ERA Energy Resources Of Australia

Ranger Mine Closure Plan 2024

Appendices

Cover: Sharon Paulka - Rio Tinto Closure Subject Matter Expert

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APPENDICES

APPENDIX 1.1: 2023 RANGER MINE CLOSURE PLAN FEEDBACK AND RESPONSES

Table 1: Response to OSS Assessment on the 2023 MCP

Recommendation	Timing / Hold Point	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[1]
Recommendation 1 Prior to deconstructing the Magela Levee, Energy Resources of Australia (ERA) should provide an Erosion and Sediment Control Plan for approval by the Supervising Authority which identifies how turbidity risks to Magela Creek will be managed and how the groundwater monitoring network in the vicinity of the levee will be protected.	Prior to deconstructing the Magela Levee	Description of Closure Activities	4.4.4.6
Recommendation 2 Future iterations of the Ranger Mine closure Plan (RMCP) should provide updated information on the activities undertaken and proposed to address the recommendations from the Supervising Scientist's assessment of the *Pit 3 Capping, Waste Disposal and Backfill Application*.	MCPs	Description of Closure Activities	4.2.5, 4.2.6
Recommendation 3 Future iterations of the RMCP should describe how infrastructure potentially required beyond 2035, such as the nursery and water treatment infrastructure, will be disposed of and any disturbance be rehabilitated.	MCPs	Description of Closure Activities	4.4.2
Recommendation 4 Specific details of proposed erosion, sediment and water control structures should be included in future versions of the Final Landform design (e.g. FLv7), including at the northern boundary of the Ranger Water Dam where there is a risk that the re-establishment of Coonjimba Creek could cause significant erosion and mobilise soils contaminated by the prior storage of tailings.	Future versions of the Final Landform design (e.g. FLv7)	Landform	6.9
Recommendation 5 Information on how risks to the surrounding environment, particularly from surface water runoff and dust, will be managed during the construction phase as well as a detailed **Landform Construction Monitoring Plan** and associated Trigger Action Response Plans (TARPs) should be included in the Final Landform Application.	Final Landform Application	Landform	Recommendation relates to the Final Landform Application

1 whilst sections of the MCP may discuss the topic of the feedback raised, further studies are occurring or planned and therefore the cross-referenced sections may not/do not resolve the feedback raised

Recommendation	Timing / Hold Point	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[1]
Recommendation 6 A detailed quality assurance and quality control program should be included with the Final Landform Application that will be implemented to ensure the final landform is built to design, and that appropriate material is used to form the surface layer.	Final Landform Application	Landform	Recommendation relates to the Final Landform Application
Recommendation 7 Information obtained from erosion and sediment control trials conducted by ERA should be included and discussed in the next RMCP.	MCPs	Landform	6.3.1.4
Recommendation 8 A detailed **Post-closure Landform Monitoring Plan** and associated TARP should be included in the Final Landform Application which clearly links to monitoring objectives and allows for any issues to be quickly identified and resolved.	Final Landform Application	Landform	Recommendation relates to the Final Landform Application
Recommendation 9 The surface water closure criteria for Ranger should include a site-specific Guideline Value for aluminium which is being developed by OSS.	MCPs	Water and Sediment	Tables 7-6 & 7-7 footnote, 7.3.7
Recommendation 10 A success metric should be developed for surface water closure criteria linked to the validation of groundwater modelling predictions.	MCPs	Water and Sediment	To be discussed
Recommendation 11 The Ranger groundwater uncertainty analysis should be reviewed and if required updated based upon the outcomes of future groundwater studies and be included in the Final Landform Application.	Final Landform Application	Water and Sediment	Recommendation relates to the Final Landform Application
Recommendation 12 Prior to the finalisation of contaminated site assessments and planning of remediation activities, stakeholders should be consulted on: • the identification of potentially contaminated areas prior to further investigations • on the final Areas of Potential Concern • on the draft Remediation Action Plans prior to their implementation.	MCPs	Soils	8.9

Recommendation	Timing / Hold Point	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[1]
Recommendation 13 The Ranger Ecosystem State and Transition Model should be completed as a priority with an update on the status of the model provided in the 2024 RMCP.	2024 MCP	Ecosystems	9.3.3, 9.8, 9.9
Recommendation 14 Trials should be implemented in current revegetated areas at Ranger where deviated states are occurring to test the ability to correct deviated states. Information on these trials should be provided in future RMCP submissions.	MCPs	Ecosystems	9.3.4.3
Recommendation 15 Should ERA propose an alternative Conceptual Reference Ecosystem (CRE) for the Ranger Water Dam area which does not satisfy ER2.1 and 2.2(a), ERA will need to conclusively demonstrate that all other options to manage groundwater contamination from the RWD, such as water treatment and landform redesign, are not viable.	MCPs	Ecosystems	9.3.1.4
Recommendation 16 An operational **Revegetation Plan**, or a similar tool, should be developed in consultation with stakeholders and be provided with the Final Landform Application.	Final Landform Application	Ecosystems	Recommendation relates to the Final Landform Application
Recommendation 17 An **Ecosystem Rehabilitation Monitoring Plan** should be developed and updated annually, including: • an outline of monitoring methods, scale, locations, sampling frequency and parameters • weed monitoring methods and an assessment of weed management efforts • alignment with the Trigger, Action, Response Plan (TARP) • consideration of methodological advances as new technologies become available (e.g. AI assisted classification of remote imagery).	MCPs	Ecosystems	9.6

Recommendation	Timing / Hold Point	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[1]
Recommendation 18 An **Ecosystem Rehabilitation Monitoring Report** should be developed and updated annually, including: • provision and interpretation of monitoring data • identification of risks, preventative controls and corrective actions • identification of any requirements for updates to the State and Transition Model and the Revegetation Plan identified in Recommendation 16 • identification of additional monitoring requirements and contents for updates to the **Ecosystem Rehabilitation Monitoring Plan** identified in Recommendation 17.	MCPs	Ecosystems	9.6
Recommendation 19 A whole-of-site radiation dose assessment (public and non-human biota) should be completed for the Final Landform Application.	Final Landform Application	Radiation	Recommendation relates to the Final Landform Application
Recommendation 20 Prior to commencement of new activities or significant changes to existing site activities, the **Ranger Radiation Management Plan** should be reviewed to ensure that it accurately reflects the radiological risks from the activity and describes fit for purpose management systems.	Prior to commencement of new activities or significant changes to existing site activities	Radiation	Provided to MTC on 13 September 2024 as part of the Pit 3 approval condition Number 1
Recommendation 21 ERA's radiation monitoring program should include the following requirements: • annual radiation monitoring of drinking water from Magela Creek during the closure phase • a systematic approach to monitoring of radon decay products for worker radiation safety during the closure phase.	MCPs	Radiation	To be discussed

Recommendation	Timing / Hold Point	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[1]
Recommendation 22 Prior to discrimination of bulk material, ERA should undertake the following activities: • test the ability of the radiometric discriminator to distinguish between low grade 1 (<0.007% U3O8) and high grade 1 (>0.007% U3O8) waste rock • specify focus and action level trigger values for material grade discrimination within the TARP.	Prior to BMM	Radiation	To be discussed
Recommendation 23 The Ranger post closure monitoring program should include: • a monitoring program for radon exhalation from final landform surfaces of sufficient duration to demonstrate stabilisation of exhalation flux • atmospheric monitoring for dust and radon (or radon decay products) as part of the post-closure radiation monitoring program.	MCPs	Radiation	10.6

Table 2: Response to ARRTC Feedback on the 2023 MCP

Feedback	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[2]
The MCP does not provide adequate information about gully erosion, options for its control, and how drainage lines and gullies on the final landform will be revegetated in a way that acknowledges the role of established vegetation in stabilising channels.	Landform	6.5.5 - Future iterations of the MCP
The final landform forms the basis of the remediated site because it is the foundation on which weathering of the material (waste rock) occurs to form soil, controls surface hydrology and serves as the base for revegetation. The focus is largely on the physical characteristics of the materials, and potential for erosion. A general characterisation of the landform materials across the RPA which includes the geochemical and physical characteristics and how they vary spatially would be considered necessary. There is a good understanding of the physical characteristics, but the general geochemical characteristics and their variability is less certain, particularly with regards to the cut-to and fill areas.	Ecosystems	9.9 (Table 9-18 KKN ESR7D)
"Constructed drainage channels that will have increased water flows will be rock armoured". This can be expected to result in limited variation substrate properties and limited variation in water depths, reducing the ecological value of stream habitat onsite relative to what would be achievable by instead controlling bed elevation and allowing some lateral freedom of the channel shape. This appears to be inconsistent with ER 1.2(e) on P150 that environmental impacts should be ALARA. On the other hand, controlling all channel erosion assists achievement of the landform closure criteria related to bedload and denudation rate and suspended sediment concentrations (P112). How these two closure criteria are to be traded off and resolved is not described.	Landform	To be discussed
Although '…ERA will likely install sediment basins at the terminal point of each sub-catchment' (p. 115), it is unclear how this sediment will be removed and where it will be taken. Erosion and sedimentation are natural fluvial features in all stream systems so there will need to be some clear criteria as to what levels are acceptable, especially as these processes are likely to create riparian and in-channel microhabitats that support different plants and animals from the rest of the landform.	Landform	6.6.2.2

[2] whilst sections of the MCP may discuss the topic of the feedback raised, further studies are occurring or planned and therefore the cross-referenced sections may not/do not resolve the feedback raised

Feedback	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[2]
6.6.3 refers to temporary erosion and sediment control features, but permanent structures are not mentioned.	Landform	6.3.2.4
The Ranger Conceptual Model was developed to understand contaminant sources and transport. The conceptual model consists of three models at three difference spatial scales. I would be interested to know if the conceptual models for Ranger are nested (p166), if they are spatially related and can then be scaled from smallest scale up to the regional scale, and if there is similarity between results at different scales with only differences in resolution.	Water and Sediment	7.3.1
Refinement of understanding the distribution of acid sulfate soils is ongoing. There needs to be some clarification on the processes in the description of acid sulfate soil effects (p204). Acidification events caused by oxidation of hypersulfidic soils will likely lead to increased concentrations of soluble metals, but impact on dissolved oxygen (and potential for deoxygenation) is largely the effect from mobilization and oxidation of monosulfidic materials, which are usually much younger newly formed, and less likely to be caused from hypersulfidic materials.	Water and Sediment	7.3.10
Step 4 of the WQMF is to 'Determine water/sediment quality guideline values' and this is described on pp. 159-161. Although there are general claims about highly variable natural ranges (e.g. for pH), there is little explanation of the importance of 'hot spots' and 'hot moments' in the area when extremes, especially of multiple parameters, might occur as a result of the combined effects of the mine and natural phenomena.	Water and Sediment	Future iterations of the MCP
It was good to see the highlighted new text added to Figure 7-6 of the conceptual model underpinning the Aquatic Pathways Risk Assessment (APRA) indicating the addition of detrital pools and microbial activity to acknowledge their potential importance. However, it is less clear what work is planned to validate these additions to the conceptual model and how they may alter the vulnerability assessment framework (VAF) described on p. 184.	Water and Sediment	7.3.12.3
ASS have been observed in Coonjimba Billabong, and p. 189 goes on to say, 'The occurrences of acidification observed in Coonjimba Billabong have been linked to false start wet season events, indicating that the absence of flushing associated with a continuation of rainfall may be a driver of more significant acidification related events (e.g. lower levels of dissolved oxygen and increased concentrations of metals) being observed in these years.' Work on this KKN is still ongoing but it would be interesting to know whether false starts are more likely under predicted future climatic conditions for this area, and if so, how this might affect the potential likelihood of future episodes of acidification arising from a combination of mine-related and natural processes.	Water and Sediment	Future iterations of the MCP

Feedback	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[2]
Regarding the length of planned monitoring of Coonjimba Billabong, on p. 235, the MCP states 'The on-site supervision will continue throughout the remediation activities and the validation sampling. Validation sampling and 'sign-off' that remediation targets have been achieved is typically a one-off process undertaken at the completion of the remediation works. However, ERA will undertake annual sampling for a further five years after the final landform has been created in the areas of the Magela LAA and Coonjimba Billabong to ensure levels remain within acceptable limits.' I wonder whether five years will be long enough after the final landform has been created, given that there is a good chance that settlement and stabilisation of erosional processes (with their concurrent effects on infiltration and subsurface water movement) may take longer than five years. Perhaps following up for a longer period (say, a decade) sampled every two years would provide more peace of mind about the effectiveness of controls of sediment contamination after the final landform is built.	Soils	8.6
Closure criteria (Table 9.2). Although not yet approved by the Minister, these are largely settled now following stakeholder review. Nonetheless, there are some concerns.	Ecosystems	Future iterations of the MCP
In the discussion on CREs, the following (p. 249) is stated about the riparian CRE: 'It is recognised that a distinct CRE is required for the planned drainage lines on the final landform, and the surrounding Myrtle-Pandanus Savanna / Paperbark Forest vegetation community may be used as a basis for this. I would argue that there is some urgency about deciding on this CRE which can then lead on to assessments of appropriate revegetation options for the proposed riparian species (e.g. seed viability, seedling establishment and persistence, substrate requirements, etc.) so that these plants can be introduced onto the final landform along the planned drainage lines as soon as possible and start to play a role in stabilising the channels.	Ecosystems	9.3.1.3 - Future iterations of the MCP
Regarding cut-to areas (p. 254), the plan recognises that, to date, there has been little research (stage 13, of 4 ha) undertaken on restoration in cut-to areas, and that this limited research indicates poor success in plant establishment (p. 254). Given that cut-to areas will constitute 28 to 47% of the final landform (p. 254), there is a high priority for such research including on the efficacy of potential remedial approaches.	Ecosystems	4.8.3.2 - Future iterations of the MCP
While there is mention of broader invertebrate monitoring for the conceptual S&T models only ants are considered for the closure criteria. Focusing only on ants may lead to a narrow understanding of ecosystem condition and determining the establishment of desirable invertebrate communities at the RPA. Ideally, broader monitoring which includes invertebrate functional groups, including pollinators, decomposers, and herbivores, would allow a more holistic assessment and comparison for determining trajectory towards, that of the reference ecosystem.	Ecosystems	To be discussed

Feedback	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP[2]
The chapter states that litter decomposition and nutrient cycling is to be monitored every five years. There are some characteristics of soils that change very slowly, and some that can potentially act as early indicators of perturbations to decomposition and nutrient cycling processes. I would suggest that monitoring should be undertaken more frequently early in the monitoring program following final landform and revegetation (suggested the first five years), which can then be stepped out to monitoring every five years after the initial five years. Microbial communities and mineralizable nitrogen are very responsive to management actions and disturbance events, whereas soil organic carbon and nitrogen are indicators which are better suited to longer term monitoring.	Ecosystems	9.6.5
Future work: This section provides a summary of the considerable research effort still needed to provide the required evidence base. It would help to link it more explicitly to the KKN tabulation at Appendix 5.1. There appears to be no consideration of research needed to address some closure criteria: for example, there is no consideration of the evidence base needed to evaluate progress towards the attribute (closure criterion) of 'Composition and abundance of threatened species' or of the likely effectiveness of any potential remedial actions if there is limited progress.	Ecosystems	9.9 (Table 9-18)

Table 3: Response to GAC/NLC Feedback

Feedback on 2023 MCP	Relevant Theme / Section of 2023 MCP	Section discussed in 2024 MCP
The document contains some new material that is factually wrong and must be corrected.	Chapters 3 and 11	Chapters 3 and 11
Input to the 2024 MCP		
On 5 September 2024, a representative of the Ranger Project Team met with a representative of GAC and reviewed Chapters 1, 2, 3 and 11 of a draft 2024 Ranger MCP. This resulted in several changes to the 2024 MCP, primarily related to stakeholder engagement and reference to the Cultural Reconnection Steering Committee.	Not applicable	Chapters 1, 2, 3 and 11

APPENDIX 4.1: CHRONOLOGY OF COMPLETED ACTIVITIES

Date	Description of Event / Milestone
1969	Discovery of Ranger ore deposit by joint ventures Electrolytic Zinc Company of Australasia Ltd (EZ) and Peko-Wallsend Operations Limited (Peko).
1974	February: Submission of Environmental Impact Statement (and supporting material) under the Australian Government's *Environmental Protection (Impact of Proposal) Act 1974*.
1975	May: Submission of Supplements 1 and 2 to the Environmental Impact Statement.
	The Ranger Uranium Environmental Inquiry (Fox *et al.* 1976) commences.
1977	The Ranger Uranium Environmental Inquiry Reports (Fox *et al.* 1976 and 1977) recommend that uranium mining proceed.
	Much of the Alligator Rivers Region (ARR) is declared a National Park (NP) and Aboriginal people are given a major role in the management of Kakadu NP.
1978	Title to the Ranger Project Area (RPA) is granted to the Kakadu Aboriginal Land Trust, in accordance with the *Aboriginal Land Rights (Northern Territory) Act 1976* (Aboriginal Land Rights Act).
	The Commonwealth Government enter an agreement with the Northern Land Council (NLC) to permit mining to proceed.
	The role and function of the Supervising Scientist is established under the *Environment Protection (Alligator Rivers Region) Act 1978*.
1979	Section 41 Authority under the Commonwealth *Atomic Energy Act 1953* is issued.
	Construction at Ranger commences.
1980	Energy Resources of Australia Limited is established as a public company. It was the largest public float in Australian history at the time.
	May: Mining of Ranger Pit 1 orebody commences using open cut methods.
1981	13 August: The first drum of uranium oxide is produced.
1994	December: Mining of Ranger Pit 1 orebody is completed.
1995	Preparation of Pit 1 to receive tailings commences, including construction of an underdrain and a horizontal rock-filled adit from the base of the pit to intercept a vertical dewatering bore.
1996	May: Approval is granted to mine Pit 3 orebody.
	August: Tailings deposition into Pit 1 begins.
1997	July: Open cut mining of Pit 3 begins.
1999	Environmental Requirements revised to include rehabilitation conditions.
2000	August: Rio Tinto becomes a major shareholder in ERA.
2006	October: ERA announces an increase in Ranger mine's reserves due to a reduction in the cut-off grade of ores for processing, adding about six years to the predicted life of processing at Ranger to 2020.

