, stabilisation and monitoring and post-closure)	Controls that are not realised (still in progress or not implemented) are not considered in the risk evaluation and captured under "actions".	7

A.2 SSB feedback on 2019 MCP

Comment #	MCP reference	SSB comment	SSB recommendation	ERA response	2020 MCP Section
70	n/a	Insufficient details on future applications was provided.	The RMCP should include a table detailing the application, the expected date for submission, the date approval is required by, a description of the scope of the application and the information it will provide.	This was an accidental omission from the 2019 MCP and has now been again included in the 2020 MCP (Section 1)	1

COMMENTS FROM COMMONWEALTH MINISTER – APPROVAL LETTER RECEIVED 12 MAY 2020

A.3 Feedback from Commonwealth Minister on 2019 MCP

Comment #	Minister Pitt's comments	ERA Response	2020 MCP Section
71	I am conscious that ERA is entering a particularly important period at Ranger and wish to identify three specific areas that I request ERA address in greater detail in its 2020 MCP. Firstly, I request that ERA present closure criteria for my approval either in the 2020 MCP or earlier. I appreciate that this is a significant task and encourage ERA to continue to work with the Supervising Scientist in relation to closure criteria.	ERA have further developed closure criteria in consultation with the Supervising Scientist and the Northern Land Council and have reached agreement on the majority. These have been provided in Section 8. ERA are now requesting formal approval from the Minister for these agreed criteria. A few criteria are subject to the completion of scientific studies, these are due for completion in the coming 12 months and will be included for final approval in the 2021 MCP.	8
72	Secondly, I request that ERA provide further detail on the sequence of substantive rehabilitation works at Pit 3 and the Tailings Storage Facility and process water management activities which are planned to take place over 2021-22. As the timely implementation of these operations will be critical for ERA to achieve its planned closure schedule, I request that the 2020 MCP describe the risks associated with individual activities as well as how delays or issues could potentially affect related operations. Where possible, alternatives and contingencies should be identified.	Additional information on Pit 3 capping, the management of contaminated material in the Tailings Storage Facility, process water management has been provided in Section 9. In addition to this ERA will be submitting a separate application for the capping of Pit 3 for approval of the minister in Q4 2020. This will provide the full details of the rehabilitation works and mitigation measures to protect the environment. The 2021 MCP will then provide details of this application.	9
73	Thirdly, I request that ERA describe in the 2020 MCP its additional work to mitigate the risk that it is unable to collect sufficient seed stock to meet its revegetation requirements. ERA's revised risk assessment in the 2019 MCP identified this as a new critical risk. I therefore request that ERA advise what additional steps it will take to mitigate this risk.	ERA have been undertaking a significant amount of work to mitigate this critical risk to the closure project. With the support of the Gundjeihmi Aboriginal Corporation, ERA has obtained a permit from Kakadu National Park for the local aboriginal business Kakadu Native Plant Supplies to collect seed from with the local provenance area in the park. Seed collection within the park has now commenced with successful results. In addition to this ERA have completed the following activities: • commenced full scale seed collection activities with the Ranger Project Area; • completed construction of a Nursery on the RPA with security and fire systems to protect the seed; • storage of seed has been split in two locations in the case of a major incident at one location only half the seed will be lost; • ERA employees have been trained in seed identification and collection to allow for opportunistic collection on the Ranger Project Area Based on the successful completion of these actions the risk has now been re-evaluated down to a high risk. High risks still require active management through ERAs risk management system; therefore, ERA will continue to actively monitor and manage this risk. Further details have been provided in Section 9.4.6.2.	9

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
1	General	Glossary	Acronyms	Recommend spelling out rare, unusual, topic, chapter and Section specific acronyms. It is difficult to keep abreast whilst reading the MCP all the various acronyms. The MCP appears written by a number of different authors depending on the Section. Each Section introduces acronyms specific for that Section. Readers are therefore repeatedly required to try to remember topic-specific acronyms for parts of the MCP. Suggest writing out acronyms, especially those that are rare and/or unusual.	Acronyms have been minimised where possible, in particular for rare or unusual names. All key terms (names, locations, documents etc.) have been presented as acronyms (i.e. ERA, RPA, MCP, TSF). An acronym table has been included at the front of each Section as a reference to assist the reader.	ALL
2	General	MCP	'How to read this document' Section	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.	Improvement will be considered as part of future submissions. For 2020 MCP, the table of contents and layout has been updated to further align with the WA MCP guidelines and will improving readability and identifying relevant information throughout. The Executive summary is intended to summarise Sections to follow.	ALL
3	General	MCP	Non-technical summary	It is recognised that the MCP is not statutorily required to be a public document. And that ERA has taken the progressive step to make it publically available. In this regard a Non Technical Summary would be a useful chapter.	Suggestion noted. ERA makes the MCP publically available for transparency. The MCP has been written for ERA employees and key stakeholders that have an understanding of the background and technical aspects.	ALL
4	General	MCP	Supplementary text	Throughout the MCP there is much supplementary information that supports closure planning and activities. It is recommended that this information be transferred to text-boxes to avoid disrupting the narrative in the body-text. For example, on ES 15 there is mention of a Closure Criteria Working Group. A text box could be used to **describe who is in the group and its purpose.**	ERA intends to ensure all supplementary information is provided where relevant. The format for presentation follows the WA MCP guidelines whilst effort is made to make linkages to additional information clear and easy to follow. For example, "Refer to Section 4" With the updated MCP guidelines this year there was a requirement to change the structure of the document. This did not allow time for any additional formatting improvement. These will be considered for subsequent updates.	ALL

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
5	Exec Summary	MCP	General comment.	The Executive Summary reads more like a 'how to use- how to read this document' than an Executive Summary. The Executive Summary does not summarise impacts that have been identified and are mentioned throughout the summary. It misses simple visual aids for particularly non-technical Stakeholders to understand where on the Ranger Project Area the discussion centres, as well as whether that aspect of the closure plan is progressing satisfactorily, and the **overall status** of that aspect of the closure plan. It is noticed that there is not a Non Technical Summary. Considering the most important Stakeholder groups is the Mirarr Traditional Owners whose first language is not English, the **Executive Summary should include a discussion on how the Mirarr Traditional Owners are being included in the development and progression of the closure plan.** Such a discussion should include the intention to translate the closure plan or key aspects of it into an appropriate language either written or visual.	Comment noted. In following the WA MCP guidelines, the executive summary provides an outline of the Sections that follow. Specific results/outcomes of studies are often difficult to communicate without supporting context and detail and therefore are contained within the relevant Sections. Stakeholder consultation is a central part of the MCP development and progression. A number of forums have been organised to ensure closure planning involves representatives of the Mirrar Traditional Owners (i.e. NLC and GAC). Stakeholder engagement is referred to both in the Executive Summary and Section 4. The Executive Summary is updated to include more figures.	Exec Summary
6	Exec Summary	ES-3 (2 Project overview)	The Commonwealth Government introduced laws covering the Alligator Rivers Region (Commonwealth Environment Protection (Alligator Rivers Region) Act 1978) and established several research bodies and committees to overview the environmental regulation of mining in the region.	Of mining or of uranium mining? If different bodies have different mandates please describe them.	The functions of the two committees mentioned are described in Section 4 of the MCP and further details are described in the Environment Protection (Alligator Rivers Region) Act 1978. They both relate to uranium mining.	Exec Summary
7	Exec Summary	ES-5 (3 Closure obligations)	It is implicit that ERA will comply with all necessary legal obligations and uphold internal standards during closure	What commits ERA to completing MCP in it's entirety?	The MCP is prepared with all information as required by Annex B of the Authorisation. The Plan provides updated information on an annual basis and at the end of closure will provide a record of all closure activities. A copy of the Closure Legal Obligations Register is also available as an Appendix to Section 3	3
8	Exec Summary	ES-6 (a.a.)	The transition into closure will involve applying for regulatory approvals to authorise new requests or to modify the currently authorised activities that have the potential to result in an environmental impact to either intact or undisturbed areas of the RPA.	The inclusion of an impact assessment of the chosen BPT would strengthen the MCP.	As described in Section 6, ERA adopts a site specific process to assess BPT and risk in relation to approval applications. Risks associated with the options during assessments are described in the applications when submitted.	6

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
9	Exec Summary	ES 10 (Table ES 2 radiation)	"ERA & SSB have developed a pre-mining radiation baseline"	EIA. The elements of an EIA are alluded to or mentioned through the MCP. A dedicated EIA would strengthen the document and the BPT choices made throughout it.	Previous BPT assessments and future BPT assessments are described in Section 6. A dedicated EIA will not be completed as part of the MCP as the MCP includes the specific elements as described in Annex B of the Authorisation and the minister approved guidelines (WA 2020).	6
10	Exec Summary	ES 6 (aa)	Historical land use within the Alligator Rivers Region has included indigenous occupation, buffalo hunting, missions, pastoral grazing, agriculture, mining exploration, uranium mining and tourism.	Which one is the MCP primarly designed to accommodate post-closure?	The 2020 MCP describes the final land uses in Section 8.	8
11	Exec Summary	ES-7 (4 Env & Social setting)	Terrestrial flora. On the RPA in 2013 a survey found "These species are common in surrounding Kakadu NP and did not include any threatened or rare species."	It seems unlikely that not a single local, regional, national or internationally identified threatened or even a rare species was identified. **Has ERA independent verification of this finding?**	The cited 2013 Eco Logical Australia survey (Eco Logical Australia, 2014) covered only the potentially impacted area by the proposed Ranger 3 Deeps underground mine (see Figure 1: Proposed vent corridor within the survey area and RP1 outside the survey area, and Figure 6: Broad vegetation mapping groups, of the cited report). To be more precise, the sentence shall be revised as "These species are common in surrounding Kakadu NP and did not include EPBC and TPWC Act listed flora species". ERA has not independently verified this finding. However, this finding is consistent with Firth (2012)'s finding that was based on review of 20 past surveys on RPA. Reference: Eco Logical Australia. 2014. Vegetation and fauna assessment, for the proposed Ranger 3 Deeps underground mine. Prepared for Energy Resources Australia Ltd., Darwin. 2014. Firth, R. 2012. Flora and Fauna Literature Review of the Ranger Uranium Mine Project Area - Report 1. ENV Australia Pty Ltd. 25 June 2012, p 40.	
12	Exec Summary	ES 10 (Table ES 2. Contamination)	In general, activities at the Ranger Mine are thought to have influenced the formation of ASS in some areas such as the Coonjimba Billabong and Retention Pond 1 (RP1) by affecting sulfide, sulfate and water balance dynamics.	This must form part of a **detailed PAF management plan** for post-closure, building on the Acid Sulfate Sediments site-wide ASS conceptual model.	Based on the results of the Acid Sulfate Sediments (ASS) site-wide conceptual model and field assessments, a risk assessment of domains across the mine site will be undertaken to understand the future ASS occurrences/persistence in the billabongs. If the risk assessment indicates sulfate in water needs to be reduced or ASS sediments treated, then trial mitigations and remediation options will be investigated. Refer to section 5.5.2.13	5