Date	Description of Event / Milestone
2007	June: Approval received to deposit tailings into Pit 3.
	September: Extension of Pit 3 is announced, extending mining until 2021.
2008	Trial Landform (TLF) construction commences.
	November: ERA announces a significant mineral exploration target defined at Ranger 3 Deeps.
	December: Tailings deposition in Pit 1 ends.
2009	April: The laterite treatment plant is commissioned to extract uranium from weathered ores (referred to as laterite ores) that are unable to be processed through the existing mill circuit.
	Trial Landform is planted with seeds and seedlings.
2011	August: The ERA Board approves the construction of an exploration decline to conduct underground exploration drilling of Ranger 3 Deeps.
2012	February: ERA approves the design, construction and commissioning of a Brine Concentrator.
	May: Phase 1 construction of the Ranger 3 Deeps exploration decline begins.
	May – September 7,554 wick drains are installed in Pit 1.
	Onsite water management capacity was expanded to beyond potential flood levels, with the completion of Retention Pond 6 and Ranger Water Dam (RWD) wall lift.
	Magela Creek levee is constructed to guard Pit 3 from a potential large flood event.
	November: Mining of Ranger Pit 3 orebody is completed.
	Pit 3 backfill activities commence in preparation for the planned transfer of tailings from the then Tailings Storage Facility (now Ranger Water Dam) and the final repository of brine from the Brine Concentrator.
2013	January: The Ranger Mining Agreement is finalised with Mirarr Traditional Owners, the Northern Land Council, ERA, and the Commonwealth government. The Mining Agreement establishes the Relationship Committee.
	September: Completed construction of the Brine Concentrator. Commissioning tests and verification phase commences.
	October: Phase 2 construction of the R3 Deeps exploration decline begins including extending the decline and constructing a ventilation shaft.
	December: Completed the placement of approximately 70 per cent of the initial capping over Pit 1 tailings to assist in tailings consolidation and the ongoing dewatering of the pit.
2014	August: Underfill installed in Pit 3. An underdrain is constructed on top of the underfill, and five brine injection wells and an extraction pumping system installed.
	Ranger 3 Deeps underground drilling program completed
	Construction of the purpose-built tailings dredge completed.

Date	Description of Event / Milestone
2015	Tailings dredge, tailings transfer and water recovery/pumping infrastructure commissioned.
	Pit 3 brine injection piping and infrastructure installed and commissioned.
	Tailings from the mill begins to be transferred directly to Pit 3.
	June: ERA announces that the R3 Deeps underground mining project would not proceed, and the R3 Deeps exploration decline is placed into care and maintenance.
2016	January: Completed initial capping and impervious laterite layer in Pit 1. Bulk backfilling commences.
	All production tailings directed to Pit 3 and tailings transfer from RWD into Pit 3 commences.
	Brine injection into the Pit 3 underfill begins.
2017	April: Approval granted for ERA to begin the final stages of Pit 1 backfill.
2018	Laterite plant ceased operation due to exhaustion of laterite ore. Laterite plant placed under care and awaiting demolition as part of the site closure project.
2019	Ministerial approval granted to commence decommissioning of the R3 Deeps exploration decline.
	Remnant tailings cleaning from the walls of the RWD commences.
2020	19 February: Approval granted (High-Density Sludge (HDS) plant application), allowing the release of partially treated process water into the pond water circuit.
	July: Approval granted to leave the subfloor of the RWD in-situ rather than to remove and transfer into Pit 3.
	August: Final backfill and landform contouring on Pit 1 completed.
	November: Scarification of Pit 1 final landform.
2021	Production at the Ranger mine ceased on 8 January 2021, concluding processing activities on the RPA after ~40 years of operation.
	Dredging of tailing for transfer from the then TSF (now RWD) to Pit 3 is completed.
	Processing Plant is decommissioned.
	Planting on the backfilled surface of Pit 1 begins.
2022	January: Planting on the backfilled surface of Pit 1 is completed.
	Final remnant tailings are transferred from RWD to Pit 3 via truck.
	31 May: ERA sells final drum of uranium oxide.
2023	March: Directionally drilled brine injection wells completed and commissioned.
	April: Wicking in Pit 3 completed and wicking barge demobilised.
	June: Approval granted to dewater and begin drying the tailings in Pit 3.

Date	Description of Event / Milestone
	August: dewatering of Pit 3 commenced.
	September: Pit 3 Capping, Waste Disposal and Bulk Material Movement Application is submitted.
	October: Pit 1 research trials and monitoring reach 2 year milestone – average 70% survival.
	October: Outcomes and data from the 2022 Feasibility Study received.
	November: Approval granted for the brine squeezer to treat process water.
2024	The Brine Squeezer process water treatment upgrade work is completed, although performance testing with RWD feed water has not yet commenced.
	4 March: Direct release of surface water runoff from the Pit 1 landform to Corridor Creek via Corridor Road Sump (CRS).
	3 April: ERA appoints Rio Tinto to manage the Ranger Rehabilitation Project under a new Management Services Agreement.
	3 June: Rio Tinto takes responsibility for management of the Ranger site on ERA's behalf.
	June -July: Limestone added to the RWD to raise pH.
	2 and 11 August: Pit 3 Capping and Backfill Approval received from the Commonwealth and NT minister respectively.

APPENDIX 4.2: COMPLETED BPT ASSESSMENTS

Ranger Mine Closure Plan
2024

Completed BPT Assessments

Unique Reference	PLN007
Revision:	1.23.2

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FIGURES

TABLES

ERA Energy Resources Of Australia

1 SALT TREATMENT AND DISPOSAL

The need to dispose of saline water is a common process in several industries and, as a result, 25 methods were identified as potential salt management options and were considered for the BPT assessment. Many of the options considered had fatal flaws for Ranger and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table 1-1).

Table 1-1: Salt treatment and disposal options

Category	Brine injection	Crystallisation	Thermal distillation
Method	pit 3 underfill underground silos pit 3 underfill with rock screening	pit 3 placement underground silos placement	pit 3 underfill injection underground silos injection

The overall outcome of the BPT assessment was that brine injection to the underfill without rock screening was the highest ranked alternative. Brine injection to underground silos scored well but concerns were identified on Occupational Health and Safety issues during both the construction and the operational phases of this option. Major problems were identified for the crystallisation and distillation options, and it is considered unlikely that either option assessed would be viable. The only uncertainty remaining for the preferred option related to the potential for reactivity between the brine and the waste rock of the underfill and possible limitation on the volume available for the storage of brine.

It was concluded that this issue required further assessment prior to a final decision on the salt management option to be implemented. For this reason, crystallisation was taken forward into the overall strategy assessment pending further testing to confirm the brine injection option.

2 BRINE SQUEEZER

Report: *Application to operate a Brine Squeezer. 2019*

Water management is an environmentally and operationally relevant aspect of Ranger. Concentration and isolation of contaminants through water management is a significant component of the Ranger 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. However, the Water Treatment Plant (WTP) brines are less concentrated than process water (less than 25% 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 Brine Concentrator, and reducing overall risks to the closure schedule and costs associated with water treatment.

ERA investigated options to concentrate WTP brines over many years. Given the high scaling and membrane fouling potential of WTP brines, it was necessary to consider alternatives to standard reverse osmosis. 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, a thorough BPT assessment process was undertaken. This began in 2013 with a preliminary desktop screening assessment that investigated 27 options. From this assessment 15 options were hard show-stopped, whilst four options were soft show-stopped and four options scored poorly relative to the remaining four options, which were considered appropriate to progress for further assessment. A second, BPT assessment was then conducted in 2018 on:

- vibratory shear enhanced processing (VSEP);
- Brine Squeezer;
- electro dialysis reversal (EDR); and
- additional reverse osmosis.

Using a 5-level technology ranking system where a ranking of three meets industry standards, the second BPT assessment showed the Brine Squeezer (Figure 2-1) to be the highest-ranking option.

Pilot studies and test work were completed on two options: VSEP and Brine Squeezer. The results of these studies were used to inform the BPT assessment and revise the relevant criteria of the 2013 BPT assessment. The seven-month Brine Squeezer pilot study, completed in 2016, conclusively demonstrated that this technology has the capability to treat the Ranger 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 reverse osmosis (Table 2-1 and following ranking matrices).

It has been demonstrated during field trials that WTP brine can be treated at up to 94% recovery of permeate of quality equal to, or better than, current WTP permeate. The plant, installed adjacent to the sand blast yard, comprises three trains, providing for 99% availability of two trains (1 standby/cleaning). Commissioning of the Brine Squeezer commenced in June 2019, with the plant now fully operational.

Table 2-1: Comparison of final BPT scores (2013 vs 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

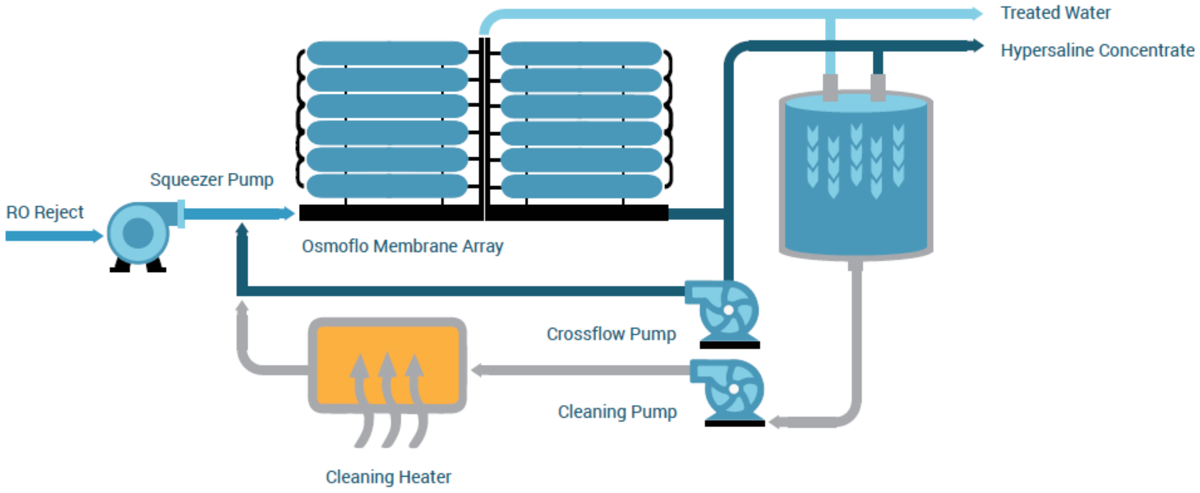

Figure 2-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

BM Brine Minimisation

		Rehabilitation and Closure							Constructability		
		Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
		1	1	1	1	1	1	1	1	1	1
Option ID	Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Cost	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
BM1	VSEP (FilTek)	NA	NA	NA	NA	NA	3	4	4	4	3
BM2	Brine Squeezer (Osmoflo)	NA	NA	NA	NA	NA	3	4	4	4	3
BM3	EDR - Electro dialysis reversal	NA	NA	NA	NA	NA	3	4	4	4	3
BM6	Additional RO (includes pre-treatment step)	NA	NA	NA	NA	NA	3	3	4	4	3

	Inadequate	Poor	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

3 RANGER 3 DEEPS

Report: *Application Ranger 3 Deeps Exploration Decline Decommissioning. 2018*

In May 2012, phase 1 construction works of the Ranger 3 Deeps (R3D) decline began after being approved in September 2011. This allowed for underground exploration that could provide further information regarding the viability of the proposed R3D underground mine. An additional application was submitted for phase II construction works and was approved for the extension to the exploration decline, installation of a ventilation shaft, and acquisition of bulk samples on 4 June 2013.

Exploration in the decline (Figure 3-1) continued until December 2014, whilst submissions were made for the construction of the R3D underground mine at the same time. In October 2014, a draft environmental impact assessment (EIS) was submitted but, following an ERA board decision in June 2015, the statutory assessment process for the proposed R3D mine was halted and the decline was placed in long-term care and maintenance.

The primary objective of the BPT assessment was to determine which combination of options was best practice for the closure of the exploration decline. For the assessment, the decline was divided into three closure areas:

- main decline (2,710 m) – seven BPT closure options assessed;
- portal (185 m) – three BPT closure options assessed; and
- ventilation shaft (located at -260 mRL; vertical length 280 m) – nine BPT closure options assessed.

The BPT assessment rankings reflect known hydrogeological conditions obtained during decline construction and core sampling of resource holes, and subsequent hydrological modelling completed by INTERA (2018). The assessment also took into consideration ground conditions and potential heavy mobile equipment limitations (e.g. gradient, manoeuvrability). The assessed option and BPT outcomes are presented in Table 3-1 and the ranking matrices at the end of this sub-section.

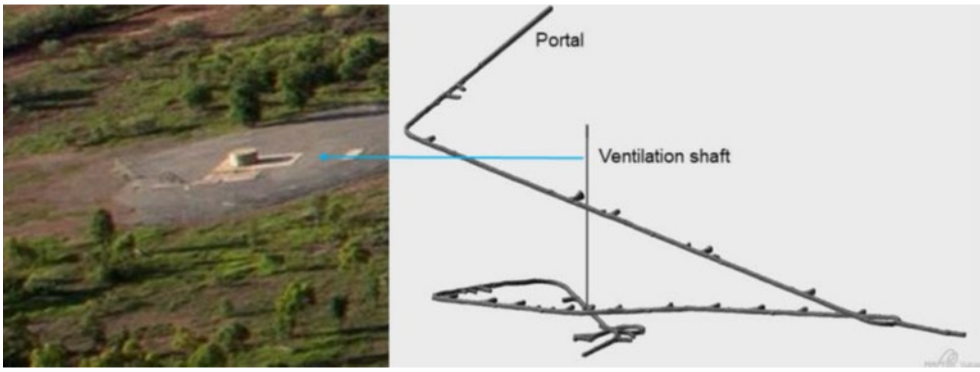

Figure 3-1: Aerial view of the ventilation shaft and underground infrastructure

Table 3-1: Decline options and best practicable technology assessment summary

Option ID	Option Description	Overall Rank
Decline closure (2,710 m)		
A1	Waste rock (full decline) and grouting of open holes	16.7
A2	A1 + bulkheads	12.5
A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m)	29.2
A4	A3 with cemented rock fill (CRF) instead of waste rock	25.0
A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	20.8
A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	-4.2
A7	A3 (without grouting of open holes and bulkheads)	41.7
Portal (185 m)		
B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	-11.5
B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	30.8
B3	Leave entire portal in situ and cover with waste rock	-10
Ventilation Shaft		
C1	Waste rock; concrete collar removed	-100
C2	Waste rock, concrete in situ	-100
C3	Crushed waste rock; concrete collar removed	31.6
C4	Crushed waste rock; concrete collar in situ	-100
C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	21.1
C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	-100
C7	Steel plate; concrete collar removed and allow to flood	13.2
C8	Steel plate and allow to flood; concrete collar in situ	-100
C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	39.5

3.1 Main decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped based on occupational health and safety (OHS) concerns, cost and operability. Three options, scoring similarly, with one of these, A5, eliminated due to cost and reliability concerns. Option A6 was eliminated due to OHS and fitness for purpose. Option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7 and selected as the preferred option.