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
13	Exec Summary	ES 11 (Table ES 2 Water quality)	Surface water. Based on the predicted downstream solute concentrations, and the magnesium-calcium ratios, the post-closure final landform therefore does not pose a risk to the downstream environment. … multiple projects including assessments of sediment accumulation, human diet and health, ecosystem vulnerability, release water pathways and cumulative aquatic risks will be conducted to assess if water quality closure criteria/objectives will be met under the current closure strategy.	Key impact assessment results. Summarising how ERA derived these conclusions – assumptions, methodology, etc – would strengthen stakeholder acceptance. An Impact Assessment is a good place to do this.	ERA is in the process of undertaking further updates to the surface water model. This updated information will be included in the next iteration of the MCP. More information is provided in Section 5.	5
14	Exec Summary	ES 13 (aa)	'use of low-permeability caps was preferred' which 'only have a marginal impact on loads' but 'these low permeability caps will not be required'	Can ERA clarify this as it is not clear **whether low-permeability caps will be used or not.**	ERA will not be using low permeability caps in Pit 3.	5
15	Exec Summary	ES 13 (Table ES 2 Landform)	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 current or the predicted climate/rainfall regime that will result from climate change.	First time climate change has been mentioned. **Modelling for 10 000 years needs to consider climate change.** Post-closure landforms and rehabilitation techniques **need to demonstrate that Mirarr perspectives are considered.**	Landform evolution modelling for 10,000 years does consider climate change scenarios. Synthetic rainfall data sets are being used to assess the design of the final landform for different wet and dry future scenarios. Mirarr considerations were included in the design of the Final Landform through the development of Cultural Closure Criteria consultation work completed by Murray Garde in 2014 (Garde 2015). See Section 8 for Cultural Criteria.	8
16	Exec Summary	ES 13 (aa)	Each version of the landform has been subjected to landform evolution modelling by the Supervising Scientist	Inclusion of Mirarr perspectives in final landform development and modelling should also be highlighted.	Mirarr considerations were included in the design of the Final Landform through the development of Cultural Closure Criteria consultation work completed by Murray Garde in 2014 (Garde 2015). See Section 8 for Cultural Criteria.	8
17	Exec Summary	ES 14 (Table ES 2 Ecosystem Rehabilitation)	ERA implemented a long-term fauna and flora monitoring program on the RPA and in adjacent areas of Kakadu NP (in agreement with Mirarr Traditional Owners and Kakadu NP Management).	Mirarr involvement should be explicit and visible in all final landform and rehab discussions and analysis.	Mirarr considerations were included in the design of the Final Landform through the development of Cultural Closure Criteria consultation work completed by Murray Garde in 2014 (Garde 2015). See Section 8 for Cultural Criteria.	8
18	Exec Summary	ES 14 (aa)	… development of fit for purpose closure criteria	Does this approach underlie all aspects of closure, incl: surface & groundwater, landform, rehab, etc? It is a nice sound-bite but should be true of all closure criteria.	The refined closure criteria statements presented in this MCP have been divided into two categories; proposed criteria for minister approval, and draft criteria for further review. These have been divided into separate tables in order to clearly identify those that have been agreed between stakeholder groups and are ready for finalisation with ministerial approval and those that require further review and consultation.	8
19	Exec Summary	ES 15 (8. Closure Criteria)	Closure criteria Working Group	Who is involved in this group? A textbox would be useful.	The CCWG was be a sub-committee of the Ranger Minesite Technical Committee (MTC) and was be chaired by ERA. Technical representatives from all stakeholder groups were invited. Ongoing Closure Criteria discussions are held through the MTC as required.	8

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
20	Exec Summary	ES 19 (11 Closure implementation)	ERA is committed to completing rehabilitation and the achievement of the environmental requirements.	This commitment should be at the front of the Exec Summary and closure plan. It is a/the key message of the MCP.	Noted.	Exec Summary
21	Exec Summary	ES 20 (aa)	… 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.	This commitment should be at the front of the Exec Summary.	Noted.	Exec Summary
22	Exec Summary	ES 23 (Table ES 6 TSF)	… the TSF will be cleaned of all visible tailings	This is different to "11.2 By the end of operations all tailings must be placed in the mined out pits." as in the Environmental Requirements.	This has been updated for clarity. Refer to Section 9.3.3	9
23	Exec Summary	ES 25 (Table ES 6 Stockpiles)	All mineralised material not processed at the completion of milling in January 2021 will be placed well below final landform surfaces.	Presumably more detailed information on volumes, grade, depth of disposal will be presented.	Detail on volumes, grade and depth of disposal of hazardous waste was provided in the 2019 MCP. See Section 11.10: *Waste and hazardous material management.* This information is provided in the 2020 MCP in Section 9.4.2	9
24	Exec Summary	ES 25 (Table ES 6 Final landform)	(T)o validate design attributes such as landform stability, erosion topography, and visual amenity.	Please check punctuation. T**o what extent does social and cultural utility inform** the design attributes?	Mirarr considerations were included in the design of the Final Landform through the development of Cultural Closure Criteria consultation work completed by Murray Garde in 2014 (Garde 2015). This was presented in detail in Section 8.7 of the 2019 MCP. It is presented again in Section 8.3.6 of the 2020 MCP.	8
25	Exec Summary	ES 27 (12 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.	**A discussion on what the 'potential access to and final land use of the area' and how this is determined is necessary.** Reference to where in the MCP this can be found would suffice.	This was presented in detail in the 2019 MCP in the Section 6, titled *Post-mining land use and closure objectives*. Due to the title of the section, ERA did not consider a cross reference to be necessary. The 2020 MCP describes the final land uses in Section 8.1	8
26	Exec Summary	ES 27 (aa)	Given the possible post-closure uses of the landform, the critical group will be Traditional Owners using the site for traditional activities	There is **limited discussion** about this critical group and how the closure plan is being developed in collaboration with them. Please include better linkage to the TOs and how the MCP is designed to address their being 'the critical group'.	ERA has a long history of stakeholder engagement with the Mirarr people through consultation with the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC). In 2014, ERA formalised this engagement regarding post-mining land use and closure criteria development with extensive consultation with Traditional Owners, through the consulting linguist and anthropologist Murray Garde. This report was summarised and refined for habitation, use of traditional plants and animals and the assumed post closure bush food diet (Paulka 2016). Details on the summarised report is described in Section 8.1.	8

ERA

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
27	Exec Summary	ES 29 (13 Financial provision)	Separate to this MCP, each year ERA prepares and submits an Annual Plan of Rehabilitation	Once the mine closure plan is live, there is no 'annual plan of rehabilitation' since rehabilitation is an integral part of closure. Can these not be integrated?	The plan for rehabilitation works has been detailed within the MCP. The Annual Plan of Rehabilitation (APR) is high-level, commercially sensitive information which is not appropriate for public release. This is provided separately for review to regulators and it is not suitable for public access.	11
28	Scope & Purpose	1-6 (1.3 Scope of MCP)	To plan for the retention and transfer of the airport for future use	… transfer of **ownership** of the airport … ?	This has been updated to clarify "transfer of ownership." Refer to Section 1.3.	1
29	Scope & Purpose	1-7 (Table 1-1)	Closure. Period between 8 January 2021 & 8 January 2026. Decommissioning, completion of rehabilitation & transition of monitoring requirements	"Completion of rehabilitation" implies a functioning ecosystem, which is not possible. Suggest changing it to reflect the state of rehabilitation likely at 2026.	This has been updated to read "Decommissioning, completion of rehabilitation groundworks & transition of monitoring requirements". Refer to Section 1.3, Table 1-1.	1
30	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.	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.	Noted. This will be considered for future MCPs.	All