3.2 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 with the final landform and therefore at odds with the cultural criteria. Option B2 (partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock) with a score of 30.8 and no show-stoppers, was ranked the highest and selected as the preferred option.

3.3 Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped based on fitness for purpose or cultural criteria (specifically visual amenity). Two options recorded soft show-stoppers for cultural criteria (also visual amenity) and two options, C3 and C9 scored closely on the BPT assessment. For its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, option C9 (crushed waste rock up to weathered zone, then ten metres cemented rock fill and then ten metres of crushed rock to surface; concrete collar removed) was identified as the highest-ranking option with a score of 39.5 and selected as the preferred option.

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	Decline closure (2,710 m)				0.0						
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	4	3	5	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	4	3	5	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	4	3	5	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	4	3	5	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	4	3	5	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	1	3	5	1
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	4	3	5	3
	Portal (185 m)				0.0						
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	NA	NA	4	3	5	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	NA	NA	4	3	5	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0	1	NA	4	3	5	1
	Vent shaft				0.0						
1	C1	Waste rock; concrete collar removed	1	0	-100.0						
1	C2	Waste rock, concrete in situ	1	0	-100.0						
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	4	4	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0	1	1				

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	2	2	4	3	4	3
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0	1	1				
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	2	4	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0	1	1				
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	5	4	3	4	3

						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								

						Fit for Purpose				Operational Adequacy			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	5	3	4	2	3	3	3	5
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0								
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	1	3	3	5	3	4	5	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0								
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	3	4	3	3	3	3	5

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
	Decline closure (2,710 m)				0.0					
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	NA	NA	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	NA	NA	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	NA	NA	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	NA	NA	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	NA	NA	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	NA	NA	3
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	NA	NA	3
	Portal (185 m)				0.0					
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	4	NA	NA	NA	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	NA	NA	NA	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0					
	Vent shaft				0.0					
1	C1	Waste rock; concrete collar removed	1	0	-100.0					
1	C2	Waste rock, concrete in situ	1	0	-100.0					
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	5	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0					
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	4	5	3	4	3

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0					
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	5	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0					
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	4	5	3	4	3

4 PROGRESS OF PIT 1 TO FINAL LANDFORM

Report: *Application of Progress Pit 1 Landform. 2019*

To support progress of the Pit 1 final landform, additional work was undertaken to address Supervising Scientific Branch (SSB) comments (Department of the Environment and Energy 2018) on an earlier change application (ERA, 2018a). Works included:

- a risk assessment undertaken to update the 2016 risk assessment;
- solute mass balance and water balance;
- soil-vegetation-atmosphere modelling to estimate plant available water under various conditions;
- revision of the final landform cover on Pit 1 to maximise plant available water;
- review of research relevant to rehabilitation of the Ranger Mine;
- preliminary flood modelling and hydraulic design work were updated and refined from work in 2017 to create a Digital Elevation Model (DEM); and
- erosion and sediment control features were refined based on conceptual designs developed in 2017.

The digital elevation model (DEM) was also provided to the MTC for assessment and SSB feedback was included in the change application report (ERA, 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework was developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works supported ERAs continued backfilling of Pit 1 ahead of the initial tree planting of the Pit 1 landform surface.

An application was submitted to the Director of Mining Operations, DITT in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the Mining Management Act (NT) and was approved in May 2019.

During the life of Pit 1, ERA has undertaken many studies and BPT assessments, including:

- assessment of the selected tailings deposition options for Pit 1, to ensure the long-term stability of tailings as part of the final rehabilitated landform in 1994;
- assessment of seepage limiting options in 2005; and
- closure studies undertaken as part of a 2008 PFS, 2009 feasibility study and further review and validation of the preferred Pit 1 closure option as part of the ITWC prefeasibility study in 2012.

Landform design has involved several iterations of the post-closure landscape models over the life of the mine with significant options analysis and refinement of the landscape reconstruction over several years. Through supporting investigations and thorough refinement processes, the backfilling option being implemented is optimal. In particular, bulk backfilling of Pit 1 has been completed using the selected bulk backfill methodology.

5 TAILINGS MANAGEMENT

5.1 Integrated tailings, water and closure – PFS 1

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study (ITWC PFS): Analysis of Best Practicable Technology. 2013*

The focus of the ITWC PFS program was to evaluate the technology for reclamation, treatment and transfer of tailings from the TSF to the mined-out Pit 3, and salt management technology to ensure physical containment of brine (from the BC treatment of process water) within Pit 3 with no detrimental impact to the environment for a period of 10,000 years as required by the ERs.

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described in the sub-sections below.

5.1.1 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 5-1).

Table 5-1: Tailings reclamation options

Category	Excavation	Hydraulic Mining	Dredging
Transfer options	• dewater and truck • dewater and conveyor • slurry and pump.	• pump • thickener and pump.	• pump • thickener and pump • thickener, filtration and truck • thickener, filtration and conveyor.

Of the reclamation and transfer options, excavation rated poorly compared with hydraulic mining and dredging. The principal deficiencies identified were the sensitivity of excavation techniques to extreme rainfall events, environmental protection and OHS issues arising from dust from the disturbed tailings, the considerable operational effort that would be required, and the drainage requirements required for successful implementation of the process. Hence, excavation was rejected as a method for reclamation of tailings from the TSF.

Hydraulic mining and dredging emerged from the workshop with approximately equal BPT assessment scores. An overall assessment of the relative significance of the various advantages and disadvantages of the two options led to the conclusion that the disadvantages of the dredging option (operability, maintainability, radiation protection) are much more amenable to management than those associated with hydraulic mining (sensitivity to extreme rainfall, environmental protection, high capital costs). This is particularly the case for the issue of sensitivity to extreme rainfall events where management options are extremely limited, and the occurrence of such events could have a major impact on the rehabilitation schedule. For this reason, dredging was selected as the preferred option.

5.1.2 Tailings treatment

The principal technical advantage of filtration is the reduced time required for tailings consolidation. It was thought to have some advantages for long-term dispersal of contaminants in groundwater, but this was yet to be demonstrated and the advantage was considered to be small. Disadvantages of this option included high costs to construct, install and operate, and the high maintenance requirements. The assessment outcome of filtration at the tailings workshop was that the option should be retained for whole-of-project BPT assessment, but it appeared to be a very expensive option with limited advantages.

Cementation was considered an option to potentially reduce dispersion of solutes in groundwater if required, however, it did not emerge as a viable treatment option. 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.

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

5.1.3 Tailings deposition

Options assessed for deposition of tailings into Pit 3 considered either subaerial or subaqueous techniques for thickened tailings and dry stacking or co-disposal with waste rock for filtered tailings.

The assessment outcome for deposition of thickened tailings was that either option would be acceptable, however subaqueous deposition was preferred principally because it rated higher on the operability and operating costs criteria and was assessed that Traditional Owners would have a distinct visual preference for tailings covered by water rather than an exposed tailings surface. Subsequently, initial BPT workshop consolidation modelling demonstrated that subaerial deposition would provide an advantage over sub aqueous deposition. Since both options were determined to be BPT, the method was changed without the need for an additional assessment.

With filtration of tailings being retained as an option, the deposition of tailings needed to be considered. Two options were considered: dry stacking, and co-disposal with waste rock. Co disposal of filter cake and waste rock led to higher maximum elevation of tailings in Pit 3, giving preference to dry stacking. There were, however, concerns expressed about the degree to which either technique had a proven track record, and it was noted that both would be sensitive to rainfall (a dry pit would be required).

The conclusions arising from the BPT workshop on tailings management were:

- dredging is the preferred tailings reclamation method;
- cementation is not currently considered viable as a treatment method; and
- tailings filtration should be retained as a potential treatment method to be considered in the overall strategic workshops but is a very expensive option that produces little benefit.

5.2 Integrated tailings, water and closure – PFS 2

The combination of the feasible tailings management options and the feasible salt management options resulting from PFS1 and the BPT assessment are provided below:

- dredged tailings, thickened and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill);
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill);
- dredged tailings, thickened then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3; or
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3.

These options progressed through ITWC PFS2 and were assembled into closure strategies where the preferred technical options from PFS1 were combined with two possible processing cessation dates:

- milling will cease in 2016 - these options were given a 'C' designation; or
- milling will cease at the end of 2020 consistent with the terms of the Ranger Authorisation - these options were given a 'B' designation.

This provided a total of eight closure strategies that were assessed in two stages; these are shown in Table 5-2.

Table 5-2: Initial closure strategies to be assessed

Strategy	Brine strategy	Tailings strategy	Milling end
1C	Injection	Thickened	2016
2C	Injection	Thickened and filtered	2016
3C	Crystallisation	Thickened	2016
4C	Crystallisation	Thickened and filtered	2016
1B	Injection	Thickened	2020
2B	Injection	Thickened and filtered	2020
3B	Crystallisation	Thickened	2020
4B	Crystallisation	Thickened and filtered	2020

5.2.1 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 that clearly did not constitute BPT, and to more clearly identify information gaps in the remaining options needing to be addressed prior to the final BPT assessment of the strategic options.

The key options that were eliminated in the stage 1 assessment were tailings filtration and brine crystallisation. The results of the stage 1 assessment are shown in Figure 5-1.

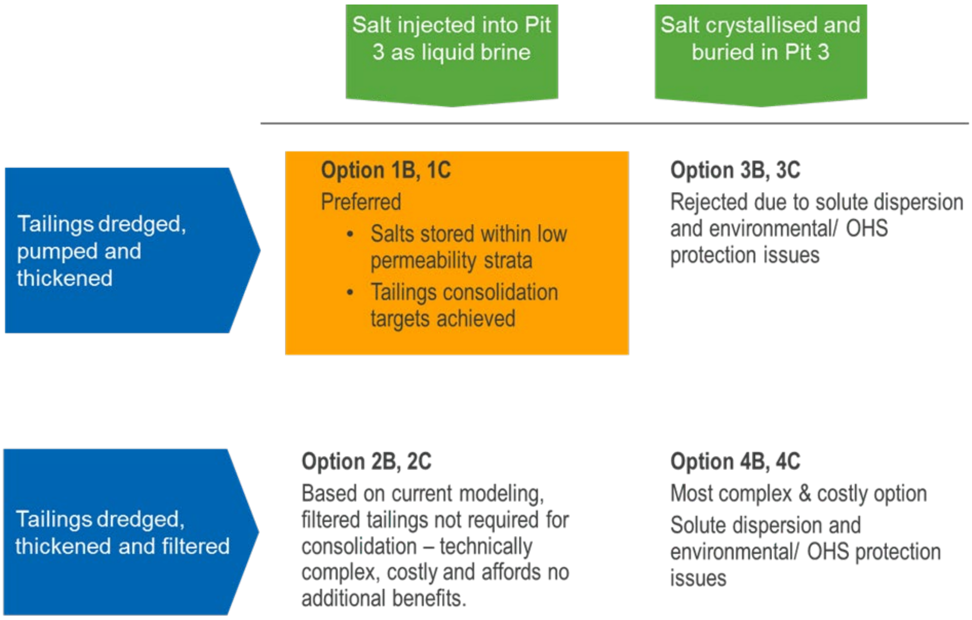

Figure 5-1: Outcomes of the Stage 1 assessment

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.

5.2.2 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.

Table 5-3 lists the options assessed in Stage 2 (detailed ranking matrices at the end of Section 6.5).

Table 5-3: Final closure strategies assessed

Strategy	Brief description
1C	Brine injection, thickened tailings, milling until 2016
1B	Brine injection, thickened tailings, milling until 2020
5C	Strategy 1C with extended water treatment
5B	Strategy 1B with extended water treatment

The highest BPT score of 19 was recorded for Strategy 1B; the three other options scored 15. To put this result in perspective, changing the assessed score for any individual criterion by one unit would change the overall score for that option by about two units. Hence, these results imply that option 1B is the favoured option based on the BPT assessment process, but the result is marginal.

The criteria where differences were recorded were:

- socio-economic impact on Jabiru and the region: the two extended options provide additional time for community partnerships to run and continued retention of services, the 5B case also provides additional royalty income;
- technical performance: both 2020 options scored higher because the extended milling period enables the processing of lower grade ores, previously assessed as not commercially viable;
- capital expenditure: the two extended options scored higher primarily because only one BC is required for these options;
- maintainability: the 2020 milling option with extended water treatment results in the use of the BC for nine years beyond its planned lifetime;
- operating costs: the operating costs of the extended 2020 option would be higher because replacement of major BC parts would almost certainly be required; and
- schedule: both extended options scored lower than the primary options under the schedule criterion.

5.2.3 Supplementary integrated tailings, water and closure prefeasibility study

A review of the ITWC BPT assessment was conducted in August 2016. This determined, with the exception of tailings treatment, all technical options selected as BPT remained valid.

Eight options were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment. The results are presented in Table 5-4. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table 5-4: Supplementary tailings treatment assessment

Strategy	Technology	Show-stopper		Overall rank
		Hard	Soft	
A1	Thickened tailings (ITWC base case)			32.6
A2	Unthickened tailings	✓		-100
A3	Unthickened tailings, with prefabricated vertical drains (wicks)			41.3
A4	Unthickened tailings, with extended water treatment		✓	-6.5
A5	Unthickened tailings, with inline agglomeration and wicks			10.9
A6	Unthickened tailings with neutralisation and wicks		✓	17.5
A7	Thickened and filtered tailings (ITWC assessed)		✓	13.0
A8	Thickened, filtered and cemented tailings (ITWC assessed)		✓	6.8

For most of the detailed options assessed, a NA (not applicable) result was obtained for criteria in the ‘Culture and Heritage’, and ‘Ecosystems and Natural World Heritage Values of Kakadu NP’ categories. All activities associated with all options occur within the cultural heritage exemption zone. In addition, these methods do not have any impact on the surrounding ecosystems and World Heritage values of Kakadu during the operational phase. Hence, the BPT assessment of the tailings treatment options was dominated by the criteria under the ‘Fit for Purpose’, ‘Operational Adequacy’ and ‘Constructability’ categories.

The base case for this assessment assumed tailings would be unthickened, with three options being considered a) with wicks, b) with extended water treatment, and c) with inline agglomeration and wicks. These were assessed against the previous ITWC thickened tailings options.

The results of the BPT indicate that unthickened tailings with wicks (A3) have advantages over unthickened tailings and extended water treatment (A4) and unthickened tailings with inline agglomeration (A6). It was assessed that the use of wicks would be viewed more favourably by Traditional Owners under the ‘Living Culture’ criterion compared to unthickened (A2). The unthickened tailings option (A2) was hard show-stopped due to factors including: not all process water being removed during consolidation, subsidence and erosion of the landform, impacts on rehabilitation performance, impacts to water quality and the formation of visible salts in the landform surface, all of which could lead to an unwillingness for Traditional Owners to resume cultural practices on the site post-closure.

Unthickened tailings with wicks (A3) have been demonstrated as proven technology through its application in Pit 1. Prefabricated vertical drains, or wicks, present a sound technical method of achieving increased consolidation and ensuring the schedule requirements on rehabilitation on the RPA are met.

Inline agglomeration and wicks (A5) option faired less favourably across ‘Fit for Purpose’ and ‘Operational Adequacy’ categories than options A1 and A3, predominantly based on less certainty around achieving consolidation targets and potential reliability issues related to inconsistent input densities. There was also a high uncertainty around the complexity of integration with existing dredging operations, high operational expenditure and complexities associated with construction of the plant on the pit access ramp.

Unthickened with extended water treatment (A4) was soft show-stopped under category ‘Construction, Environmental and Cultural risks’ because of the increased number of vehicles through Kakadu National Park necessary to transport new infrastructure and the substantial increase in workforce required to construct a new water treatment plant. It emerged as the least favoured option, scoring ‘inadequate to ‘poor’ against most categories under ‘Fit for Purpose’, ‘Operational Adequacy’ and ‘Constructability’. The low ranking against these criteria was strongly influenced by high sustaining capital and operating costs associated with the existing BC, long procurement lead times required to purchase a new plant or additional infrastructure to expand the existing plant, and the complex operational nature of the plant potentially leading to a high number of interruptions and downtime.

Strategies A6 through A8 all recorded soft show-stoppers under ‘Construction’, ‘Environmental’ and ‘Cultural’ risks criterion, attributed to the effects of increased traffic volumes through Kakadu NP associated with new infrastructure and increased construction workforce in Jabiru. These options also recorded soft show-stoppers under OHS, attributed to increased risks of vehicle incidents during tailings transfer to Pit 3. In addition to the above, concerns identified during the ITWC PFS around strategy A8 (thickened, filtered and cemented) remain. These include the extremely high operational costs as a result of high cement consumption and uncertainty around the long-term stability of cement, which is susceptible to sulfate attack. Significantly more development work would be required before this would be considered a viable option when compared to strategies that were assessed.