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
31	Project Overview	2 (2.1 Project overview)	Construction of the Ranger Mine began in January 1979 and the mine came into full production in October 1981. During the early stages of construction, the Commonwealth Government announced its intention to divest its interest in the project. Peko subsequently established a new company, Energy Resources of Australia Ltd (ERA), to purchase the existing partners' interests. Mining of the Ranger 1 orebody (Pit 1) was completed in December 1994 and development of the adjacent Ranger 3 orebody (Pit 3) commenced in 1996. ERA sells its product to power utilities in Asia, Europe and North America under strict international and Australian Government safeguards3. The company aims to maintain long-term relationships with its customers to meet their energy needs and provide a reliable supply of high quality product.	The paragraph starts with discussing start of construction, then migrates through ownership and finishes with customers. Essentially three distinct subjects in one paragraph. **Recommend splitting the paragraph based on subject.** The overall subject of this paragraph concerns commencement of civils and mining.	Updated to split paragraph	2
32	Project Overview	2 (2.1)	During the early stages of construction, the Commonwealth Government announced its intention to divest its interest in the project. Peko subsequently established a new company, Energy Resources of Australia Ltd (ERA), to purchase the existing partners' interests.	The discussion about the formation of ERA and where ERA sells its products is somewhat incompatible with the overall subject.	The history of the formation of ERA is an important note to have in the "History" section of the Project Overview. ERA also believes it is important to assure the public that all product from the Ranger Mine is distributed to countries under strict international and Australian Government safeguards.	2
33	Project Overview	aa (aa)	ERA sells its product to power utilities in Asia, Europe and North America under strict international and Australian Government safeguards3.	Perhaps shift this to a new paragraph about customers.	Updated.	2
34	Project Overview	aa (aa)	Potental of 30,000 to 40,000 T of contained uranium oxide.	"of contained"? Containing, with, of concentrated? Grammar seems incorrect.	The word 'contained' has been removed	2
35	Project Overview	3 (2.2 Overview of operations)	Sections 2.2.1 to 2.2.8 provide an overview of the components of the mining and processing operations at the Ranger Mine (Figure 2-1), including the associated key activities and infrastructure. Section 2.2.9 summarises the site wide water management system. Discussion on the closure of Jabiru East area and the Jabiru Airport are not included within the Mine Closure Plan (MCP).	Is the start of a Section on Overview of Operations the right place for these paragraphs? Generally an 'overview' chapter describes the methodology used to mine: Conventional open pit mining methods … drilling & blasting (what equipment) … transport to ROM (type of trucks) … ROM … primary crushers, secondary crushers, SAG AG mills … concentrators … use of chemicals … thickeners … driers … etc … A basic run through of the flow of ore from pit floor to transport off-site. Then the bit about when extraction finished, stockpiling took over, etc, leading to where Ranger is now.	These details are provided within the Mining Management Plan. Only a brief description of the operations (stages of mining) has been included in this section. Water management is integral to all stages of Ranger Mine operation and rehabilitation therefore a short summary is included here and discussed in detail within the Ranger Water Management Plan.	2

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
36	Project Overview	aa (aa)	Section 2.2.1 to 2.2.8	It shouldn't be necessary to continuously tell readers d where in the document readers can find what. A dedicated Section can be provided for this. Shouldn't this Section simply start by describing the 'overview of operations'	The table of contents for each section provides a quick reference. To avoid repetition section references are placed within internal text to guide the reader throughout the document, given the document's large size and complexity.	ALL
37	Project Overview	15 (2.2.9.3)	[WLF] was designed primarily to polish ammonia from treated pond water permeate and uranium from surface water runoff	Please explain what 'polish' means in this context. A text box could be useful.	This has been updated to clarify. Refer to Section 2.2.9.6.	2
38	Closure Obligations	3 (3 Closure Obligations)	ERA is commited to…	Is there a commitments register or a list of key commitments? The ERs form the basis but there must be a number of ERA corporate, operations and closure commitments too.	ERA maintains a legal commitments register (Closure obligations register). Legal commitments pertaining to closure were included as Appendix 3.2 in the 2019 MCP. This register, expanded to include commitments made in relevant approvals, is included as Appendix 3.2 in the 2020 MCP.	3
39	Closure Obligations	aa (aa)	To ensure closure design decisions mitigate potential impacts	Is there a list of impacts and how they are to be mitigated and managed? Assessing the impacts of closure plan is (international) industry best practice.	BPT assessments are undertaken for all proposals to amend or introduce operational approaches, procedures and mechanisms to Ranger Mine during operation and closure. Please refer to Section 6 for the assessment criteria. Risk scenarios that result in the highest ranked potential impacts (class III and IV risks) were provided in Section 10 of the 2019 MCP. Section 7 of the 2020 MCP now provides this list as an analysis of threats and consequences to the environment that may result from closure operations. Section 9 of the Mine Closure Plan also describes contingency planning per domain for Rehabilitation works.	3, 7, 9
40	Closure Obligations	10 (3.2.1)	The Rio Tinto Closure Standard (HSEC-B-27) requires each Rio Tinto operation (globally) to develop and implement a plan for closure which sets the minimum requirements.	Suggests ERA does not have a suitable closure standard. Can ERA explain the relationship between RT and ERA?	ERA operates under the Rio Tinto Closure Standard which requires each Rio Tinto operation (globally) to develop and implement a plan for closure which sets the minimum requirements under the RT standards. Where site specific gaps exist, ERA standards apply (i.e. ERA BPT Assessment Standard).	3
41	Closure Obligations	aa (aa)	ERA Environmental policy	Does ERA have a dedicated Closure Policy, given the significance of closure relative to the project's authorisations?	ERA operates under the Rio Tinto Closure Standard which requires each Rio Tinto operation (globally) to develop and implement a plan for closure which sets the minimum requirements under the RT standards.	3

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
42	Closure Obligations	14 (3.4 Closure permits and approvals)	The transition into closure will involve applying for regulatory approvals to authorise new requests or to modify the currently authorised activities.	If closure planning is sufficiently advanced is there not the opportunity re-think the entire Authorisation to cover the entire phase?	The Authorisation administered under the Mining Management Act should be relevant and applicable to all closure activities. At times ERA will need to apply for specific approvals for activities that have not been approved through the MCP previously or that are not suitably covered by the existing Authorisation. To meet timeframes for implementation applications may need to be submitted outside of the MCP approval cycle to avoid delay. Responsibility for revisions of the Authorisation rest with the Northern Territory Government.	3
43	Environmental & social setting	2 (Climate)	associated with the effects of the El Niño Southern Oscillation, the Madden-Julian Oscillation and tropical cyclone activity … Increased cyclone activity in the Australian region has been associated with La Niña years …	It would strengthen understanding of these if there were a simple explanation as to why they are influential, perhaps in a text box.	Noted. This will be considered for future MCPs	5
44	Environmental & social setting	3 (aa)	When cyclones and tropical lows are present, the Alligator Rivers Region can experience high winds and rainfall.	Examples of when this has occurred and the wind speeds and rainfalls experienced would be handy. Text box?	Noted. This will be considered for future MCPs	5
45	Environmental & social setting	3 (4.2.2.1. Soils)	Iron oxyhydroxides	A simple explaination of what this is would be good.	Iron(III) oxide-hydroxide or ferric oxyhydroxide is the chemical compound of iron, oxygen, and hydrogen with formula FeO(OH).	5
46	Environmental & social setting	aa (aa)	be inherited from underlying Cahill formations schists	… as explained in Section 4.2.2.3 Geology and mineralisation	Updated	5
47	Environmental & social setting	15 (4.2.3.1 surface water)	Periodically submitted to the MTC for review	Text box of **who/what the MTC is.**	The Minesite Technical Committee is described as being formed as a result of the recommendation from the Fox inquiry. The definition of the MTC is now supplied in the Glossary attached to the 2020 MCP.	5
48	Environmental & social setting	17 (4.2.3.2 surface water chemistry)	whereas turbidity is high during the accessional limb, but decreases to a steady low during the recessional limb	Please explain what "accessional and recessional" limb is.	Accessional limb refers to the early period of the wet season when stream flow in Magela Creek is increasing. Recessional limb refers to the late period of the wet season when stream flow in Magela Creek is decreasing. This is now clarified in Section 5.2.8.2	5
49	Environmental & social setting	17 (aa)	indicates that generally'	"indicates" is 'general' only one needed.	ERA has chosen to keep the wording unchanged.	5

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
50	Environmental & social setting	18 (4.2.4 groundwater)	Most of the data are non-parametic…	The MCP is a public document as well is to be reviewed by people with different knowledge backgrounds. Topic specific word, such a 'non-parametric', will not be understood by all readers. To facilitate review and acceptance of the document strongly suggest simplifying technical terminology or using text-boxes to explain them.	Text is updated with new studies completed with regards to Background Constituents of Potential Concern in Groundwater. As a result this wording has not been included in the 2020 MCP.	5
51	Environmental & social setting	23 (4.3.1 Bioregions)	Most of the RPA lies within the northeast Section of the 28,520 km2 Pine Creek Bioregion. Features of the Pine Creek Bioregion include:	most of' implies some of the RPA lies in another bioregion. Which is it?	A small (0.3km^2) section in the northeast of the RPA is contained within the Arnhem Plateau Bioregion.	5
52	Environmental & social setting	23 (4.3.2 National parks)	The RPA is surrounded by Kakadu NP … (and) … The RPA is also within 150 km of three other national parks: Warddeken Indigenous Protected Area (approximately	Does the indigenous protected area have the same protections as a National Park? If different suggest explaining what the difference is.	Mention of the additional National Parks and the Warddeken Indigenous Protected Area is made in order to describe the location of Ranger Mine. In accordance with the Primary Environmental Objectives of the Commonwealth of Australia for the Operation of Ranger Uranium Mine, ERA must ensure that operations at Ranger Mine are undertaken in such a way to: • maintain the attributes for which Kakadu national Park was inscribed on the World Heritage List, and • maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands. It is for this reason that Section 5.3 details the attributes of the World Heritage listing attributes, the ecology of Kakadu and the Ramsar criteria, rather than listed the attributes of the nearby additional National Parks and the Warddeken Indigenous Protected Area.	5
53	Environmental & social setting	27 (4.3.3.1 vegetation)	… four vegetation types in the RPA dominated by eucalypt open forest and/or woodland (Figure 4-10). … mostly co-dominated by Eucalyptus (E) miniata and/or E. tetrodonta.	Photos of the types of trees and the kinds of communities would be illustrative.	Photos of fauna and flora have been included in the MCP where relevant to supporting studies (i.e. Flowering and fruiting on the Trial Landform; directly seeded *Galactica tenuiflora*; various grasses, herbs, sedges and vines that have naturally colonised the Trial Landform; Leguminous understorey self-colonisers on the Trial Landform and Fauna visitations. Please refer to Appendix 5.1	5
54	Environmental & social setting	28 (Table 4-6)	Area and proportion of vegetation communities on the RPA	**The % of the RPA of communities means there is no mine footprint, since they tally to 100%. Suggest adding the mine footprint (disturbed) areas as a percentage to the RPA, and as a total of Kakadu.** **Is there any way to speculate what the community/ies is likely to be established or desired to be established on the mine footprint?**	The table has been updated to clarify that this relates to the undisturbed or non-mining sections of the RPA only.	5

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
55	Environmental & social setting	33 (4.3.3.3 Fauna)	Kakadu NP contians over one third of..	They first impression suggests that they only occur in Kakadu, as in are endemic to. If not, perhaps simply better to put the number of species and mention it equals 1/3 of Australia's species.	ERA has chosen to keep the wording unchanged.	5
56	Environmental & social setting	aa (aa)	A number of conservation significant species (including a large number of mostly bird species listed under various migratory agreements) have	Suggest moving the bracketed text to the end of the sentence, since it's somewhat confusing when after discussing birds the 'identified species' includes the quoll, a mammal.	ERA has chosen to keep the wording unchanged.	5
57	Environmental & social setting	38 (4.3.3.4 Bushfires)	The management approach in Kakadu NP has been to copy the indigenous burning regime by using helicopter incendiary burning combined	The way it's written suggests that indigenous people used to fly helicopters to perform control burns	The indigenous burning regime is aimed at replicating the fine scale burning early in the dry season which is made easier by the use of helicopters by Park Management. Helicopter incendiary burning is a method used at the start of the dry season by Park Management to increase the burnt area in the early dry and as such decreasing the potential for late dry season burns. The section 5.3.3.4 has been updated to provide more clarity.	5
58	Environmental & social setting	aa (aa)	Further to this, a high fire frequency has been shown to have a propensity for producing a grass-fire cycle (D'Antonio & Vitousek 1992) where trees and shrubs are replaced by annual grasses	**Has an assessment been made of the impact of climate change to success of re-establishing vegetation types on the RPA?**	ERA has completed a Climate Change Risk Assessment which is discussed in Section 5.5.5 (Assessing the cumulative risks to the success of rehabilitation on-site and to the protection of the off-site environment). This risk assessment also discussed vegetation aspects.	5
59	Environmental & social setting	aa (aa)	Fire within the RPA is managed by ERA primarily for asset protection	Is ERA's fire regime in keeping with traditional indigenous fire practices? Or designed for ERA's specific needs? Will it change once operations and closure finish and post-closure begins?	During operations ERA's fire regime has been focussed on asset protection. In recent years with the transition to closure there has been more focus on traditional burning practices for weed and land management. It is expected that as closure progresses there will be more focus on the traditional practices and less need for asset protection.	5
60	Environmental & social setting	39 (4.4.1 Aboriginal culture)	Where necessary, sites will be protected from disturbance during closure activities by the implementation of management plans, barriers and awareness.	Where necessary' creates the wrong impression. Suggest starting with 'Sites will be protected by … ' which more accurately describes ERA's approach to protected cultural heritage sites.	This section has been updated (Section 5.1.1).	5
61	Stakeholder Engagement	9 (5.3 Ranger Mine Closure)	The SIA is scheduled for review in late 2019	Has the SIA been reviewed? If so, when will the results be described in the MCP, and how the results influence the MCP?	ERA will update the SIA in early 2021 to incorporate both specific information on the cessation of Ranger Mine operations and recent developments around the future of Jabiru	4

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
62	Post-mining land use	1 (6.1 post-mining land use)	The Environmental Requirements (ERs), conditions of the Section 41 Authority issued under the Atomic Energy Act 1953 and appended to the Ranger Authorisation (as Annex A) issued under the Mining Management Act 2018 (NT) (Section 3.1.3) specify that the Ranger Project Area (RPA) must be rehabilitated	Suggest prefixing the word 'Section' with something that informs the reader that the Section in question is in the MCP and not, as initially read, in one of the documents above, such as in the Mine Management Act. This comment is applicable throughout this Section.	To improve clarity, this particular reference to Section 3 of the MCP has been has been changed to "MCP Section 3" as the reference to this Section is relevant.. All other references to Sections of the MCP were reviewed and established to be free of ambiguity.	8
63	Post-mining land use	1 (aa)	extensive consultation with Traditional Owners regarding their planned use of the site which resulted in the Garde report (2015).	It may be illustrative to **describe** in a text box what the **purpose of the Garde report is.**	Reference to work undertaken by Murray Garde has been modified to clarify the purpose of his consultation. Refer to Section 8.1.	8
64	Post-mining land use	2 (aa)	Aboriginal people indicated that a familiarisation of young people with certain cultural sites on the RPA post-rehabilitation would be desirable	Young people in general or young Mirarr people?	The word Bininj has been included to improve clarity.	8
65	Post-mining Land-use	2 (6.2 Closure objectives)	…as to what the proponent…'	The proponent? Or ERA?	In this case, the proponent is ERA. As this is a reference to WA guidelines, wording has been kept as per the referenced guidelines.	8
66	Supporting Studies	General	Chapter is not specifically about how ERA intends to close the Ranger mine.	The information in this Chapter concerns studies which underpin strategies of different aspects of the closure process. At 322 pages it is a substantial document which does not add much value to the actual closure plan. As in, it is not about closure per se. **Recommend appending it to the mine closure plan, referring to it when relevant.** The focus of the MCP should be on what ERA intends to do to close the site in compliance with legislation and SH expectations.	The information in this Section incorporates the scientific studies to establish a baseline (pre-mining) case while also sharing a summary of the current technical knowledge base including site conceptual models. This is in accordance with the WA Mine Closure Plan Guidance. An integral part of Ranger's progressive rehabilitation and closure is addressing the knowledge needs (gaps) to assess the post-mining environmental impact as well as studies to inform regulatory requirements, operational investigations and global emerging issues like climate change. ERA believe this section is an important section to include as part of the MCP and not as an appendix.	5

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
67	Supporting Studies	53 (General comment from text)	The micrometeorological feedback of the sensitivity of transpiration to a marginal change in stomatal conductance at the stand level is regulated by a dimensionless decoupling coefficient proposed by McNaughton and Jarvis (1991).	The various Sections in the chapter appear written by experts. The style or writing and terminology can be difficult for non-experts to understand. Suggest the experts/authors are directed to be more descriptive and use less complex terms. Or have the Section edited by a suitable editor.	This Section is aimed at providing scientific evidence for Closure planning. It is aimed at a technical audience to addressing the knowledge needs (gaps) to assess the post-mining environmental impact	5
68	Supporting Studies	95 (General use of brackets)	The criteria for site selection included: vegetation community (similar to those to be established on the final landforms), fire regime (captures variability of vegetation communities under different fire regimes), surface geology/soils (similar to those identified in the final landform vegetation communities), position in the landscape (captures the variability in crest, upper/mid/lower slope vegetation communities), cultural heritage (no impact on cultural heritage), access (easy access during all seasons and in the long term) and weed status (weed free at time of establishment). The criteria were consulted with relevant stakeholders and experts. Based	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 will be considered in future submissions of the MCP.	5
69	Closure Criteria	Closure criteria status (Section 8.8)	Closure criteria status (Section 8.8)	The last Section in the chapter - 8.8 - describes the status of the closure criteria. It would be preferable to have this Section at the front of the chapter, as it is the most important part of the chapter, then structure the rest of the chapter around it. Reading the other Sections 8.1 – 8.7 there is an impression that selection of the closure criteria is not well advanced. In Section 8.8 the reader is informed that a large number of criteria have been agreed.	The refined closure criteria statements presented in this 2020 MCP have been divided into two categories; proposed criteria for minister approval, and draft criteria for further review. These have been divided into separate tables in order to clearly identify those that have been agreed between stakeholder groups and are ready for finalisation with ministerial approval and those that require further review and consultation.	8