5.2.4 Conclusions

The BPT assessment has considered viable thickened tailings options from the previous ITWC PFS and new, unthickened tailings treatments. Of the eight options assessed, one option was hard show-stopped (unthickened A2) and four were soft show-stopped.

Three options were considered viable; however inline agglomeration with wicks (A5) scored the lowest of the three with the assessment identifying some inherent issues around achieving consolidation targets, high operational costs and construction complexities, compared to the other two options (e.g. thickened and unthickened with wicks).

There was no material difference in the assessment scores for the thickened (A1) and unthickened with wicks (A3) options. However, ERA has extensive knowledge around strategy A3, based on the performance of the Pit 1 backfill strategy and subsequent tailings consolidation being achieved via this method.

6 TAILINGS DEPOSITION INTO PIT 3 FOR MILL TAILINGS AND DREDGE TAILINGS

Report: *Application Pit 3 Tailings Deposition. 2019*

In preparation for cessation of mining and processing activities at Ranger Mine, a further assessment of the methods for tailings deposition was undertaken. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 to change the deposition method of tailings in Pit 3 from subaerial (to a tailings beach) to subaqueous (into water) (ERA, Alan Irving & Associates 2019). The application was approved in July 2019. The change was proposed to improve deposition, specifically to:

- prevent segregation;
- prevent accumulation of fine tailings in inundated areas of the pit; and
- accelerate backfilling with consolidated tailings.

Following detailed assessment of various subaqueous deposition configurations and multi spigot subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 to assess the range of potentially viable deposition options (GHD, 2019). To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria. This resulted in an overall ranking calculated for each option (Table 6-1 and the ranking matrices at the end of this sub-section).

Table 6-1: Tailings deposition options and best practicable technology assessment summary

Option	Option description	Overall Rank
Mill Tailings		
M1	Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing)	41.7
M2	Subaerial deposition from multiple spigots on the east wall (one at a time, frequently changing)	35.4
M3	Subaqueous deposition	16.7
Dredge Tailings		
D1	Dredge 1 and 2 subaerial	20.8
D2	Dredge 1 and 2 subaqueous	16.7
D3	Dredge 1 subaqueous & Dredge 2 subaerial	12.5
D4	Dredge 1 subaerial & Dredge 2 subaqueous	10.4

The BPT assessment found that for mill tailings, the two subaerial options (M1 and M2) were similarly effective, and slightly better, than subaqueous discharge (M3) due to the higher cost and greater complexity of subaqueous deposition. Option M2 has the advantage of maintaining a lower, more level tailings surface. Both M1 and M2 promote overall drainage from east to west and are more cost effective than subaqueous deposition. However, M1 scored lower on schedule and both M1 and M2 will result in a slightly higher tailings level in the east of the pit.

The assessment found that for dredge tailings, the subaerial options scored more favourably on costs, constructability, operability and maintainability criteria. This is primarily due to the lower complexity of the subaerial method and because most of the subaerial facilities are already in place. However, the subaerial options scored poorly on schedule and technical performance, as the tailings surface will be more steeply sloping with a higher maximum elevation in the pit requiring additional work to even out the tailings prior to commencement of pit capping.

Conversely, the subaqueous option scored more favourably on schedule, technical performance and environmental protection, since this method promotes less tailings segregation and more rapid consolidation, and the tailings surface will be flatter with a lower maximum elevation in the pit.

Whilst relative advantages and disadvantages were identified, and all options were considered acceptable against each of the assessment criteria, a combination of options M2 (subaerial deposition from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected.

Energy Resources Of Australia

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

ERA Energy Resources Of Australia

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				

ITWC Project	Fit for Purpose					Operational Adequacy				
	No	No		Yes	No	Yes	No	No	No	No
	1	1	1	1	1	1	1	1	1	1
Option Description	Proven technology	Technical performance	Robustness	Environmental Protection	CAPEX	Safety Occupational Health	Operability	Inherent availability and reliability	Maintainability	OPEX
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	4	3	4	3	3	4	4	3	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	4	3	4	4	3	4	4	3	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	5	3	4	3	3	4	4	3	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	5	3	4	4	3	4	4	2	2

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option		
	1	2	3	4	5	UTE	NA		

ITWC Project	Rehabilitation and Closure						Constructability		
	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
	1	1	1	1	1	1	1	1	1
Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	3	3	UTE	2	2	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	3	3	UTE	2	1	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	3	3	UTE	2	2	3	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	3	3	UTE	2	1	3	4	3

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area
A1	Thickened (ITWC base case)	0	0	32.6	4	NA	4	3	NA	3
A2	Unthickened	4	0	-100.0	1					
A3	Unthickened - wicks	0	0	41.3	3	NA	4	3	NA	4
A4	Unthickened - extended water treatment	0	1	-6.5	3	NA	4	3	NA	3
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	NA	4	3	NA	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	UTE	NA	4	4	NA	3
A7	Thickened & filtered tailings	0	3	13.0	4	NA	4	3	NA	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	NA	4	3	NA	2

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No	No	Yes	No	Yes	No	No	No	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
A1	Thickened (ITWC base case)	0	0	32.6	5	4	3	4	2	4	4	4	4	3
A2	Unthickened	4	0	-100.0		1								
A3	Unthickened - wicks	0	0	41.3	5	3	2	4	3	4	5	5	5	5
A4	Unthickened - extended water treatment	0	1	-6.5	5	2	2	4	1	4	1	2	2	1
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	3	2	4	3	4	3	3	3	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	5	UTE	2	4	2	2	4	4	4	1
A7	Thickened & filtered tailings	0	3	13.0	5	4	3	4	1	2	3	3	3	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	UTE	3	5	1	2	3	3	2	1

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					Rehabilitation and Closure						Constructability		
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
A1	Thickened (ITWC base case)	0	0	32.6	4	4	3	4	4	3	4	3	4
A2	Unthickened	4	0	-100.0	1		1	1					
A3	Unthickened - wicks	0	0	41.3	4	4	3	4	4	3	3	4	4
A4	Unthickened - extended water treatment	0	1	-6.5	4	4	3	4	4	2	4	2	2
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	4	4	3	4	4	3	3	3	2
A6	Unthickened - neutralisation and wicks	0	2	17.5	4	4	3	4	4	3	4	2	UTE
A7	Thickened & filtered tailings	0	3	13.0	4	4	3	4	4	4	4	2	3
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	4	3	4	4	4	4	2	3

						Traditional Owner Culture & Heritage		Protection of People and the Environment			
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Ecosystems & the natural world heritage values of Kakadu	Ecosystems of the project area	Community Health and Safety	Socio-economic Impact on Local Communities	Ecosystems & natural world heritage values of Kakadu	Ecosystems of the Project Area
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	4	3	3	3	4	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	3	3	3	4	3
No	M3	Sub-aqueous	0	0	16.7	4	3	3	3	4	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	3	3	3	4	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	4	3	3	3	4	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	4	3

Best Practicable Technology Matrix continued...						Fit for Purpose					Operational Adequacy
			Showstopper column setting			No	No	No	Yes	No	Yes
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental protection	CAPEX	Occupational health & safety
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	4	3	3	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	5	4	3	3	4	4
No	M3	Sub-aqueous	0	0	16.7	5	3	4	4	2	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	2	3	3	4	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	5	4	5	4	2	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	5	3	4	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	5	3	4	3	3	3

Best Practicable Technology Matrix continued...						Operational Adequacy				Rehabilitation and Closure	
			Showstopper column setting			No	No	No	No	Yes	Yes
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Operability	Inherent availability & reliability	Maintainability	OPEX	Revegetation (closure only)	Radiation (closure only)
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	5	5	5	3	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	5	4	4	3	3
No	M3	Sub-aqueous	0	0	16.7	3	4	3	2	3	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	3	4	4	3	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	2	3	3	2	3	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	3	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	3	3

Best Practicable Technology Matrix continued...						Rehabilitation and Closure				Constructability		
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes	No
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Erosion (closure only)	Water (closure only)	Tailings (closure only)	Schedule	Construction occupational health & safety	Construction environmental and cultural risks	Construction complexity
Mill Deposition												
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	3	NA	4	2	4	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	3	NA	4	3	4	5	4
No	M3	Sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
Dredge Deposition												
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	NA	3	1	4	5	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	NA	3	2	3	5	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	NA	3	2	3	5	3

7 REMNANT TAILINGS TRANSFER

The bulk of the tailings within the Tailings Storage Facility (TSF) was dredged and transferred into Pit 3 in 2020/2021. Remnant tailings, the material that remained on the TSF floor and walls after the bulk tailings transfer, also needed to be encapsulated in Pit 3 as per the ERs. This BPT investigated 10 options to determine the best method to undertake this activity.

A BPT workshop was conducted in February 2021 to assess the range of potentially viable transfer options. Each option was assessed against the relevant criteria and the resulting scores are shown in Table 7-1.

Table 7-1: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
1	Pre-Cap Pump (base case)	2
2	Post-Cap Truck (Pit 3 west end)	6
2a	Post-Cap Truck (Pit 3 east end)	0
2b	Post-Cap Truck (temp store in Pit 3 THWS rather than TSF SE temp cell)	-6
3	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall, tailings slurried to push lower into pit)	17
3a	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	6
3a (i)	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	4
3b	Pre-Cap Truck, sucker truck ramp to north wall (below cap)	2
3c	Pre-Cap Truck, Pit 3 west ramp, barge or floating conveyor transfer to west central end of pit	0
4	Bury tailings in TSF	Hard show-stopped

Option 3 was selected as the preferred method for the transfer of remnant tailings, having the highest score of 17. Each individual criteria ranked for Option 3 received as ‘3’ or greater, indicating that the selected approach meets or exceeds current standards across all assessed fields.

The remnant tailings transfer commenced in Q2 2021, following construction of the Pit 3 tip head and upgrades to the required haul roads. Some of the remnant tailings have ‘hung up’ on the internal wall of Pit 3 and the most effective method to move these tailings deeper into the pit is the subject of current assessment.

8 HIGH DENSITY SLUDE PLANT RECOMMISSIONING

Report: *Application to release water from High Density Sludge (HDS) Plant. 2020*

The HDS plant was recommissioned on a trial basis in 2019 with the HDS product water recycled into the process water inventory. The recommissioning of the HDS plant was a planned strategy to increase the capacity of process water treatment during closure. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in January 2020 to approve the release of HDS treated process water generated from the recommissioned plant by either of the following options:

- direct treatment through Water Treatment Plant 1 (WTP1) and subsequent release to the Corridor Creek Wetland Filter;
- indirect treatment by releasing HDS product into the pond water inventory, for subsequent treatment through any of the pond water treatment plants (WTPs).

Approval was granted in February 2020 with specification for discharge of water to RP2 when releasing HDS product water via indirect treatment as per the application. This approval was contingent on ERA implementing operational controls described in the revised application.

To support this application a BPT assessment was conducted to build upon the previous BPT analysis that was completed to support the original construction of the HDS plant in 2004. The recent BPT assessment evaluated twelve (12) options to address additional process water treatment capacity. The majority of options scored high (31 – 44.4) and differed marginally in the weighting of individual criteria namely ‘Robustness’, ‘Cost’, ‘Schedule’ and ‘Construction complexity’ (Table 8-1 and the ranking matrices at the end of this section).

Table 8-1: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
5.1	Recommission the existing HDS plant, full treatment and transfer of product water direct to WTP1 (dry season only).	31.0
5.2	Recommission the existing HDS plant, full treatment and transfer product water direct to pond water inventory (year round).	33.3
5.3	Recommission the existing HDS plant, adaptive operation (full treatment) with product transfer to either WTP1 (dry season) or pond water storage (year round).	33.3
5.4	Recommission the existing HDS plant, partial treatment and transfer product water direct to WTP1 (year round).	31.0
6.1	Repurpose of mill infrastructure for large scale HDS treatment.	16.7
6.2	New build of larger HDS plant for large scale HDS treatment.	16.7
7.1	BC single train equivalent construction.	35.7
7.2	BC duplication construction.	33.3
8.1	Direct feed process water (untreated) to existing UF/RO infrastructure.	40.5
8.2	Direct feed process water (untreated) to new UF/RO infrastructure similar to current.	33.3
8.3	Discharge process water (untreated) direct to pond water inventory (untreated).	38.1
11	Do nothing.	44.4

All options exceeded current standards for environmental protection and proven technology. The options that ranked highest overall (38.1 – 44.4) were assessed as not feasible for current implementation on the basis that they did not align with the overarching objectives, required significantly high capital expenditure ($10M+), or would likely cause impacts to the closure schedule (i.e. construction delays or conflicts with other closure commitments).

The option identified as most suitable for implementation involved the use of the existing HDS plant under adaptive operational conditions to optimise treatment capability (option 5.3). This option received the mean overall ranking (33.3) and represents a rational approach to addressing project limitations whilst maintaining effective environmental outcomes.

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting				Yes	Yes	No	Yes	Yes
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local	Ecosystems & Natural world heritage	Ecosystems of the Project Area
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	3	4	4	3	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	3	4	4	3	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	3	4	4	3	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	3	4	4	3	4	4
6.1	Re-purpose mill infrastructure			16.7	3	4	3	3	4	4
6.2	New build HDS plant			16.7	3	4	3	3	4	4
7.1	BC single train equivalent			35.7	3	4	4	3	5	5
7.2	BC duplication			33.3	3	4	4	3	5	5
8.1	Direct feed to existing UF/RO infrastructure			40.5	3	4	4	3	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	3	4	4	3	4	4
8.3	Discharge direct to pond inventory			38.1	3	4	4	3	4	4
11	Do nothing			44.4	3	4	4	3	5	5

					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No		Yes	No	Yes	No	No	No	No
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	4	4	3	4	4	4	3	3	3	3
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.4	Recommission the existing HDS plant, partial treatment			31.0	4	4	3	4	4	4	3	3	3	3
6.1	Re-purpose mill infrastructure			16.7	4	4	4	4	3	4	3	4	3	3
6.2	New build HDS plant			16.7	4	4	5	4	2	4	3	4	3	3
7.1	BC single train equivalent			35.7	4	5	4	5	2	4	4	4	4	3
7.2	BC duplication			33.3	4	5	5	5	1	4	4	4	4	3
8.1	Direct feed to existing UF/RO infrastructure			40.5	4	3	3	4	5	4	4	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	4	3	4	4	2	4	4	4	4	4
8.3	Discharge direct to pond inventory			38.1	4	3	2	4	5	4	4	4	4	4
11	Do nothing			44.4	5	4	1	4	5	4	NA	NA	NA	3

					Rehabilitation and Closure						Constructability			
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
6.1	Re-purpose mill infrastructure			16.7	NA	NA	NA	3	NA	2	3	3	2
6.2	New build HDS plant			16.7	NA	NA	NA	3	NA	2	3	3	2
7.1	BC single train equivalent			35.7	NA	NA	NA	4	NA	3	3	3	2
7.2	BC duplication			33.3	NA	NA	NA	4	NA	2	3	3	2
8.1	Direct feed to existing UF/RO infrastructure			40.5	NA	NA	NA	4	NA	3	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	NA	NA	NA	4	NA	3	4	4	3
8.3	Discharge direct to pond inventory			38.1	NA	NA	NA	4	NA	3	4	4	4
11	Do nothing			44.4	NA	NA	NA	4	NA	1	5	5	5

9 TSF NORTH NOTCH STAGE 3

Report: *Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility North Notch Stage 3. 2020*

The water level of the TSF continued to be lowered to maximise the efficiency of the dredges during the transfer of tailings to Pit 3. As a result of the lowering water level, there was a need to create notches within the TSF walls to increase the pumping efficiency and to maintain safe access to the floating infrastructure. An application was submitted to the Director of Mining Operations, Department of Primary Industry and Resources (DPIR) (now Department of Industry, Tourism and Trade [DITT]) in April 2020 to approve reduction of the clay core crest height to Relative Level (RL) 37.8 m and to manage future raises in crest height with the construction of clay bunds across the notch if required. The DPIR (now DITT) approved the application in June 2020 and agreed to the provision of water balance modelling updates of the inventory at the beginning of each dry season to ensure sufficient capacity for the upcoming wet season.

Notching the TSF wall proved to be fit for purpose and environmentally sound for the construction of the previous three notches. The construction of a further notch within the footprint of the North wall notch did not require a BPT assessment. However, the reduction in crest height to a level that enabled the completion of dredging presented a risk of inadequate water storage volume when considering the future needs of the TSF for process water storage facility. The purpose of this BPT assessment was to identify the most environmentally sound approach for ongoing safe access to the TSF during dredging whilst ensuring adequate crest height to meet the freeboard requirements of the Ranger Authorisation until 2024.