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
70	Closure Criteria	14 (8.3.3 Justification of outcome...)	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).	Can ERA explain more about their **approach to address the concerns of TOs regarding integrating cultural values with scientific, legal and technical aspects**?	Further information regarding engagement with Traditional Owners and the integration of cultural values with non-indigenous scientific, legal and technical domains was provided in the 2019 MCP in Section 5, Stakeholder Engagement and Section 8.7.1 of Closure Criteria. These Sections are within the 2020 MCP as Section 4 and Section 8.3.6.	4 and 8
71	Closure Criteria	30 (8.4.1.2) Radiation effects	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	Where is the benchmark documented? Can ERA explain more about this benchmark? Text box?	The definition for benchmark dose rate has been added to the glossary at the beginning of Section 8.	8
72	Closure Criteria	8.6.1 Justification for outcome …	The closure criteria for flora and fauna (Table 8-5) were developed through information from appropriate reference sites and rehabilitation trials … This model is key to defining the target ecosystem/s and will determine the quantitative, semi-quantitative and/or qualitative closure criteria for assessment of success	The first tells the reader that closure criteria 'were developed', that is, they exist. The second tells the reader that closure criteria 'will be determined', that is they do not exist. Please resolve the discrepancy.	It is explained within the same paragraph of the Section 8.6.1 of the 2019 MCP, that '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 conceptual model is further developed and/or finalised'. Hence, the correct statement that the criteria 'were developed' and the equally correct statement that the model is key to determining the 'quantitative, semi-quantitative and/or qualitative closure criteria'. Section 8.8.5 of the 2019 MCP expounds on this, noting that a number of studies were underway that would provide results to refine and finalise the closure criteria. The refined closure criteria statements presented in this 2020 MCP have been divided into two categories; proposed criteria for minister approval, and draft criteria for further review. These have been divided into separate tables in order to clearly identify those that have been agreed between stakeholder groups and are ready for finalisation with ministerial approval and those that require further review and consultation.	8
73	Closure Criteria	8.8 Status of closure criteria	The Supervising Scientist has developed a series of rehabilitation standards for Ranger Mine (Table 8-9) against which the Supervising Scientist will judge the success of the rehabilitation	Is this the same as closure criteria? It would be expected that stakeholder agreed closure criteria would be the universal criteria against which rehabilitation is judged.	The closure criteria are the final agreed parameters for assessing the performance of rehabilitation. The rehabilitation standards developed by the Supervising Scientist are guiding standards of an advisory nature only. ERA work closely with the SSB, and all other MTC members as part of the Closure Criteria Working Group in developing the closure criteria and refer to the rehabilitation standards when establishing parameters, however, the standards will not necessarily be integrated in their entirety into the closure criteria.	8

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
74	Best Practicable Technology	7 (9.2 Completed BPT)	Completed closure related BPT assessments	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.	Suggestion noted. Consideration will be given to restructuring this section in future submissions. In accordance with the requirements of the WA Mine Closure Plan Guidance for baseline and closure data and analysis, a summary of supporting studies is provided within the body of the Mine Closure Plan. Relevant technical reports are provided as appendices.	6
75	Risk Assessment	3 (10.2 previous risk assessment)	Previous risk assessment	Section has strong links to the BPT assessments of the same infrastructure. Is there a way to link them directly in the same Section?	BPT assesssments are undertaken for all proposals to amend or introduce operational approaches, procedures and mechanisms to Ranger Mine. As such, the BPT assessments address a narrower field of activies than the closure risk assessment, which covers all potential environmental risks of closure, be they associated with new proposals or ongoing activities. Although there is a strong linkage between the two Sections, they remain separate.	6
76	Risk Assessment	3 (aa)	Ranger closure feasibility study 2018: risk assessment	Is this the overarching risk register for the Ranger mine including the MPC? If so, can ERA briefly describe the overall risk register and what else it pertains to?	All risks relevant to the Closure of Ranger Mine is described in Section 7	7
77	Risk Assessment	4 (10.3 closure risk assessment)	Outcomes from this risk assessment will continue to be reviewed and additional risks identified during internal or external workshops (e.g. the cumulative risk assessment currently being run by Supervising Scientist Branch (SSB))	How many risk assessments relevant to the MCP exist? Can they be cross-referenced & compiled into one?A brief explanation of the SSB's 'cumulative risk assessment' would be informative. It is not included in the preceding Section.	There is a single ERA closure risk register. This has been constructed from previous assessments and updated over time to reflect current status. This Section describes each preliminary assessment that has taken place and recent updates. The outcomes of SSB Cummulative Assessment will be presented as per their own schedule.	7
78	Risk Assessment	5 (10.4.2 Purpose and objective)	The purpose of the closure risk analysis was to identify and evaluate the consequences and significance of the threats on the surrounding environment associated with the closure of Ranger Mine, effective 8 January 2026	It seems to very similar to that of an impact assessment. Strongly recommend the MCP include an impact assessment.	The layout and format of the MCP is in line with the WA MCP Guidelines. An impact assessment was not identifed in the feasibility study and a number of independent studies (addressing numerous issues) have been scheduled. Reports of these will form the overall assessment.	7

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
79	Risk Assessment	5 (aa)	The three phases of closure: decommissioning, stabilisation and monitoring and post-closure. Decommissioning commences at the completion of processing, currently scheduled to end in 2020, and will continue to 2026. Decommissioning includes 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 stabilisation and monitoring 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 achievement of closure criteria has commenced. This phase may require initial management as landform settling, subsidence and erosion occur, and vegetation establishes. Passive water management techniques will be implemented where required. The post-closure phase occurs when monitoring has demonstrated the closure criteria have been achieved and a close-out certificate has been issued. It is in this period the site will be returned to the Traditional Owners, and the site may be incorporated within Kakadu NP.	3 closure phases: 1. 2020-2026. Decommissioning. rehabilitation, recontouring, revegetation. 2. >2026-closure criteria achieved. Stabilisation & Monitoring. Development of long term viable ecosystem. 3. Post-closure. Close-out certificate issued. Site returned to TOs, able to be incorporated into Kakadu National Park. This is the key overall long-term conceptual plan. **Suggest placing it at the front of the MCP.** Describes how ERA defines the key phases: decommissioning; stabilisation & monitoring, &; post-closure. The MCP could be constructed based around these phases. **Has ERA achieved consensus from stakeholders - NLC, SSB, DPIR, DIIS - on the definition of The Three Phases of Closure?**	The phases of closure have now been included in Section 1 of the MCP (Table 1-1). These phases were all agreed with stakeholders as part of the early work of the MTC working group "Closure Criteria Working Group".	7

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
80	Risk Assessment	aa (aa)	decommissioning, stabilisation and monitoring and post-closure.	This is good and important info and could/should be much earlier in the document 1. Decommissioning Decommissioning commences at the completion of processing, currently scheduled to end in 2020, and will continue to 2026. Decommissioning includes 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. 2. Stabilisation & Monitoring The stabilisation and monitoring 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 achievement of closure criteria has commenced. This phase may require initial management as landform settling, subsidence and erosion occur, and vegetation establishes. Passive water management techniques will be implemented where required. 3. Post-closure The post-closure phase occurs when monitoring has demonstrated the closure criteria have been achieved and a close-out certificate has been issued. It is in this period the site will be returned to the Traditional Owners, and the site may be incorporated within Kakadu NP.	See response to comment #79	7
81	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	'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.	For the purposes of developing the closure risk profile by reviewing existing risk assessments, hazards were analysed with mitigation measures in place as inherent and current risk had already been identified and the mitigation measures applied would remain. Without mitigation measures in place the risk evaluations would show a different profile. The use of text boxes will be considered for the 2021 MCP.	7
82	Risk Assessment	13 (Table 10.5)	Threat code: heading of columns on the left of table.	Explanation of Threat Code required to understand how these columns work.	Table 10-4: page 10-11, provided the risk breakdown structure/Threat code explanations in the 2019 MCP. The equivalent information is now found under 7.3.5 Risk Relationships in the 2020 MCP.	7
83	Risk Assessment	16 (aa)	Insufficient volume or quality of viable seed stock available for whole of site revegetation	The only Class IV risk. The Threat Code does not inform the reader that this is a Class IV risk. Table would be strengthened by have the risk Class clearly indicated.	Appendix 7.1 Ranger Closure Risk Assessment provides the risk management class I – IV.	7

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
84	Risk Assessment	18 (aa)	Large scale fire or natural disaster (e.g. cyclone) destroys immature vegetation.	This threat is repeated on the same page of the table albeit with a threat code.	This has been rectified in Appendix 7.1 of the 2020 MCP.	7
85	Risk Assessment	20 (10.5.1)	Insufficient volume or quality of viable seed stock.	What about the **risk to produce the number of viable tubestock** to meet revegetation targets by 2020? Especially when Threat Code T C 04 01 Low plant survival rate states under evaluation rationale that an "additional 20% plants die" which suggests a high mortality rate (additional to what rate?). The risk table does not mention desired/required viable tubestock numbers.	Appendix 7.1 shows detail on the following related risks; • Insufficient volume or quality of viable seed stock available for whole of site revegetation [504574] • Insufficient volume or quality of trees from nursery for revegetation [505249] • Low plant survival rates in the field during establishment and vegetation decline after/at establishment [504500] The related controls are: • Revegetation strategy designed to meet closure criteria for resilience (e.g. species mix, irrigation, weed monitoring, viability/germination rate/mortality rate/large scale failure contingency) [602395] • 20% allowance for infill. [505250]. • 30% allowance for unviable seeds. [505251]. The 20% allowance for infill [505251] specifically addresses the mortality rate across multiple species and multiple target ecosystems. Tubestock numbers are managed via the Revegetation Management Plan.	7
86	Risk Assessment	10.5 and 10.6	Discussion on Class IV and III risks	Is it necessary to repeat what is well represented in Table 10.5? Table is actually easier to read and absorb information. What is missing from Table 10.5 is likelihood of occurrence of the risk. It may be in the Threat Code, but without it clarified it is not clear.	The risk ranking is made up of both likelihood and consequence. The majority of risks have multiple consequences, therefore it is not possible to include this in simple table. The inclusion of the likelihood without the consequence did not seem to add value so this has not been included. If required the additional information on consequence and likelihood of threats could be provided seperately the regulator.	7
87	Implementation	11.2.1 Closure activities	Closure activities, eg bulleted lists of historic timelines concerning key infrastructure, Pit 1, Pit 3, etc	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	This section includes a summary of completed rehabilitation to date has been summarised for each Closure domain. Each domain's historic, current and planned activities (including contingencies) have been kept together in the Implementation section.	9