A total of six options were assessed as part of the BPT assessment (Table 9-1 and the ranking matrices at the end of the section).

Table 9-1: BPT options assessment for TSF notch

Option	Option description	Score
A1	Construct North Notch 3 to RL 36. (clay core RL 35.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0
A4	No additional notch. 1.1 Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services and gantry into a local cutting. Crane used from Notch 2 for large lifts.	-2.8
-A5	Continue use of North Notch 2 using large crane and modified gantry.	Hard show-stopper
A6	North-East Ramp. Remove current ramp in North-East corner of TSF. Cut in new ramp, beginning from further back, in stockpile area, and notching down into TSF wall to RL36.3m. Creates notch in North-East corner. Access as per A1.	-19.4

Most of the options received scores close to zero, indicating that they meet industry standard. No option was considered to substantially exceed industry standard. This is expected given the unfamiliar activity of removing tailings from a tailings storage facility. The continued use of North Notch 2, requiring a modified gantry and an estimated 600–700 tonne crane for ongoing access to the lift workboats, was hard show-stopped at the beginning of the assessment. Gantry modification to the extent required to meet safety requirements was considered to be prohibitively expensive.

Option A2, the construction of a third notch in the North wall to a height of RL 37.3 m, was determined to be the most suitable approach. This option includes the contingency to construct a clay bund within the notch if it is required to ensure adequate freeboard during the wet seasons. It is assumed that Pit 3 remains available to receive process water from the TSF during extreme weather events to minimise the risk of overflow into the notch.

Although options A1 and A3 received the same final overall ranking, option A2, with the higher notch level, has a lower capital expenditure and construction time than A1 and A2. Capital expenditure and construction time includes clay bund and notch infill. There is a risk of overtopping the notch resulting in seepage into the dam walls in option A2. This risk is removed with the infill of the notch as proposed in option A3. Proposed risk mitigation measures, such as the construction of a clay bund and the cessation of tailings pore water transfer from Pit 3 reduce this risk to an acceptable level and justified the selection of option A2 over option A3.

						Protection of People and the Environment			Fit for Purpose				
			Show stopper column setting			Yes	No	Yes	No	No		Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Community health & safety	Socio-economic impact on local communities	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1			3	3	3	2	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1			3	3	2	2	4	4
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1			3	3	3	3	4	1
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6			3	2	2	3	3	3
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0								
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8			3	2	3	2	1	1

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						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

10 TAILINGS STORAGE FACILITY SUBFLOOR MATERIAL MANAGEMENT

Report: *MTC Application Ranger Mine Tailings Storage Facility – Subfloor Material Management. 2020*

ERA undertook an assessment into the viable options for managing the TSF subfloor contaminated material as part of closure planning for the TSF and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material *in situ* rather than disposal into Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 was required to consider this subfloor material. The deconstruction of the TSF does not occur until later, and as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works.

Based on the outcomes of the BPT assessment, an application was submitted to the Director of Mining Operations, DITT for approval in March 2020. The application was updated in June 2020 following stakeholder feedback and the DITT approved the application in August 2020.

The BPT assessment involved comparing the option of leaving the contaminated subfloor material *in situ* against a number of methodologies for disposing the material within Pit 3 (Table 10-1 and the ranking matrices at the end of this section).

Option 1 was developed as a worst-case scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, to allow for completion of the relevant supporting studies. It is intended that Option 2 will be reviewed on the basis that Option 1 demonstrates a greater 'net environmental benefit' than Option 3 as part of this initial assessment. A total of 12 options were reviewed for disposal of the material within Pit 3.

Table 10-1: BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	Option description	Score
1a	Leave material *in situ*. TSF subfloor material left undisturbed in situ. All visible tailings removed. TSF is then used for process water storage.	38.2
2	Leave material *in situ*. TSF subfloor material left undisturbed in situ with some form of remediation which may use TSF wall material for capping or another methodology.	Initial show-stopper
3a.1	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 for use as secondary cap. TSF used for process water storage.	-17.6
3a.2	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, intermediate stockpile, with transfer to Pit 3 for use as primary cap.	Initial show-stopper
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

Option	Option description	Score
3a.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 and intermixed with mineralised waste rock (co-disposal). TSF used for process water storage.	-23.5
3a.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically, stockpiled, with transfer to south-west of Pit 3 as secondary cap wedge deposit. TSF used for process water storage.	-23.5
3b.1	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and use as secondary cap. TSF used for process water storage.	Initial show-stopper
3b.2	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, partially transferred to Pit 3 and use as secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	Initial show-stopper
3c.7	Dispose of material within Pit 3. 4 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and placed in south-west as secondary cap deposit. TSF used for process water storage.	-29.4
3d.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Schedule optimised.	-29.4
3d.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Solute optimised.	-29.4

To compare Options 1 and 3, an understanding of the risk of contaminants mobilising into the surrounding environment was necessary to determine how effectively the TSF subfloor could be isolated at each management location. Isolation effectiveness is assessed with regard to the likelihood of contaminants entering groundwater and surface waters, which create solute transport pathways and potentially increase exposure of contaminants to sensitive receptors. The management option that poses the lowest environmental risk and/or avoids having ‘a net adverse effect’ would be considered the most viable for implementation.

Option 1a (leave *in situ*) ranked highest overall and is the only option with a positive ranking of 38.2. This option scored highest overall for aspects such as ‘Environmental Protection’, ‘Living Culture’, ‘Cultural Heritage’, ‘Ecosystems & Natural World Heritage’, and ‘Tailings’, indicating that these aspects meet current standards and are more likely to achieve greater level of environmental and cultural protection than the other management options. This option scored lowest overall for ‘Revegetation’ (3) and ‘Erosion’ (2), indicating that this option presents greater risk to final landform management than the Pit 3 transfer options. Overall, this option had the least number of soft show-stopper aspects (‘Community Health’, ‘Radiation’ and ‘Erosion’) in comparison to the other options and was identified as the most viable option for contaminated material management.

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
						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
	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

						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

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	2	2	2	3	5	5	5	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0									
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	4	2	3	1	2	2	3	3	3
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	4	2	3	1	2	2	2	2	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	4	2	3	1	1	1	2	3	2
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	4	2	3	1	2	2	3	2	3
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	4	2	3	2	2	2	3	2	2

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	0	0	0	0	0	0	0	0	0
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0									
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0									
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	4	2	3	1	2	2	3	2	2
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** schedule optimised ** Note: **It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	4	2	3	1	2	1	3	2	3
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** solute optimised ** Note: **It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	4	2	3	2	2	1	3	2	2

11 BLACKJACK WASTE DISPOSAL

Report: *Best Practicable Technology (BPT) Assessment Blackjack Waste Disposal. Coffey 2018*

July 2018, Coffey Services Pty Ltd (Coffey) facilitated a BPT workshop to assess options for the disposal of hydrocarbon waste generated by the Ranger Mine. As part of uranium ore processing, a hydrocarbon lubricant known as blackjack (gear oil), is injected onto the spindle of the ball mill. The inventory forecasted at closure is approximately 72 kL, which equates to approximately 10 (205 L) waste blackjack drums produced annually. There are potential risks associated with blackjack disposal.

Analysis of drummed waste blackjack concluded that the waste at Ranger is contaminated above exemption levels as set out in the National Directory for Radiation Protection (Welman, 2013). Therefore, the waste blackjack cannot be disposed of off-site at a non-radioactive waste facility. The disposal of blackjack is required to be in line with Rio Tinto and ERA policies and standards, and the Ranger ERs. Another risk includes the possibility of light-non-aqueous phase liquids to separate as free product from the blackjack and potentially leak into groundwater. As part of the BPT assessment, each option submitted for review identified and discussed the potential risks associated with the method proposed.

The BPT assessment considered five options for waste disposal including:

- Tellus ‑ National Geological Repository (A1)
    - Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise contaminants prior to disposal in a bed of low permeability clay.
- Scholer ‑ Diesel fired waste incinerator (A2)
    - Design, manufacture and supply a two-stage waste oil incinerator for consecutive burning of black jack at the Ranger Mine. Overall, the two-stage incineration system ensures complete combustion, eliminating discharge of any toxic incompletely combusted compounds, including potential and actual carcinogenic combustion by-products.
- CDM Smith – Immobilisation & In-cell disposal of contained blackjack in Pit 3 (A3)
    - A proposal was submitted by CDM Smith based on a concept design to include an underground repository during the backfilling of Pit 3. The blackjack waste in this case would be pre-treated and immobilised, retained in a containment structure and buried in a multi-layered barrier system. With regards to pre-treatment, the blackjack waste will be treated physically (solidification process) and chemically (stabilisation process) then be encapsulated within a purpose-built cell in Pit 3 to provide additional layers of containment.

- In-cell disposal of contained blackjack in Pit 3 (A4)
    - Blackjack waste that is currently stored in metal drums will be placed in a containment structure and backfilled in-between waste rock and tailings in Pit 3. This excludes the pre-treatment process and immobilisation as per the CDM Smith A3 option above.
- National radioactive waste management facility (A5)
    - A national radioactive waste management facility was included as part of the original submissions of options however was removed from further consideration before the scheduled BPT assessment, as the proponents were unable to meet the closing date for submissions.

The BPT Assessment determined rankings for each of the five options (Table 11-1 and the ranking matrices at the end of this section).

Table 11-1: Blackjack disposal options and best practicable technology assessment summary

Option	Option description	Score
A1	Tellus – National Geolgoical Repositories	50.0
A2	Scholer – Waste Oil Incinerator	23.8
A3	CDM Smith – Immobilisation and in-cell disposal into Pit 3	-7.1
A4	In-cell disposal into Pit 3	-2.5
A5	National radioactive waste management facility	0.0

Tellus' National Geological Repository (Option A1) received the highest overall score, with 50 points. The second highest was Scholer's Waste Oil Incinerator, scoring 23.8 points. Tellus' National Geological Repository (Sandy Ridge) has received final approval and licencing to accept low-level radioactive waste and is the adopted option.

						TO Culture & Heritage		Protection of People and the Environment				
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes	Yes
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area	Long term protection of the environment (Operations only)
	A1	Tellus - National Geological Repositories	No	No	50.0	3	3	4	NA	3	5	5
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	2	3	NA	3	3	5
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	4	4	NA	4	4	3
	A4	In-cell disposal into pit 3	No	Yes	-2.5	3	4	4	NA	4	4	1
	A5	**National Radioactive Waste Management Facility	Yes		0.0							

						Fit for Purpose			Operational Adequacy	Rehabilitation and Closure			Constructability		
			Show stopper column setting			No	No	Yes	No	Yes	No	No	Yes	Yes	No
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Environmental Protection	OPEX	Environmental Acceptability (Operations only)	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Tellus - National Geological Repositories	No	No	50.0	4	3	4	5	5	5	5	NA	4	NA
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	4	4	3	3	3	5	3	4	3
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	2	2	3	1	3	2	2	4	2
	A4	In-cell disposal into pit 3	No	Yes	-2.5	4	2	1	4	1	3	2	2	4	3
	A5	**National Radioactive Waste Management Facility	Yes		0.0										

REFERENCES

Bryant PA, Croft J, Cole P. (2017). Integration of risks from multiple hazards into a holistic ALARA/ALARP demonstration. *J Radiol Prot*. 2018 Mar;38 (1):81-91. doi: 10.1088/1361-6498/aa8e53. Epub 2017 Dec 6. PubMed PMID: 29211686.

Department of the Environment and Energy. 2018. *RE: Ranger Pit 1 Final Landform*. 27 September 2018.

Ecologically Sustainable Development Steering Committee. 1992. *National Strategy for Evological Sustainable Development,* Available: http://www.environment.gov.au/about-us/esd/publications/national-esd-strategy [Accessed July 2019].

Energy Resources of Australia Ltd. 2018a. *Application to Progress Pit 1 Final Landform*, March 2018.

Energy Resources of Australia Ltd. 2018b. *Application: Ranger 3 Deeps Exploration Decline Decommissioning*, 21 September 2018.

Energy Resources of Australia Ltd. 2019a *Application to Progress Pit 1 to Final Landform.* For Energy Resources of Australia Ltd. 1 March 2019.

Energy Resources of Australia. 2019b. *Application to operate a brine squeezer*, 7 January 2019.

Energy Resources of Australia Ltd, Alan Irving & Assoc. 2019. *Application Pit 3 Tailings Deposition.* For Energy Resources of Australia Ltd, 29 March 2019.

GHD 2019*. Best Practicable Technology Assessment for Tailings Deposition in Pit 3.* For Energy Resources of Australia Ltd, 07 February 2019.

Hatch. (2021). *Pit 3 Capping Trade Off Study - Final Report*. Hatch. Document Number H366609-00000-100-066-0001.

IAEA (2010). Frequently Asked Questions on ALARA…optimization of doses for occupational exposure. IAEA consultancy meeting, 4th and 5th of March 2010 https://nucleus.iaea.org/sites/orpnet/resources/frquentlyaskedquestions/SitePages/Home.aspx accessed 19 September, 2019.

Johnston, A and Iles, M. 2013. *Integrated, Tailings, Water and Closure Prefeasibility Study - Analysis of Best Practicable Technology*. Energy Resources Australia Ltd, Darwin. April 2013, p 112.

Murphy, J, 2018. *Ranger 3 Deeps exploration decline decommissioning plan.* Energy Resources of Australia Limited, Darwin, NT.

Supervising Scientist. 2000. *Ranger Environmental Requirements Section 19.2 Explanatory Material: Best Practicable Technology*.

Supervising Scientist Branch. 2018. approval letter for Progress of Pit 1 to Final Landform. 27 September 2018.

Supervising Scientist Branch. 2020. SSB letter to L Bryce, pers comms, 12 October 2020.

Supervising Scientist Division. 2001. *Annual report 2000 - 2001*. Department of the Environment and Heritage, Canberra. 3 October 2001, p 32.

NLC. 2020. Northern Land Council letter to Paul Arnold, pers comms. Ref: E2020/13572, 1 September 2020.

APPENDIX 5.1: CONSOLIDATED KKN LIST

CONSOLIDATED LIST OF KEY KNOWLEDGE NEEDS, OWNER AND STATUS

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
Landform					
LAN1A	What are the baseline rates of gully formation for areas surrounding the RPA?	Closed Out	Determine baseline extent, size and rate movement of gullies in undisturbed areas surrounding the mine site.	OSS	Cancelled
LAN1B	What are the baseline rates of sediment transport and deposition in creeks and billabongs?	Open	Assessment of sedimentation risk to on-site and off-site billabongs.	OSS	Completed
			What are the baseline rates of sediment transport and deposition in creeks and billabongs?	OSS	Active
			Mapping and characterisation of geomorphology of on-site creeks in and adjacent to the mine site, including historical change.	OSS	Completed
			Determine the baseline depths of 3 Billabongs downstream of the Ranger mine site using a comparison of standard survey methods and drone based survey.	OSS	Active
LAN2A	What major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate)?	Closed Out	Extreme natural events and the stability of tailing repositories at Ranger Uranium Mine, NT. Blong, R and Mitchell, P (1996).	ERA	Completed
			Ranger uranium mine closure first pass climate change assessment. BMT (2020).	ERA	Completed
			Evaluation of features, events and processes and safety functions for the Ranger uranium mine. Kozak, M, Sigda, J, Jones, T, Iles, M and Pugh, L (2017).	ERA	Completed
			SSB Paper: Managing for extremes: potential impacts of large geophysical events on Ranger Uranium Mine, N.T. Erskine, WD, Saynor, MJ, Jones, D, Tayler, K and Lowry, J (2012).	OSS	Completed
LAN2B	How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?	Open	Impact of Cyclone Monica on Gulungul Creek catchment, Ranger mine site and Nabarlek area.	OSS	Completed
			Landslips in the upper Magela catchment.	OSS	Completed
LAN3A	What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?	Open	Preliminary flood modelling and hydraulic design.	ERA	Completed
			Rock Size Distribution on Pit 1 final landform.	ERA	Completed
			Impact of rip lines on runoff and erosion from the Ranger trial landform.	OSS	Completed
			Water, Erosion and Sediment Control Plan incorporating LEM Revision.	ERA	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
LAN3B	Where, when and how much consolidation will occur on the landform?	Open	Pit 1 Tailings consolidation modelling.	ERA	Completed
			Pit 3 Tailings consolidation modelling.	ERA	Completed
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)?	Open	Ranger trial landform erosion research.	OSS	Active
			Assessing the geomorphic stability of the Ranger trial landform: calibrating model outputs.	OSS	Completed
			Determining and testing representativeness of long-term rainfall patterns for use in final landform modelling.	OSS	Completed
			Analysis of data from historical unpublished erosion studies in the ARR.	OSS	Completed
			Development of enhanced vegetation component for the CAESAR model.	OSS	Completed
			Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to the rehabilitated Ranger mine – Gulungul Creek scale.	OSS	Completed
			Weathering of Ranger waste rock to inform landform evolution model predictions.	OSS	Completed
			Assessment of the constructed Pit 1 landform using the CAESAR-Lisflood LEM.	OSS	Completed
			An improved method for modelling erosion and gully formation on the Ranger landform.	OSS	Completed
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)?	Open	Assessing the geomorphic stability of the proposed rehabilitated Pit 1 landform.	OSS	Completed
			Model Geomorphic stability of Pit 1 landform.	OSS	Completed
			Model the geomorphic stability of the landform for up to 10,000 years – finalising longterm rainfall datasets and weathering impacts for the landform.	OSS	Completed
			Model geomorphic stability of pre-mine landform for up to 10,000 years.	OSS	Completed
			Assessing the final landform design.	OSS	Active
			Assessing the impact of groundwater discharge on landform stability.	OSS	Completed
			Assessment of the constructed Pit 1 landform using the CAESAR-Lisflood LEM.	OSS	Completed
			An improved method for modelling erosion and gully formation on the Ranger landform.	OSS	Completed
LAN3E	How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?	Open	No open projects.	N/A	N/A

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
LAN4A	How do we optimise methods to measure gully formation on the rehabilitated landform?	Open	Development of a method for monitoring gully formation on the rehabilitated landform using stereopsis and LiDAR.	OSS	Active
			Monitoring of gully erosion using drone 3D photogrammetry and LiDAR.	OSS	Proposed
LAN4B	What monitoring data are required for ongoing LEM validation?	Removed		N/A	N/A
LAN5A	How can we use suspended sediment in surface water (or turbidity as a surrogate) as an indicator for erosion on the final landform?	Open	Turbidity & suspended sediment relationships for Gulungul and Magela Creeks.	OSS	Active
Water and Sediment					
WS1A	What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?	Open	TSF Wall Drilling program.	ERA	Completed
			Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Acid sulfate sediments conceptual model.	ERA	Completed
			Soil assessments for LAA.	ERA	Completed
			Non-aquatic contaminated sites sampling.	ERA	Completed
			Processing plant contamination sampling.	ERA	Completed
			TSF floor drilling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
			Stockpile drilling program.	ERA	Completed
			Solute source area/concentration conceptual model update.	ERA	Completed
			Wetlands investigation program.	ERA	Proposed
WS1B	What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?	Open	Literature review on mobilisation of contaminants.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS2A	What is the nature and extent of groundwater movement, now and over the long-term?	Open	Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
			Distribution of groundwater sources of Ranger mine contaminants in Magela sands.	OSS	Active
			Monitoring surface water and sediment chemistry of Magela creek pools.	OSS	Active
WS2B	What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?	Open	Literature review on mobilisation of contaminants.	ERA	Completed
			Mg:Ca input into solute transport models.	ERA	Completed
WS2C	What are predicted contaminant (including nutrients) concentrations in groundwater over time?	Open	Background CoPC in groundwater.	ERA	Completed
			Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
WS3A	What is the nature and extent of surface water movement, now and over the long-term?	Open	Preliminary surface water modelling.	ERA	Completed
			Surface water groundwater interaction.	ERA	Completed
			Update surface water model.	ERA	Completed
			Spectral investigation of Ranger salts.	ERA	Completed
WS3B	What concentrations of contaminants from the rehabilitated site will aquatic (surface and ground-water dependent) ecosystems be exposed to?	Open	Preliminary surface water modelling.	ERA	Completed
			Mg:Ca input into solute transport models.	ERA	Completed
			Update surface water model.	ERA	Completed
			Monitoring surface water and sediment chemistry of Gulungul & Mudginberri Billabong.	OSS	Completed
WS3C	What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?	Open	Update surface water model.	ERA	Completed
			Coonjimba Billabong hydrodynamic modelling.	ERA	Active
WS3D	Where and when does groundwater discharge to surface water?	Open	Surface water groundwater interaction.	ERA	Completed
			GW/SW interaction model validation.	ERA	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS3E	What factors are likely to be present that influence contaminant (including nutrients) transport between groundwater and surface water?	Open	Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
			Preliminary surface water modelling.	ERA	Completed
			Surface water groundwater interaction.	ERA	Completed
			Coonjimba Billabong hydrodynamic modelling.	ERA	Active
WS3F	What are the predicted concentrations of suspended sediment and contaminants (including nutrients) bound to suspended sediments in surface waters over time?	Open	Preliminary surface water modelling.	ERA	Completed
WS3G	To what extent will the interaction of contaminants between sediment and surface water affect their respective qualities?	Closed Out	Predicting uranium accumulation in sediments.	OSS	Completed
WS3H	Where and when will suspended sediments and associated contaminants accumulate downstream?	Open	Coonjimba Billabong hydrodynamic modelling.	ERA	Active
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?	Open	Distribution of groundwater sources of Ranger mine contaminants in Magela sands.	OSS	Active
			Monitoring surface water and sediment chemistry of Magela Creek pools	OSS	Active
			Preliminary mapping of groundwater dependent ecosystems (GDEs) on the Ranger lease.	OSS	Completed
			Magela Creek sandbed water quality and subsurface fauna – pilot.	OSS	Completed
			Assess the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel.	OSS	Completed
			Identification and mapping of groundwater dependent ecosystems (GDEs).	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS5A	Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?	Open	Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Acid sulfate sediments conceptual model.	ERA	Completed
			Surface water pathway risk assessments (release pathways onsite).	ERA	Active
			Sulfate-ASS risk & management options.	ERA	Active
			The toxicity of U to sediment biota of Gulungul Billabong.	OSS	Completed
			Effects of uranium on the structure and function of bacterial sediment communities.	OSS	Completed
			Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate.	OSS	Completed
			Impact of acid sulfate soils on aquatic ecosystems.	OSS	Completed
WS5B	What are the factors that influence the bioavailability and toxicity of contaminants in sediment?	Closed Out	Predicting uranium accumulation in sediments.	OSS	Completed
WS5C	What would be the impact of contaminated sediments to surface aquatic ecosystems?	Removed	Predicting uranium accumulation in sediments.	OSS	Completed
WS6A	What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?	Closed Out	Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value.	OSS	Completed
			Toxicity of ammonia and other key contaminants of potential concern to freshwater mussels.	OSS	Completed
			Toxicity of ammonia to local species at a range of pHs.	OSS	Completed
WS6B	Can annual additional load limits (AALL) be used to inform ammonia closure criteria?	Removed		N/A	N/A
WS6C	What concentrations of nutrients (N and P) in waterbodies will cause eutrophication?	Open	Eutrophication risk study.	ERA	Superseded
			Monitoring surface water and sediment chemistry of Gulungul & Mudginberri Billabong.	OSS	Completed
			Nutrients thresholds defining trophic status of ARR surface waters.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS7A	Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios?	Closed Out	Billabong macroinvertebrates responses to mine-derived solutes.	OSS	Completed
			The effect of dissolved organic matter on the bioavailability and toxicity of metals to tropical freshwater biota (PhD project).	OSS	Completed
			Effects of Mg pulse exposures on tropical freshwater species.	OSS	Completed
			Re-analysis of existing uranium freshwater chronic toxicity data to revise the site-specific and national U trigger values.	OSS	Completed
			Effect of manganese on tropical freshwater species.	OSS	Completed
			The effect of multiple Mg pulses on tropical freshwater species with an emphasis on recovery and carry over toxicity.	OSS	Completed
			Desktop assessment of historical Direct Toxicity Assessment data to evaluate multiple single toxicant water quality limits (including the magnesium Limit).	OSS	Completed
			Assessing the toxicity of mine water mixtures for operational and closure scenarios.	OSS	Completed
			Deriving a candidate Mg guideline value based on a mesocosm study (re-analysis of 2002 PhD data).	OSS	Completed
			Deriving site specific guideline values for copper and zinc.	OSS	Completed
WS7B	What is the risk associated with emerging contaminants?	Open	Background CoPC in groundwater.	ERA	Completed
			Toxicity of treated process waters from Ranger uranium mine to five local freshwater species.	OSS	Completed
			Hazard and risk assessments for potential / emerging water quality contaminants and toxicity modifying factors.	OSS	Completed
			PFAS in Biota (fishes, reptiles, Eleocharis) downstream of Jabiru and Ranger.	OSS	Active
			Surface water monitoring of PFAS around Ranger mine and Jabiru.	OSS	Active
			Development of a site-specific guideline value for aluminium.	OSS	Proposed
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	Closed Out	Seasonal sensitivity (to Mg) profile for macroinvertebrates in the Magela creek channel.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
	(e.g. flow-dependent insects, hyporheic biota and stygofauna)?				
WS7D	How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota?	Removed		N/A	N/A
WS7E	How will Mg:Ca ratios influence Mg toxicity?	Closed Out	Billabong macroinvertebrates responses to mine-derived solutes.	OSS	Completed
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)?	Closed Out	Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration).	OSS	Completed
WS7G	What concentrations of contaminants will be detrimental to the health of (non-riparian) aquatic vegetation?	Closed Out	Evaluation of aquatic vegetation data.	OSS	Completed
WS7H	What concentrations of contaminants will be detrimental to the health of riparian vegetation?	Closed Out	Ecohydrology and sensitivity of riparian flora (NESP project).	OSS	Completed
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)?	Removed		N/A	N/A
WS8B	To what extent does salinity affect suspended particulates, and what are the ecological impacts of this?	Removed		N/A	N/A

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS9A	How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?	Open	Developing best practice and guidance documents for environmental omics in Australia.	OSS	Completed
			Developing the capacity to collect water samples from drones.	OSS	Active
			Develop a technique for automating snail egg counts for toxicity testing and monitoring.	OSS	Completed
			Developing videography-based methods for monitoring fish communities in channel billabongs.	OSS	Active
			Building the metacode database for northern macroinvertebrate species.	OSS	Active
			Developing a short-term chronic toxicity test for the fish, Mogurnda mogurnda.	OSS	Completed
			Developing methods for monitoring fish communities in shallow lowland billabongs.	OSS	Active
			Use of DGTs for uranium (and other metal) measurement.	OSS	Active
			Assessment of algae populations with new technologies.	OSS	Suspended
			Automation of fish identification.	OSS	Completed
			Measuring river discharge from drones.	OSS	Cancelled
			Use of DNA to survey aquatic macroinvertebrate assemblages.	OSS	Active
			Acoustic Backscatter sensors for total suspended sediment monitoring.	OSS	Active
			Building the DNA database of northern aquatic vertebrate species.	OSS	Completed
			Determining optimum sample volume and primers to detect fish with environmental (e)DNA.	OSS	Active
			Automating fish biomass estimated with stereo-videography and deep learning.	OSS	Completed
			Bioinformatic pipeline development for freshwater invertebrate and soil microbial eDNA amplicon analysis.	OSS	Proposed
			Automated detection of fish schools in channel billabongs.	OSS	Proposed
Ecosystems					
ESR1A		Open	Conceptual model of final revegetation reference ecosystem.	ERA	Completed
			Quantifying spatial and temporal change in savanna.	OSS	Completed
			Assessment of historical vegetation reference site information for use in ecological restoration at Ranger mine site.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
	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?		Factors affecting spatial and temporal change in savanna.	OSS	Completed
			Vegetation similarity: updated data for conceptual reference ecosystem.	OSS	Completed
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
			Collection of data to inform development of the appropriate fire regime for the Ranger rehabilitated site.	OSS	Completed
ESR1B	Which indicators of similarity should be used to assess revegetation success?	Closed Out	SERA standard and SSB ecosystem restoration standard.	OSS	Completed
			Vegetation similarity closure criteria: development of indicators.	OSS	Completed
ESR1C	What values should be prescribed to each indicator of similarity to demonstrate revegetation success?	Open	Deriving species composition measures and their environmental correlates to assess ecosystem restoration similarity.	OSS	Completed
			Deriving vegetation community structural attributes that inform the conceptual reference ecosystem.	OSS	Completed
			Conceptual Reference Ecosystem and Completion Criteria.	ERA	Superseded
			Ecosystem (flora and fauna) similarity and sustainability completion criteria.	ERA	Superseded
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?	Open	Terrestrial fauna objectives, closure criteria and recolonisation plan.	ERA	Superseded
			Ecosystem (flora and fauna) similarity and sustainability completion criteria.	ERA	Superseded
			Invertebrate assemblages at Ranger Uranium Mine's trial revegetation sites compared with natural reference sites (CDU NESP project).	ERA	Completed
			Recommendations for faunal standards for the rehabilitation of Ranger uranium mine (NESP).	OSS	Completed
			Fauna closure criteria: development of goals.	OSS	Completed
			Fauna closure criteria: development of indicators.	OSS	Completed
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active
			Ecosystem restoration trajectories for vertebrate fauna similarity indicators.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
ESR2B	What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?	Open	Habitat features that influence the colonisation of fauna on the landform.	OSS	Superseded
			Nest box trials.	ERA	Active
			Habitat features and potential enhancements for fauna colonisation.	ERA	Active
ESR2C	What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?	Closed Out	Risk assessment for feral animals impacting faunal colonisation of the landform.	OSS	Superseded
ESR3A	How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?	Open	Ranger species establishment research program (SERP).	ERA	Active
			Assessment of ecosystem restoration on revegetated domains at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active
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?	Open (Revised wording proposed at ARRTC54)	Ecosystem restoration trajectories of ant similarity indicators.	OSS	Active
			Determining the incidence of declared weeds and other introduced flora in areas of Kakadu National Park adjacent to the Ranger mine.	OSS	Active
ESR5A	What are the key sustainability indicators that should be used to measure restoration success?	Open	Conceptual model of final revegetation reference ecosystem.	ERA	Superseded
			Assessing mine restoration trajectories through studies at Nabarlek.	OSS	Active
			Vegetation sustainability closure criteria: development of indicators.	OSS	Completed
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
			Flowering and fruiting phenology of dominant species in the reference ecosystem at Ranger mine.	OSS	Completed
ESR5B	What are possible/agreed restoration trajectories (flora	Open (Revised	State and Transition model.	ERA	Active
			Review of revegetation outcomes arising from historic mine sites in the Alligator Rivers	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
	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?	wording proposed at ARRTC54)	Region.		
			Long-term viability of the ecosystem established on the trial landform.	OSS	Completed
			Assessing mine restoration trajectories through studies at Nabarlek.	OSS	Active
			Assessment of ecosystem restoration on revegetated domains at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active
			Developing restoration trajectories to predict when the restored site will move to a sustainable ecosystem.	OSS	Completed
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
			Assessment of ecosystem development at Nabarlek mine site.	OSS	Cancelled
			Monitoring and assessment of ecosystem establishment and long-term viability on Pit 1 waste rock to inform trajectories.	OSS	Superseded
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active
			Ecosystem restoration trajectories for vertebrate fauna similarity indicators.	OSS	Active
			Ecosystem restoration trajectories of ant similarity indicators.	OSS	Active
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
ESR6A	What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants?	Open	No open projects.	ERA	N/A