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
88	Implementation	aa (aa)	ERA commenced deposition of tailings within the mined-out Pit 1 in August 1996. This followed an initial Application to the Minesite Technical Committee (MTC) to deposit neutralised tailings into Pit 1, which was approved by the NT Minister in September 1995 (ERA 1995). In May 2005, ERA sought regulatory approval to increase the tailings deposition level in the pit to an interim 12 mRL, which was received in August 2005 (ERA 2005). 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.	There is a lot of such ancillary information through this and other chapters and Sections. Understandable why ERA would like to include it. However, it does not actually inform the reader what's happening or will happen regarding closure of the mine.	Each domain's historic, current and planned activities (including contingencies) have been kept together in the Implementation section	9
89	Implementation	9 (11.2.1. Pit 1 closure activities)	With due consideration given to the outcomes of the relevant risk assessments and, in particular, the range of existing and proposed controls required to eliminate, minimise or mitigate the identified risks.	Whilst this is reassuring, it could be included in Chap 10: risk assessment. Here the reader wants to know how ERA is going to finalise the work on Pit 1. The reader is not taking for granted that ERA is considering risks. ERA has specifically addressed that in Chap 10.	Noted, ERA considers it important for the reader to be clear that risk mitigations are taken into account for closure implementation planning. This paragraph has remained unchanged.	9
90	Implementation	9 (aa)	Pit tailings flux; 1s & 2s waste rock	This is the first time the reader encounters these terms. A short description, perhaps in a text box, would be handy.	This has been updated to clarify. Refer to Table 9-3. Waste characterisation is also discussed in Section 9.4.2.	9
91	Implementation	10 (aa)	Modelling has predicted total consolidation settlement after placement of backfill.	After placement of backfill' presumably has no time limit. Given limitless time, tailings will consolidate. **Can ERA provide more information in terms of the time it takes for consolidation and what risks &/or impacts to Closure objectives result from that?**	Section 5.4.1 describes the current tailings consolidation models for Pit 1 and Pit 3. After completion of tailings deposition into Pit 3, the tailings consolidation model will be updated	5

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
92	Implementation	12 (11.2.1.2 2s waste rock)	… characterised over the past 35+ years of mining	This or similar is mentioned quite a few times: monitoring, research, investigations, mining … 35 to 40 years of experience, etc. It really only needs to be mentioned once perhaps in a History/Work To Date Section. A lot of similar information extraneous to the Chapter/Section could be placed in such a Section. In this Section - Implementation – ERA is trusted to have done all the background work necessary to understand why the implementation activities have been chosen. Reference can be made to where supporting studies, etc, can be found.	Noted	
93	Implementation	12 (aa)	The U3O8 content of 1s waste rock is less than 0.02 wt%, and 2s rock (very low-grade ore) is 0.02 – 0.05 wt%.	Perhaps place in a table showing key characteristics of the different classes of waste rock (& stockpiles). Eg table 11-18	A waste characterisation section has been included and the table updated (Section 9.4.2 Table 9-37)	9
94	Implementation	14 (11.2.2 Schedule)	Pit 1 backfill, final landform contouring and ripping is schedule to be completed by mid-2020.	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 are with the area under discussion highlighted to assist the reader in understanding where they are. Perhaps based on Fig 11.66	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
95	Implementation	5 (11.2.4 Pit 1 current research)	The outcomes of the monitoring and studies will be used to address relevant Key Knowledge Needs (KKNs) (Appendix 7.1).	**Is there enough time to generate information to be used in the rehabilitation of other impacted areas? If not, what is the contingency to guide the rehabilitation of other areas?**	Pit 1 is now completed and various studies are planned to commence this year. The main bulk material movement does not commence until 2023, this gives sufficient time to incorporate any additional learnings into future closure planning.	9
96	Implementation	16 (11.3 Pit 3)	Closure activities, bullet list	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	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
97	Implementation	17 (aa)	MTC describing the assessment of potential environmental impacts from the interim final tailings level in Pit 3	An impact assessment should be done for all aspects of the closure plan. It would complement the risk assessment.	See response to comment #9	
98	Implementation	18 (aa)	Installation of geofabric	What is the expected lifespan of the geofabric? Why is it needed? What happens when it no long functions as designed?	The geofabric is required to provide sufficient geotechnical strength to allow for the capping works on Pit 3 to commence. It is only required for a short period, until sufficient strength is obtained through the placement of the cap itself.	9
99	Implementation	19 (11.3.1.1)	Tailings deposition	The desired outcome -19.7 mRL could be mentioned here.	This has been updated. Refer to Section 9.3.2.	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
100	Implementation	aa (aa)	depositing of tailings into the facility in such a manner to reduce tailings segregation that will compromise their structural integrity	Can ERA add a short description about how the deposition strategy **will actually ensure the required surface (bullet one) and reduce segregation?** The bullet points do not provide sufficient backup to have confidence in the statements. Later in the text it's stated that 'low discharge solids concentration' and 'fluctuation of process water volumes' resulted in segregation. **Can ERA explain more clearly the outcomes of the tailings deposition strategy, risks, impacts and contingencies?**	This has been included in Section 9.3.2	9
101	Implementation	20 (aa)	Residual tailings on the walls and floor that cannot be dredged from the TSF may need to be transferred by truck (Section 11.4.1.1). Plans to deposit this material into Pit 3 will be developed, if required, and included in future updates of this MCP. Tailings are recovered from the TSF with a diesel-powered cutter suction dredge. The slurry produced by the dredge varies between 18 and 28% by weight solids, depending on the type of tailings solid material (i.e. fine or coarse) and on the action of the dredge cutting head as it sweeps from side to side.	Re: point about further information on the tailings deposition and surface and segregation, the description on how deposition will achieve this needs an**d could be of a similar length and detail** as to how the tailings are to be (are being) transferred.	Noted. ERA are currently working on plans for the TSF floor clean that include deposition into Pit 3. All available information to date has been included in Section 9.3.3	9
102	Implementation	20 (aa)	demonstrated that the revised	Is this sentence correct or is there something that should come after 'the revised'? technique?/methodology/?	This has been updated to clarify. Refer to Section 9.3.2.1.	9
103	Implementation	22 (aa)	The purpose of the trial was to test the operability and maintainability aspects of the subaqueous deposition system, to develop standard operating procedures and modify the design of the system if required. A number of options for a subaqueous deposition system were identified and assessed as part of the system design and development. The final option chosen was a novel diffuser (Figure 11-12). The diffuser design was developed in conjunction with CSIRO Mineral Resources (Clayton, Victoria) who completed a series of computational fluid dynamics (CFD) simulations of subaqueous discharge into Pit 3, aimed at understanding the nature and distribution of tailings discharge into the pit.	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.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
104	Implementation	25 (aa)	Key elements of the subaqueous deposition system are:	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.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
105	Implementation	29 (aa)	The basis of the plan is to fill in the deep void at the western end of the pit. At the end of 2020 the coarse/fine interface will be at about -36 mRL.	As this is the 'basis of the plan' perhaps place it be at the front of the Section.	The section on tailings deposition has been updated and a new structure used for this section.	9
106	Implementation	29 (aa)	At the end of tailings deposition the bulk of the tailings will have a near horizontal surface of approximately -19.7 mRL.	The desired outcome. Perhaps place early in the Section discussing tailings deposition.	See response to comment #105	9
107	Implementation	29 (aa)	The wedges of tailings above -19.7 mRL have a very small volume of about 30,000 m3.	Can ERA clarify these wedges shall cause no problem to the remainder of the Pit 3 closure strategy and post-closure behaviour?	See response to comment #105	9
108	Implementation	29 (aa)	Given that tailings will remain lower than the surrounding groundwater heads in the formations surrounding Pit 3 during both deposition and consolidation, the hydraulic gradient will always be towards the pit.	“the hydraulic gradient will always be towards the pit". Can ERA **place temporal constraints on this**? **Will the hydraulic gradient be towards the pit even long after closure? If so, for how long, et**c? If this is discussed and clarified elsewhere in the document (Chap 7 for example), a reference to it would suffice.	Groundwater gradients will remain towards Pit 3 during tailings deposition and consolidation due to the operation of the Pit 3 decant system. As part of the post closure solute transport modelling currently underway, head recovery modelling is included in the scope to establish when groundwater gradients will change and Pit 3 will no longer act as a groundwater sink, Section 5.5.2.9..	5
109	Implementation	33 (11.3.1.2 consolidation modelling)	The key outcome of consolidation analysis is that the predicted time to reach practical completion of consolidation, that is removal of 95 % of mobile consolidation water, is June 2025, which is prior to the legislated closure date of 1 January 2026.	A key outcome. Recommend placing it at the beginning of the Section for ease of reader access.	See response to comment #105	9
110	Implementation	35 (11.3.1.3)	However, it is apparent that upon reaching the decant pond the mill tailings still segregate.	Please ensure the conclusions of experts following analysis of data are suitably clarified for readers who are not expert in that particular field. Adverbs and adjectives describing how obvious, clear, apparent, etc, conclusions are may not be for non-experts.	Noted	
111	Implementation	36 (aa)	Fig 11.20: contour plan of settled tailings surface “… and end of consolidation surface shown in Figure 11.20.”	It is not clear that the reference in the text actually references Fig 11.20	See response to comment #105	9
112	Implementation	37 (11.3.1.4)	Groundwater and contaminant transport modelling … The risk to the Magela Creek ecosystem …	Is this in the right place? It discusses risk, not implementation. If ERA wish to reassure the reader that the risk to Magela Creek has been assessed, refer them to the relevant Section in the Risk Assessment.	Groundwater modelling has been moved to Section 5	5
113	Implementation	43 (11.3.1.6)	It is noted that the geosynthetic will be laid over the wick drains but will not inhibit their performance.	How sure is ERA regarding this? Can ERA provide technical analysis demonstrating this?	This is the method used for Pit 1 that has worked.	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
114	Implementation	46 (Fig 11 - 31)	Legends and other information	The on-screen legends and other writing on diagrams are often very difficult to read. Enlarging does not solve the problem. It would benefit the MCP if the diagrams were more readable.	Diagrams and figures throughout the MCP have been updated to clarify.	All
115	Implementation	11.3.1.10 Bulk backfill	General note. 1st paragraph: "The total waste rock fill …. "	This is an example of how some information in the MCP that's not really needed. The key info is that 67M tonnes is to be placed. Mineralised material first. The comparison to Pit 1 ("As with Pit 1") doesn't add value to the key information, nor does the complexity of transport which could be discussed in a 'transport and logistics Section' if important. The lessons from Pit 1 inform the Pit 3 approach and should be mentioned, but in a general sense in a discrete Section at the start of, say, Chap 11.	Noted	
116	Implementation	48 (Table 111-6)	Progressive tasks for closure of Pit 3	This list could/should be at the front of the 'close pit 3' Section as a roadmap for the Section for the reader.	See response to comment #105	9
117	Implementation	49 & 55 (11.4.1.6 TSF closure activities)	TSF needs to be cleaned of all visible tailings, infrastructure and foreign objects prior to use as a process water storage. The current basis for floor cleaning is that visible tailings need to be removed.	The Environmental Requirements 11.2 state that " ... all tailings must be placed in the mined out pits". Not all 'visible tailings'. **Please clarify the discrepancy.**	ERA are currently working on a plan for demonstrating compliance with ER 11.2 and will be providing this to stakeholders for comment later in 2020.	9
118	Implementation	59 (11.4.1.6 Dredges removal)	Disposal of the dredging equipment in the TSF is the most straightforward and viable option and represents the base case option.	Can ERA explain the logic or elaborate more of this base-case option?	A section on dredge disposal has been included p 9-71	9
119	Implementation	59 (aa)	This will, in turn, mean that remnant tailings on the floor under beached equipment would not be able to be removed.	This is contrary to the Environmental Requirements. **If ERA believe this is best outcome for the least environmental impact & risk then a BPT assessment and agreement is needed between all stakeholders.** **Is ERA undertaking a process by which to obtain this agreement?**	See response to comment #117	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
120	Implementation	59 (aa)	The demolition contractor The bulk material movement contractor	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.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
121	Implementation	(61) 11.4.1.8 Process water storage	'At the completion of Pit 3 closure works … '	A graphic table with timing and sequence would be illustrative. Table 11.8 may be a suitable basis. Perhaps bring it to start of the Section on TSF decommissioning & deconstruction. The 'at the completion of Pit 3 closure works, water will be pumped back to the TSF' raises the question as to what 'completion of closure' is. If it includes final landform then the return of water has to happen prior to the final landform being constructed and therefore prior to completion of closure. End Pit 3 = TSF as process water store Retention Pond 6 as primary process water store towards end of closure. When TSF <1GL water transferred to RP6 TSF deconstructed. RP6 final process water store. **Can ERA better explain this process? It is quite confusing and difficult to follow.**	This has been updated to clarify. Refer to Section 9.4.3.	9
122	Implementation	61 (11.4.1.9 TSF deconstruction)	The TSF wall material is assumed to be suitable to use as part of the final landform.	Is there a program to confirm this? What is the assumption based on? Is the assumption robust enough?	The TSF wall material was discriminated to confirm it was 1s waste rock prior to use in wall construction.	9
123	Implementation	64 (11.4.3)	Approval for burial of the vessels within the TSF is required and proposed to be obtained as part of the TSF deconstruction approval. If approval is not given, alternate options for removal and disposal will be considered within the BPT framework.	**Has ERA performed a high-level risk and strategy assessment in case it isn't approved, particularly concerning risk to overall closure schedule.**	This information will be included as part of the TSF deconstruction application.	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
124	Implementation	69 (11.5.1.1 Brine Concentrator)	BC capacity is specified via the flow of product distillate. The BC initially has a distillate production capacity of 5.0 ML/d and has been slowly increasing through operational excellence programs. The current BC distillate production is 5.9 ML/day. The water management strategy requires the capacity of the BC to be increased to 6.7 ML/d. The increase in capacity is based on upgrading BC3 by installing a 2.1 MW vapour recompression fan, identical to the current fans of BC1 and BC2. Currently, BC3 is fitted with a 1.2 MW fan. The new fan is to be installed adjacent to the existing fan and tied into the existing vapour ductwork. The block flow diagram for the BC3 fan upgrade is provide in Figure 11-44. The upgrade to BC3 increases recovered water production, which subsequently increases flows throughout most of the existing plant. Several existing items of equipment must be upgraded for these increased flows.	This is specific technical information about the BC. However, it is not clear how it helps assess the implementation of the closure plan. In this Section ERA should be able to state that the BC has the capacity to satisfy the water management strategy and omit the technical details describing how.	The water treatment section has been updated Section 9.4.3	9
125	Implementation	71 (aa)	The first five paragraphs on P71 from "In the second stage … " ending with " … the HDS plan on low TDS process water."	See comment on BC above. In the Section on implementation it is doubtful the reader need such technical information. Such technical data on the infrastructure can be placed in an appendix, freeing the body-text to discuss how the infrastructure shall be used during closure implementation and process.	See response to Comment #124	9
126	Implementation	72 (11.5.2.1 Osmoflo Brine Squeezer)	General comment on information on Page 11-72	Further to discussion above, this is a good example of the level of information required by the reader to understand ERA has the capacity and technology to deliver their MCP	Noted	
127	Implementation	74 (11.5.3)	General comment on works and plans schedules	Implementation of the MCP will follow well considered steps captured in one or more schedules. The MCP or at least Chap. 11 should have a Section containing these schedules presented both as bullets and as Gantt charts that can be extracted and easily referred to whilst reading the text.	It is difficult to display complex schedule in the MCP. Appendix 9.1 is provided as a summary schedule that can be displayed in the document.	9
128	Implementation	81 (11.6.1.2 Demolition and disposal)	concrete slab and foundations to a depth of 1.5 m below ground level	Can ERA elaborate more on what this means?	This refers to the bunds and other infrastructure in the processing plant area that requires demolition. Details are provided in Section 9.3.5.	9
129	Implementation	82 (aa)	Demolished items must be buried on site at 8 m level deep below final landform	Can ERA provide justification for this solution? As in, why 8m?	This depth has now been refined to 6m. Details have been provided in Section 9.4.3	9
130	Implementation	82 (Table 11.10)	Demolition processes	Table should be at front of Section.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
131	Implementation	84-85 (Tables 11.11 and 11.12)	Phase 1 demolition areas Phase 2 demolition areas	Are the areas listed according to schedule priority or other criteria?	They are listed according to when infrastructure will no longer be required.	9
132	Implementation	86 (11.6.1.2)	Detailed material take-offs	What means 'Detailed material take-offs'?	This has been updated to clarify. Refer to Section 9.3.5.	9
133	Implementation	87 (aa)	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:	Is there a r**isk leak & contamination to GW, eventual mechanical degradation leading to voids, or other means for the contaminants to be released** and/or the infrastructure impact on final landform and rehabilitation efforts?	The risk from all groundwater sources is currently being modelling and will be included in future updates of the MCP. Details of these studies are provided in Section 5.	5
134	Implementation	87 (aa)	Key assumptions of Phase I (&2)	Key data, information, lists, etc, should be presented at the start of the relevant Section.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
135	Implementation	87 (11.6.1.3 continuity of services)	• essential services are assumed to remain operational, as per the current operating system, until commencement of Phase 1 demolition	What does 'assumed' mean in this context? Which 'essential services' are required until but not after Phase 1 demolition?	For the purposes of engineering and planning on continuity of services the assumption is that operations will not remove some services.	9
136	Implementation	89 (11.7.1 Ranger deeps closure activities)	First paragraph starting 'The Ranger Deeps … ".	Tabulate. Not particularly relevant for the closure plans and activities	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
137	Implementation	90 (aa)	Paragraph starting … "ERA has now commenced … "	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.	Suggestion noted. Consideration will be given to updating this Section in future submissions.	
138	Implementation	91 (aa)	A reduced level of C&M until 2021 will maintain the water level in the decline at -20 mRL.	**Why at -20mRL?** **What is the long term closure/post-closure outcome?** **Is this the long term RL for water level? Or what happens after the pumps are turned off?**	This is a commitment from the Ranger 3 Deeps decommissioning application approved by the Minister. Further information on this commitment is available in that application.	9
139	Implementation	94 (Figure 11-55)	Perspective of figure	Without the surface included for reference, figure is not informative. Suggest also including a photo with final cutting gradient superimposed.	Suggestion noted. Consideration will be given to updating this figure in future submissions.	
140	Implementation	95 (Table 11-15)	Description of geological terms	There are a lot of different types of schists with varying competence. Please describe what type of schist, eg: biotite-graphitic schist (low competence, easily weathered), quartz-feldspar schist (high competence, resistant to weathering), etc.	The upper section of the R3 Deeps exploration decline is developed within mine sequence hangingwall schists of the upper Cahill formation. There are only two types of schist exposed in the decline walls: 85% are muscovite-quartz-feldspar schists and 15% are interbedded amphibolite schist. The intent of Table 11-15 is not to specifically refer to any particular schist lithology, but to categorise the ground support based on the degree of weathering of schist exposed along the length of the decline prior to shotcreting; from completely weathered to unweathered schist as one descends through the weathering profile. Down to 30 vertical metres below surface, both types of schist are completely weathered, with very low strength. Both rock types rapidly transition into fresh rock of medium strength below that depth.	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
141	Implementation	96 (Figure 11-57)	Interpretation of figure	The figure is not easy to interpret. Is there a way to guide the reader in interpreting this figure?	This is a technical figure that is required to be included to demonstrate potential failure of the underground workings. An attempt has been made to explain this as best as possible.	9
142	Implementation	97 (11.7.1.5)	The only way to 100% guarantee the long-term stability of the shaft is to completely backfill it and the rill area at the base of the shaft.	Is this a requirement of closure of the shaft?	No this is not a requirement.	9
143	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	This and other assessments of impacts could be in a dedicated Section.	Suggestion noted. Consideration will be given to updating this figure in future submissions.	
144	Implementation	100 (11.8 Stockpiles)	This will enable revegetation works to be completed by the completion of closure milestone (8 January 2026).	It is unlikely revegetation works will be completed by Jan 2026.	ERA is committed to complete initial planting of all revegetation areas by 8 January 2026. However, it does not include the infill planting that will be implemented post 2026.	9
145	Implementation	105 (Table 11-16 & 11-17)	Dates of movements	Is it possible to put provisional dates with the final landform dozing activities?	See response to comment #127	9
146	Implementation	106 (Table 11-18)	Ore grades and material type	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.	Suggestion noted. Consideration will be given to updating this figure in future submissions.	
147	Implementation	108 (11.8)	All the material in the current TSF walls is assumed to high 1s or low 1s	'assumed (to) be'. Is ERA investigating the TSF walls to ensure it is 1s material?	See response to comment # 122	9
148	Implementation	111 (11.9.1.1 Pond water storage)	'When possible the total inventory of RP6 will be transferred to RP2'	This suggests an uncertainty, that it may not be possible. Can ERA provide reassurance that it will be possible and perhaps the likely conditions defining 'when possible'?	This has been updated to clarify. Refer to Section 9.4.3.	9
149	Implementation	112 (11.9.1.1. Retention Pond 2)	Once all the pond water has been treated on site RP2 will be prepared to receive waste	What happens to the **pond water after RP2 is closed**? Released? Likely time for this?	RP2 will be decommissioned once all the pond water has been treated.	9
150	Implementation	114 (11.10 Waste and Hazardous material)	ERA has identified that the following hazardous wastes …	It appears some on the list are not hazardous.	This has been updated. Refer to Section 9.4.2.	9
151	Implementation	116 (11.11.1 Closure activities)	Removal of infrastructure and scarifying … has been successful … for (rehabilitation of linear infrastructure) … and requires neither direct seeding nor planting to achieve acceptable outcomes	Linear infrastructure can remain visible for a long time, eg: drill lines, seismic lines, soil-sampling, old roads and tracks. Is this likely on the RPA if no specific rehabilitation program is planned? **Has this approach been OK'd by stakeholders, particularly GAC?**	Approval of the closure plan for linear infrastructure is via this MCP. Any concerns from stakeholders on the plan will be received as comments to the MCP and responded to in future versions of the MCP. To date no issues have been noted.	9