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
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?	Closed Out	No open projects.	ERA	N/A
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?	Open (revised wording proposed at ARRTC54)	Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
ESR7B	Will sufficient plant available water be available in the final landform to support a mature vegetation community?	Open	WAVES modelling (Plant available water balance modelling of the waste rock landform).	ERA	Active
			Plant available water balance modelling of the waste rock landform based on Ranger trial landform (ERA-CDU project 2013-2018).	ERA	Completed
			Study of Root Mass and depth on TLF.	ERA	Completed
			A review of compaction layers in mining landforms and possible implications for Ranger uranium mine.	OSS	Completed
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?	Open	Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed
			Soil formation and nutrient cycling monitoring.	ERA	Active
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
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?	Open	Ranger species establishment research program (SERP).	ERA	Active
			Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
ESR8A	What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?	Open (revised wording proposed at ARRTC54)	Trial landform fire report.	ERA	Completed
			Fire implementation and management plan for the Ranger Final Landform.	ERA	Proposed
			State and Transition model.	ERA	Active
			Collection of data to inform development of the appropriate fire regime for the Ranger rehabilitated site.	OSS	Completed
ESR9A	How do we optimise methods to measure revegetation and faunal community structure and sustainability on the rehabilitated site, at a range of spatial/temporal scales and relative to the areas surrounding the RPA?	Open (Revised wording proposed at ARRTC54)	Development of a low-cost method for continuous monitoring of water stress in eucalypt vegetation on a rehabilitated mine site.	OSS	Completed
			Developing monitoring methods for revegetation using RPAS: Jabiluka revegetation.	OSS	Completed
			Spectral characterisation of overstorey vegetation species using airborne hyperspectral.	OSS	Active
			Guiding ecological restoration at Ranger uranium mine with drone derived indicators of ecosystem health.	OSS	Superseded
			Assessment of ecosystem restoration on revegetated zones at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active
			Develop metrics to confirm vegetation resilience to fire events.	OSS	Superseded
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
			Measuring vegetation structure at the landscape scale.	OSS	Superseded
			Terrestrial vertebrate faunal surveys using iDNA.	OSS	Active
			Developing a method to measure and monitor soil microbial communities to assess nutrient cycling.	OSS	Active
			Application of AI to identifying vegetation species from drone data: pipeline development.	OSS	Completed
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active
			Flowering and fruiting phenology of dominant species in the reference ecosystem at Ranger mine.	OSS	Completed
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Application of AI to identifying vegetation species from drone data: model development.	OSS	Superseded
			Validating soil nutrient cycling assessments with eDNA using multi-omics approach.	OSS	Active
			Developing whole of site landform and ecosystem monitoring program at-scale.	OSS	Cancelled
			Assessment of vegetation establishment using drone imagery.	OSS	Active
			Measuring vegetation health using drone and satellite multispectral imagery.	OSS	Active
			Measuring vegetation structure at the landscape scale using drone and satellite imagery.	OSS	Active
			Classification of tree taxa/species using AI with hybrid spectral and structural datasets.	OSS	Active
Radiation					
RAD1A	What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and land application areas?	Open	Radiological Impact Assessment – Waste Rock & Tailings.	ERA	Active
			Radiological Impact Assessment – Rehabilitated Landform & LAA's.	ERA	Active
			Characterisation of contamination at land application areas at Ranger uranium mine.	OSS	Completed
RAD2A	What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?	Open	Non-aquatic contaminated sites sampling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
			Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Preliminary surface water modelling.	ERA	Completed
			Update surface water model.	ERA	Completed
			Radionuclide fluxes from the trial landform.	OSS	Completed
RAD3A	What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?	Closed Out	Atmospheric dispersion modelling of radon and particulate matter (consultant report: SLR 2018).	ERA	Completed
			Radon exhalation from the RUM Trial Landform.	OSS	Completed
			Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine.	OSS	Completed
			Atmospheric dispersion of radon and radon daughters from the Ranger rehabilitated landform.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Radon exhalation from waste rock on the Ranger trial landform.	OSS	Completed
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?	Removed		N/A	N/A
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?	Removed		N/A	N/A
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?	Removed		N/A	N/A
RAD4B	What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	Closed Out	Modelling the atmospheric dispersion of radionuclides in dust from the Ranger final landform.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
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?	Removed		N/A	N/A
RAD5A	What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?	Open	Environmental fate and transport of Ac-227 and Pa-231.	OSS	Active
RAD6A	What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?	Closed Out	Ranger 3 Deeps draft EIS.	ERA	Completed
			Dose rates to non-human biota.	OSS	Completed
RAD6B	What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?	Open	Dose rates to non-human biota.	OSS	Completed
			Radionuclide uptake in small proliferators.	OSS	Completed
			Radionuclide uptake in understorey vegetation.	OSS	Completed
			Radionuclide uptake in terrestrial invertebrates.	OSS	Active
			Updating the biota dose assessment for the Ranger final landform.	OSS	Suspended
RAD6C	What are the tissue to whole organism conversion factors for uranium and actinium series radionuclides for wildlife represented by the representative organism groups?	Removed	Dose rates to non-human biota.	OSS	Completed
RAD6D	What are the dose-effect relationships for wildlife represented by the representative organism	Removed	Radiation dose-effect relationships for non-human biota.	OSS	Cancelled

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
	groups?				
RAD6E	What is the sensitivity of model parameters on the assessed radiation doses to wildlife?	Open	Radiological Impact Assessment.	ERA	Active
RAD7A	What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?	Open	Radiological Impact Assessment.	ERA	Active
			Radionuclide uptake in traditional Aboriginal foods.	OSS	Completed
			Pre-mining radiological analogue for Ranger.	OSS	Completed
			Gamma radiation dose rates to the public from the Ranger final landform.	OSS	Completed
RAD7B	What is the sensitivity of model parameters on the assessed doses to the public?	Open	Radiological Impact Assessment.	ERA	Active
RAD8A	Will contaminant concentrations in surface water (including creeks, billabongs and seeps) pose a risk of chronic or acute impacts to terrestrial wildlife?	Open	Assessing whether contaminants in surface water pose a risk of chronic or acute impacts to terrestrial wildlife.	OSS	Cancelled
RAD9A	What are the contaminants of potential concern to human health from the rehabilitated site?	Closed Out	Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Soil assessments for LAA.	ERA	Completed
			Non-aquatic contaminated sites sampling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
RAD9B	What are the concentration factors for contaminants in bush foods?	Open	Deriving site-specific concentration factors for metals in bush foods to inform human health risk assessments for the Ranger final landform.	OSS	Completed
			Bush tucker sampling project.	ERA	Active
RAD9C	What are the concentrations of contaminants in drinking water sources?	Open	Preliminary surface water modelling.	ERA	Completed
			Update surface water model.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
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?	Open	Surface water pathway risk assessments (release pathways onsite).	ERA	Active
			Bush tucker sampling project.	ERA	Active
RAD10 A	How do we optimise methods to monitor and assess radionuclides?	Open	Development of a model for radium-226 uptake in *Velesunio angasi* (freshwater mussel).	OSS	Completed
			Quantifying radon retention characteristics of ERISS acrylic gamma spectroscopy containers.	OSS	Completed
			Developing drone remote sensing techniques for characterising radioactivity levels on the rehabilitated landform.	OSS	Active
Cross Theme					
CT1A	What are the cumulative risks to the success of rehabilitation on-site and to the off-site environment?	Open	Pollino, CA, Cuddy, SM & Gallant, S 2013. Ranger rehabilitation and closure risk assessment: problem formation. Canberra: CSIRO.	ERA	Completed
			Pollino, CA 2014. Ranger rehabilitation and closure risk assessment: Risk screening. Cangerra Australia: CSIRO Land and Water Flagship.	ERA	Completed
			An ecological risk assessment of the major weeds on the Magela Creek Floodplain, Kakadu National Park.	OSS	Completed
			Ranger rehabilitation & closure ecological risk assessment: phase 1, problem formulation.	OSS	Completed
			Ranger rehabilitation & closure ecological risk assessment: phase 2, risk analysis.	OSS	Completed
			Cumulative risk assessment for Ranger minesite rehabilitation and closure – Phase 1 (on-site risks).	OSS	Completed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – Phase 2 (aquatic pathways).	OSS	Completed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – periodic review and update (2024).	OSS	Proposed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – periodic	OSS	Proposed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			review and update (2026).		
			Vulnerability Assessment Framework.	ERA	Completed
			Ranger Rehabilitation and Closure Risk Assessment: Problem Formulation.	ERA	Completed
			Ranger Rehabilitation and Closure Risk Assessment: Risk Screening.	ERA	Completed
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?	Closed Out	ERA cultural heritage management system & GIS.	ERA	Completed
			Closure criteria development – cultural.	ERA	Cancelled
			Cataloguing the natural World Heritage values on the Ranger Project Area.	OSS	Completed

APPENDIX 5.2: CONSOLIDATED LIST OF PREVENTATIVE CONTROLS

CONSOLIDATED LIST OF PREVENTATIVE CONTROLS

Unique Identifier	Description of Preventative Control	Current Effectiveness (2024)	Active or K/A[1] type of control
C1	Final landform design and construction.	Marginal – Satisfactory	A
C2	Erosion control measures including preparation of final landform surface.	Marginal	A
C3	Sediment control measures including sediment basins.	Marginal – Satisfactory	A
C4	Drainage control structures including sinuous armoured drainage channels.	Marginal	A
C5	Revegetation of the final landform surface.	Marginal – Satisfactory	A
C6	Understanding final tailings elevations.	Satisfactory	K/A
C7	All tailings deposited into Pits 1 and 3.	Weak – Strong	A
C8	Tailings buried below predicted depth of gully formation.	Satisfactory	A
C9	Legal instruments.	Weak	K/A
C10	Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3.	Weak – Strong	A
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met.	Marginal – Strong	A
C12	Brine injected into Pit 3 underfill.	Marginal – Strong	A
C13	No water released from mine site unless it meets defined criteria and sufficient creek flow.	Satisfactory – Strong	A
C14	Understanding source terms, groundwater loads, surface water concentrations.	Satisfactory	K/A
C15	Understanding solute transport pathways, interactions and contaminant behaviour over time.	Satisfactory	K/A
C16	Refuelling and maintenance areas are appropriately bunded.	Strong	A
C17	Clay cap over RWD floor.	Satisfactory – Strong	A
C18	Retain clay core around RWD floor.	Satisfactory – Strong	A
C19	RWD and western stockpile interception trench.	Marginal – Satisfactory	A
C20	Use of approved pesticides as per instruction.	Satisfactory	A
C21	Fertiliser use based on identified nutrient need of plants.	Satisfactory	A
C22	Containment cell within RP2 for PFAS.	Satisfactory – Strong	A
C23	Excavate and dispose contaminated soil/sediments into Pit 3 and RP2.	Weak – Strong	A
C24	Detailed understanding of soil contamination levels and location.	Satisfactory	K/A
C25	Validation sampling.	Satisfactory	K/A
C26	In situ treatment of mildly contaminated, or culturally sensitive, sites.	Marginal	A
C27	Tilling.	Satisfactory	A
C28	Post-closure monitoring.	Marginal	K/A

Unique Identifier	Description of Preventative Control	Current Effectiveness (2024)	Active or K/A[1] type of control
C29	Development of appropriate vegetation CRE.	Satisfactory	K/A
C30	Weed management in non-waste rock areas within RPA.	Satisfactory	A
C31	Weed management on waste rock rehabilitation areas.	Marginal	A
C32	Application of pre-emergent herbicide.	Strong	A
C33	Implementation of suitable ecosystem establishment strategy including appropriate species mix.	Satisfactory – Strong	A
C34	Provision of suitable irrigation.	Satisfactory	A
C35	Fire management in non-waste rock areas within RPA.	Strong	A
C36	Management of introduced fauna.	Satisfactory	A
C37	Targeted pest and disease management.	Satisfactory	A
C38	Addition of organic material from surrounds.	Marginal	A
C39	Appropriate introduction of fire to rehabilitation areas.	Satisfactory	A
C40	Development of appropriate fauna CRE.	Satisfactory	K/A
C41	Installation of appropriate nest boxes and/or rockpiles.	Marginal	A
C42	Understanding radiation emissions, exposure pathways, radionuclide concentrations and doses.	Satisfactory	K/A
C43	Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods.	Satisfactory	K//A
C44	Maintain tailings in near saturated state, and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material.	Satisfactory – Strong	A
C45	Final landform designed and constructed to meet Traditional Owner requirements.	Marginal – Satisfactory	A
C46	All sediment basins will be removed and rehabilitated.	Satisfactory	A
C47	Line of site assessment for cultural landscape features undertaken and incorporated into final landform design and execution.	Strong	K/A
C48	Management of the rehabilitated landform for weeds, exotic fauna, fire, pests and natural disturbances.	Satisfactory	A
C49	Clean-up of all existing infrastructure and rubbish.	Satisfactory	A
C50	Final land use consultation with Traditional Owners.	Satisfactory	K/A
C51	Implement Cultural Heritage Management System.	Marginal	K/A
C52	Administrative weed education, awareness and hygiene programs.	Satisfactory	K/A

[1] - K/A = Knowledge-based / Administrative Control.

APPENDIX 5.3: CONSOLIDATED LIST OF CORRECTIVE ACTIONS

ERA Energy Resources Of Australia

CONSOLIDATED LIST OF CORRECTIVE ACTIONS

Unique Identifier	Description of Corrective Action	Current Effectiveness (2024)	Active or K/A[1]
A1	Maintenance of erosion and sediment control measures.	Satisfactory	A
A2	Undertaking earthworks to repair significant substrate limitations, gullying or eroded areas.	Marginal – Satisfactory	A
A3	Extension of landform monitoring and maintenance phase.	Marginal	K/A
A4	Restricting access to any exposed tailings.	Marginal	A
A5	Removing any contaminated or impacted material (water and sediment).	Weak – Marginal	A
A6	Conducting health monitoring.	Satisfactory	K/A
A7	Increasing the frequency of field inspections for erosion and gully formation.	Satisfactory	K/A
A8	Planned duration of pump and treat extended to further reduce peak contaminant loads.	Satisfactory	A
A9	Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels.	Marginal – Satisfactory	A
A10	Short-term restrictions to land access and cultural activities.	Marginal – Satisfactory	A
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform.	Marginal – Strong	A
A12	Additional interception system (e.g. passive reactive barrier).	Marginal	A
A13	Discontinue use/change pesticide.	Satisfactory – Strong	A
A14	Discontinue nutrient use/change fertiliser.	Strong	A
A15	Use of approved flocculant / coagulant.	Satisfactory	A
A16	Contaminated soils detected after the validation sampling will be excavated and disposed below the 2s cap in Pit 3 or into RP2.	Strong	A
A17	Tilled soils on the Magela LAA that do not reach target levels will be disposed to RP2 (or Pit 3 depending on timing) and the area will be replanted.	Strong	A
A18	Targeted weed management.	Marginal	A
A19	Targeted introduced fauna management.	Satisfactory	A
A20	Addition of organic material/s and or fertiliser beyond that planned.	Marginal	A
A21	Targeted pest and disease management.	Marginal	A
A22	Modified fire management.	Satisfactory	A
A23	Supplementation of habitat features and/or migration corridors.	Marginal	A

Unique Identifier	Description of Corrective Action	Current Effectiveness (2024)	Active or K/A[1]
A24	Remediation (as required) of surface radiation following construction and rehabilitation of final landform.	Satisfactory	A
A25	Increased monitoring of radiological contaminants in impacted environments and biota.	Marginal	K/A
A26	Reshape landform.	Satisfactory	A
A27	Remediation of surface sediment or salt deposition.	Marginal	A
A28	Early notification and consultation with Traditional Owners and implementation of agreed mitigation.	Satisfactory	K/A
A29	Initial response to prevent further damage.	Marginal	K/A

[1] – K/A = Knowledge-based / Administrative Corrective Action.

APPENDIX 7.1: RANGER MINE AQUATIC PATHWAYS RISK ASSESSMENT FOR PIT 3 CLOSURE

Ranger Mine Aquatic Pathways Risk Assessment for Pit 3 Closure - Draft Report

Customer	ERA
Project	A10754
Deliverable	004
Version	02
	07 September 2023

Document Control

Document Identification

Title	Ranger Mine Aquatic Pathways Risk Assessment for Pit 3 Closure - Draft Report – draft report
Project No	A10754 phase 10
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Author	Michelle Iles
Approved By	Darren Richardson
Project Manager	Michelle Iles

Amendment Record

The Amendment Record below records the history and issue status of this document.

Version	Version Date	Distribution	Record
01	28 August 2023	Energy Resources of Australia Ltd (ERA)	Report
02	07 September 2023	Energy Resources of Australia Ltd (ERA)	Report

Executive Summary

Background

Energy Resources of Australia Ltd (ERA) is planning the closure of its Ranger Uranium Mine. The Ranger Project Area (RPA) is surrounded by Kakadu National Park (KNP), KNP World Heritage Area, KNP Natural Heritage Place and KNP Ramsar site, and is on lands owned by the Mirarr Traditional Owners.

Waters from the closed mine must support protection of the people, ecosystem (biodiversity and ecological processes), and the values of the adjacent KNP, World Heritage Area, and Ramsar site. Impacts on the RPA are also to be as low as reasonably achievable (ALARA).

One challenge for closure is understanding the risks associated with contaminants of potential concern (CoPC) that will continue to discharge from the mine site via groundwater and surface water.

Pit 3 has been backfilled with brines and tailings and ERA is seeking regulatory approval for the final stages of its closure. ERA used the Ranger Surface Water Model to predict peak and 10,000-year concentrations of CoPC entering Magela Creek from Pit 3 and from multiple sources on the mine site, including Pit 3 (called Composite sources hereafter). CoPCs concentrations at one site upstream of Pit 3 (MG001) and five sites downstream of Pit 3 (MG003, MG005, MG009, End of RPA and Mudginberri Billabong) were predicted for three groundwater loads (P10, P50, P90) entering from the closed mine site. Concentrations at the latter three sites would be strongly influenced by contributions from sources other than Pit 3 which enter upstream of MG009.

Predicted concentrations of 18 CoPC (aluminium (Al), ammonia (as total ammoniacal nitrate, TAN; NH_3-N), cadmium (Cd), chromium (Cr^{3+}), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), calcium (as a ratio to Mg; Mg:Ca), manganese (Mn), nickel (Ni), nitrate-N (NO_3-N), radium-226 (^{226}Ra), selenium (Se), sulfate (SO_4), uranium (U), vanadium (V), and zinc (Zn) in Magela Creek surface waters downstream of Pit 3 were compared to guideline values (GV) for the protection of the following community values:

- Drinking and recreational water
- Animal drinking water,
- Protection against acid sulfate soils (ASS) formation, and
- Aquatic species protection (chemical and radiological).