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
152	Implementation	121 (Figure 11-67 & 11-21)	Correlation between the figure and table	Is it possible to correlate the figure and the table? They are complementary.	Suggestion noted. Consideration will be given to updating this figure in future submissions.	
153	Implementation	122 (Table 11-21)	Further work	A lot of further work is described in the tabl**e. Will it be completed in time t**o ensure appropriate management of the areas?	All work forms part of the overall closure schedule and can be completed in the required time.	9
154	Implementation	124 (11.15.1.1 Contaminated land and plume management)	During the feasibility study a Plume and contaminated site management plan was developed.	Is there a **target for when this information will be available** for inclusion in a future version of the MCP?	Further information has been included in Section 9 and 5 this year. It is expected that this work will be completed in the next 12 months to be included in the 2021 MCP.	9
155	Implementation	127 (11.16.2 Surface layer)	… the community types that best suit particular environmental conditions of the Ranger Mine final landform can be identified (Humphrey et al 2009)	After 10 years since Humphrey et al researched the area, are the community type best suited to Ranger identified?	It was a statement of the general approach "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)". 2020 MCP has extensively discussed the development of conceptual reference ecosystems (Ch5 Appendix 5.1).	5
156	Implementation	128 (aa)	The soils in the Georgetown Creek Reference Area vary in their drainage status and are typically gravelly and less than one metre deep to parent rock. Key geomorphic features (including parent material …	What is 'parent rock' and what type of 'parent rock' is referred to here?	Parent rock refers to underlying weathered Cahill Formation's Hanging Wall Sequence. The Cahill Formation Hanging Wall Sequence consists of schists composed of muscovite, biotite, quartz, hematite, garnet and/or magnetite. It is intersected by numerous thin quartz and amphibolite intrusion, and by a single, thick (20 to 30m) amphibolite sill near its base, INTERA (2019).	5
157	Implementation	128 (aa)	Given the variation in PSD of the TLF (as discussed in above),	Spell out acronyms – what is PSD? **How far 'above'? In this Section, chapter, document?** It is not clear.	PSD = Particle Size Distribution. Abbreviations have been included at the front of each section	9
158	Implementation	128 (aa)	The environmental characteristics that influence variation in plant communities, as discussed above, are likely to also vary across the Pit 1 final landform cover and result in the heterogeneous combination of vegetation communities observed in the Ranger Mine reference sites.	The waste rock which forms final landforms is likely to be a heterogeneous mix of all geology types, unweathered. Whereas in the reference area the in situ geology exists and has been there for potentially millions of years, influencing soil geochemistry and thereby plant ecosystems. Can ERA confirm this conclusion?	This work forms part of the constraints and revegetation domains planning to be conducted in the next 12 months.	9
159	Implementation	130 (11.16.5 Surface layer construction)	Non-compliances are easily discovered by survey during backfilling	'easily' is a relative term and should be removed.	This has been updated. Refer to Section 9.4.5.2	9

A.4 DITT feedback on 2019 MCP

Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
160	Implementation	130 (11.16.6 Erosion controls)	a range of annual exceedance probability (AEPs) from the 1EY (one exceedance per year) event to the probable maximum flood (PMF),	Retain full spelling of such acronyms. An explanation (in a text box) would also be useful.	A table of abbreviation and acronyms has been included at the front of each section. Text box suggestion noted. Consideration will be given to updating this figure in future submissions.	9
161	Implementation	132 (aa)	The changes to the final landform design surface to address concerns in key areas were incorporated into the final landform surface DEM Version FLV6.2	Whilst it's understandable why the author wants to emphasise that a 'concern' has been addressed it does not inform the reader of the context of the concern. If necessary to highlight a concern has been addressed info-text box could be use. **Recommend not mentioning it at all.**	This has been updated. Refer to Section 9.4.5.	9
162	Implementation	132 (aa)	Last three paragraphs starting with "Each version of the … " and ending with "… for the landform of 10 000 years are extremely low."	Text-box such supplementary information. It does not inform the reader of the closure plan. It supports why a certain closure activity has been selected (robustness and QCQA) and that work is ongoing (will be presented in subsequent MCP). But doesn't say what's actually going to happen. Large volumes of such text are throughout the MCP which makes it long and hard to read.	Noted	
163	Implementation	135 (aa)	Measures to limit erosion and sediment discharge on the general surface of the landform are arguably the most critical	By whom is it 'arguably'**? Perhaps remove**	This has been removed.	9
164	Implementation	135 (aa)	advice received (from) the Northern Land Council and the Gundjeihmi Aboriginal Corporation have indicated that ripping of the landform may impact traversibiilty, so it should be minimised wherever possible.	**Has an agreement been reached** with TOs regarding this approach?	Discussions on ripping are currently being discussed as part of Pit 1 planning, with trails to be completed.	9
165	Implementation	140 (Figure 11-76)	Flow direction	Flow direction indicator would be handy	Suggestion noted. Consideration will be given to updating this figure in future submissions.	
166	Implementation	141 (11.17.2 Provision of seeds)	ERA has been working extensively with Kakadu Native Plants Pty Ltd, a locally owned and run indigenous supplier, to provide seedlings for much of the revegetation projects that have occurred both at Ranger Mine and Jabiluka over the past 15 years. This supplier has extensive expertise in local plants including seed biology, propagation, revegetation and weed and fire management.	Perhaps "ERA has been working with a locally owned supplier with extensive local experience." Focus should be on closure, what's important to inform the reader that ERA has a viable plan and what it includes. The reader doesn't need to know about Kakadu Native Plants. The other organisations mentioned in the document do not have this kind of explanation. A list of supporting companies and organisations and their suitability and function can be placed in an appendix.	Noted	

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Comment #	MCP Overarching Section	MCP reference	MCP theme	DITT Comment/Question/Recommendation	ERA Response	MCP Section 2020
167		142 (11.17.3.1 Irrigation)	(potentially requiring mechanical equipment)	The mention of workers then the possibility of needing mechanical equipment suggests there's a rationale behind it. Why wouldn't ERA use mechanical equipment?	This has been updated. Refer to Section 9.4.6.	9
168		146 (11.17.7.1 Tubestock)	ensure tubestock production capacity of between 500,000 and 700,000 stems per annum	That's 1400 to nearly 2000 per day. **Is the nursery capable of producing this number of viable tubestock?** Does ERA have a **viable contingenc**y in case it is not possible?	The text in question describes the physical carrying capacity of the Ranger nursery, it does not necessarily represent the actual number of tubestocks required. ERA does have a viable contingency plan. ERA has approached nurseries in Darwin and seeds of required species will be free issued to engaged nursery to raise plants to fill the gaps in case the demand is over the capacity of the Ranger nursery or other emergency.	9