The risk of eutrophication is related to loads rather than concentrations of nutrients and is being assessed through a separate project.

Key Findings

CoPC concentrations were predicted to fall below cultural water use (i.e. drinking and recreational water quality), animal drinking water, and ASS formation GVs. On this basis, mine-derived CoPCs resulted in Very Low consequences and Class 1 risks.

Biodiversity risks were assessed by comparing the predicted water quality to site-specific/adjusted GVs and default GVs (DGV) in ANZG (2018). GVs for the protection of aquatic species were met for all parameters except Mn and Al. The GV for Al is exceeded naturally, and a comparison of Al median concentrations for the "No Mine" scenario against median concentrations for the other scenarios showed very small mine contributions of Al.

Species protection consequences were assessed for all predicted Mn concentrations. The consequences for the P50 peak and 10,000-year Mn concentrations were used to classify the risks at all sites downstream of Pit 3 (consequences at the MG001 upstream of Pit 3 were very low which provides a Class 1 risk). The resulting risk classifications for species protection is shown in Figure 0.1.

Location (Sites)	Value and CoPC assessed	Risk classes for P50 contaminant source sceanrios (based on worst case for any site at the location)			
		Composite sources PEAK, P50	Pit3 PEAK, P50	Composite sources 10,000 Yr, P50	Pit 3 10,000 Yr, P50
ON the RPA (MG001 / MG003 / MG005 / MG009)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	III	II
	Aquatic species protection (all other CoPC)	I	I	I	I
OFF the RPA (Mudginberri Billabong / EndRPA)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	IV	I
	Aquatic species protection (all other CoPC)	I	I	I	I

Figure 0.1 Biodiversity (species protection) risk classification for the P50 load scenarios at each site

Although not above the DGVs used in this assessment, increases in Cr and Ni concentrations appear to be mine related and reliance on DGVs for these CoPC may underestimate the risk to biodiversity. Nevertheless, any risk associated with Cr and Ni will be mitigated by management actions to reduce Mn associated risks. Consideration could be given to the need for site specific/adapted GVs for these two CoPC.

This assessment assumes that (i) CoPC concentrations predicted by the RSWM were accurate, and (ii) all Mn is present in a bioavailable form.

These conservative assumptions may overstate the risks associated with Mn.

ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered. Biogeochemical and microbial processes are now included in the conceptual model for risks via the surface water pathway. Assessing these is outside the scope of the APRA but studies that have addressed or will address these issues are discussed.

Whether the predicted concentrations of Mn in the water column will cause sediment Mn concentrations to increase beyond the natural variability is not assessed in this report. Local concentration factors and regional background datasets are available to assess this under a separate process if required.

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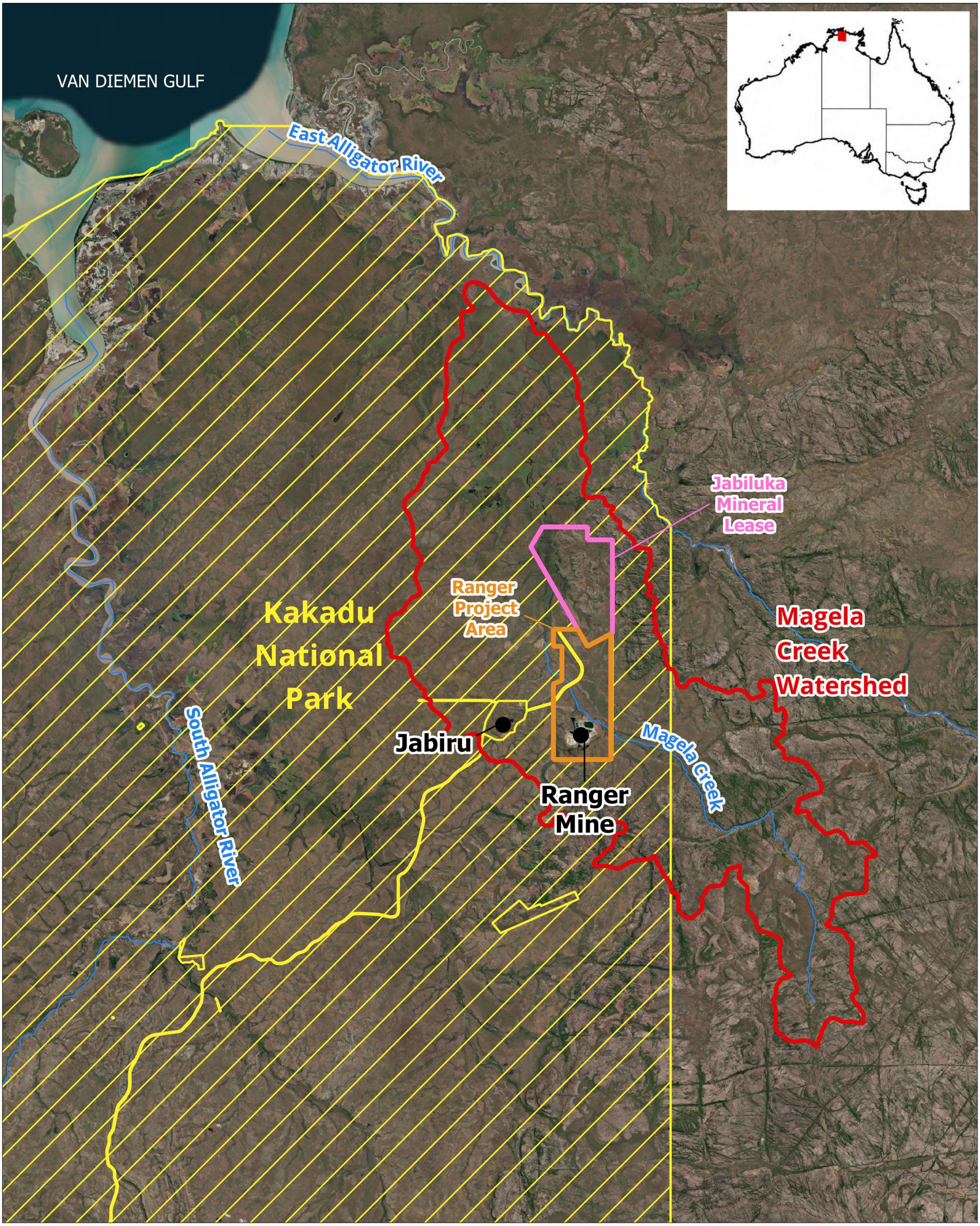
1 Introduction

1.1 Background

Energy Resources of Australia Ltd (ERA) is planning the closure of Ranger uranium mine in the Northern Territory of Australia (ERA, 2022). The Ranger Project Area (RPA; Figure 1.1) is surrounded by Kakadu National Park (KNP). KNP supports a listed World Heritage Area, Natural Heritage Place and Wetland of International Significance (KNP Ramsar site), all of which were matters of national environmental significance protected under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*.



Title:

Location of the Ranger Mine and Project Area

Figure: 1-1

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The release of contaminants from mineralised/contaminated materials (e.g. waste rock, tailings, water, soils) in mine areas into receiving environments is a potential environmental issue for operational and closure stages if inappropriately managed.

Waters from the closed mine must support protection of the people, ecosystem (biodiversity and ecological processes), and the values supported by the KNP. Furthermore, any impacts on the RPA are to be as low as reasonably achievable (ALARA).

The following tools have been developed to determine if these goals were met:

- water quality criteria for contaminants of potential concern (CoPC) for the protection of the biodiversity and human use values off the RPA (ERA 2020, Section 8.3.2),
- a process that involves a risk assessment to inform the development of criteria to ensure impacts are ALARA on the RPA (ERA 2020, Appendix 6.3),
- solute transport models for ground and surface water; the Ranger surface water model (RSWM) predicts the concentrations of the CoPC in the surface water on and adjacent to the RPA after closure,
- an Aquatic Pathways Risk Assessment (APRA) tool to assess the risks to aquatic receptors (ecosystems and people) posed by the post closure water quality predicted by the RSWM,
- an ecosystem Vulnerability Assessment Framework (VAF) to understand the vulnerability of ecosystem components exposed to CoPC concentrations greater than GVs, and
- Best Practice Technology (BPT) assessment criteria (Iles, 2020) that consider the feasibility and reasonableness of available design and impact mitigation technologies to ensure impacts within the RPA are as low as reasonably achievable.

The application of the APPRA tool is part of implementing the Water Quality Management Framework (ANZG 2018) (WQMF) and processes being used by ERA to inform closure plans that support impacts that are ALARA and development of water quality closure criteria for on the RPA.

1.2 The Issue

The first application of the APPRA tool, described in Iles and Rissik (2021), was based on preliminary surface water model predictions for the closure strategy reported in the 2020 mine closure plan, and results of sediment monitoring and field effect studies conducted on the RPA. Iles (2023) detailed the conceptual underpinning and methodology behind the APPRA tool for use in future assessments and incorporated feedback received from stakeholders on the 2021 report.

ERA is applying for regulatory approval to close out Pit 3 which contains buried tailings. Following the application of the APPRA tool to the base case for closure (Iles and Rissik, 2021), ERA reviewed its closure plans for Pit 3 and sought additional information to allow it to reassess the risks associated with the pit closure, including:

- updated contaminant source and transport studies which will culminate in updated predictions of surface water concentrations from the RSWM, and
- application of the APRA tool to the RSWM outputs; the subject of this report.

ERA now seeks to have the APRA tool applied using these recent water quality modelling results, which is the subject of this report.

The methodology for applying the APRA tool to the outputs of the RSWM is described in Iles (2023). Stakeholder feedback on Iles (2023) has been received. ERA has requested that the feedback, and necessary alterations to the APRA tool be considered when applying the tool to the Pit3 RSWM results.

1.3 Scope and Objectives

The key aims of this project were to:

- classify potential risk to aquatic receptors (ecosystems and people) associated with surface water concentrations of CoPC caused by contamination from Pit 3
- allow ERA to identify and understand potential risks to the community values for aquatic receptors on and off the Ranger Project Area (RPA), and
- identify locations where the VAF needs to be applied to provide a greater understanding of ecosystems response to CoPC concentrations posing a medium or higher risk to biodiversity.

The specific objectives of this report were to:

- describe the application of the APRA tool to the RSWM results for Pit 3
- document the consequence and risk outcomes of the assessment, and
- document the locations where the VAF is to be applied.

2 Approach

2.1 The APRA Tool

The methodology for applying the APRA tool to the outputs of the RSWM is described in Iles (2023). The same approach was used for this assessment with the following modifications:

- The scope only considered water quality issues. Risks from sediment-associated contaminants, eutrophication and effects of acid sulfate soils (ASS) were excluded from the present study but are considered by ERA in other assessments.
- The conceptual model has been updated to:
  - reflect the above scope of this assessment, and now includes detrital pools,
  - include detrital pools and microbial assemblages driving intermediary microbially mediated processes (as requested by Wong and Bolton, 2023). These processes were not assessed in the APRA tool but their importance and ways the issue is being considered are discussed (see Section 5.2), and
  - show that eutrophication is being addressed through a separate assessment.

2.2 Conceptual underpinning

Threats from CoPC were identified and assessed based on a conceptual understanding of sources, pathways, receptors and processes, and aligning these with the environmental and community values of the surrounding landscape. The focus of the integrated conceptual model for the APRA tool used by Iles and Rissik (2021) and described in Iles (2023) was the influence of the contaminant sources on environmental and community values.

Figure 2.1 shows the integrated source-pathway-process-receptor conceptual model underpinning this risk assessment. This is the conceptual model of Iles (2023) with changes (shown in red text) to include the detrital pool and microbial assemblages requested by ARRTC.

- Blue boxes show the contaminant sources and transport pathways included in the solute transport models used to predict future water quality.
- Orange boxes show sediment and soil contaminant sources and fate. The box outline is dashed indicating these contaminant sources were not considered in this risk assessment.
- Grey box shows the end points being assessed. The endpoints are aligned with the values derived from the Ranger Environmental Requirements.
- Solid green boxes show the assessment method used (i.e. exposure concentration versus GV).
- Boxes outlined in dashes show issues that were excluded from this risk assessment; they were being assessed by other assessments).

Limitations associated with excluding processes associated with detrital pools and microbial assemblages (the new additions to the conceptual model) are discussed in Section 5.2. The rationale for other exclusions is provided in Iles (2023).

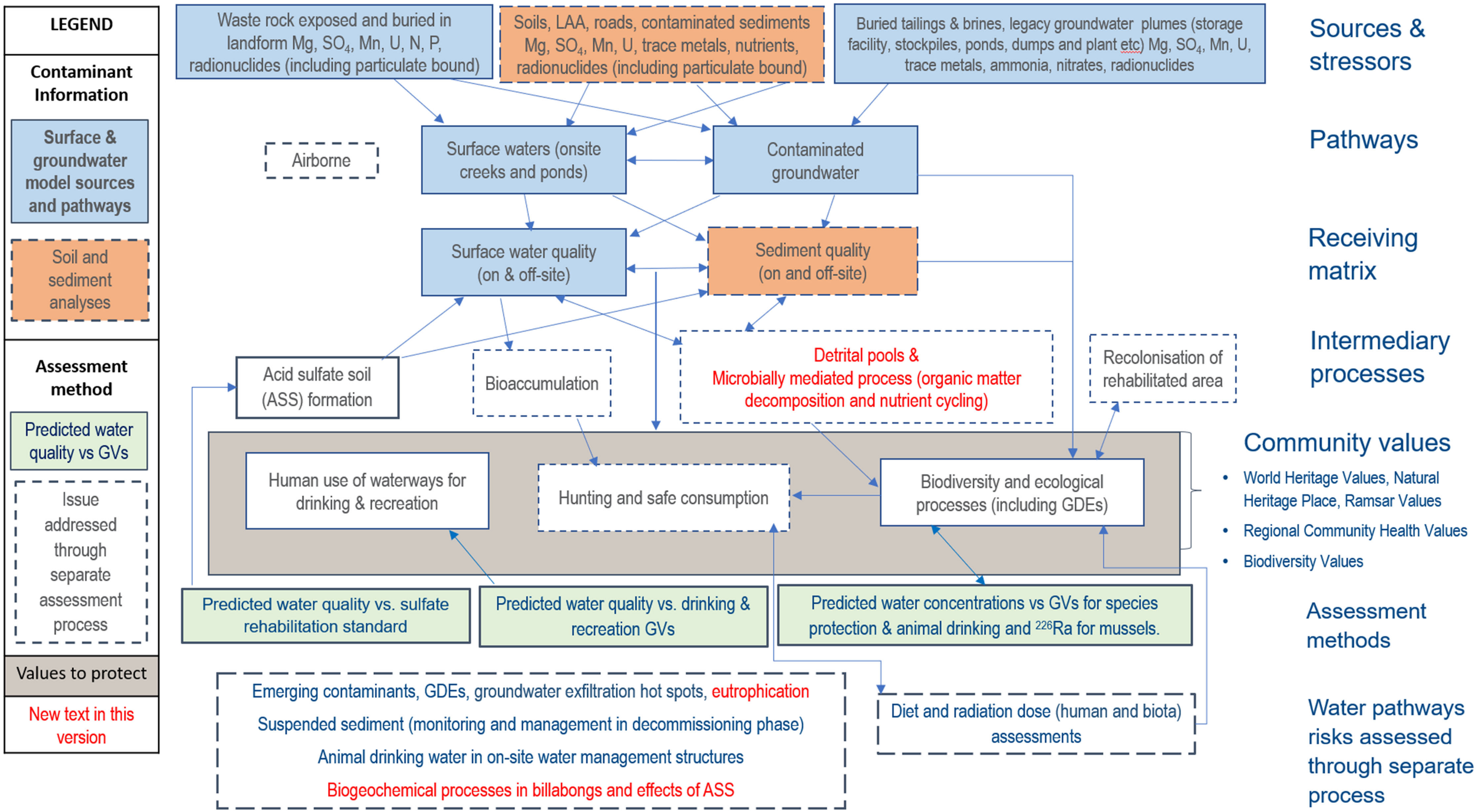

Figure 2.1 Conceptual model including source, pathway, receptors and processes assessed, assessment approaches used and issue included or excluded

2.3 Exposure scenarios

ERA requested that the RSWM results for the following scenarios be assessed at five sites in Magela Creek and at Mudginberri Billabong.

- peak concentrations and 10,000-year concentrations for 18 CoPC
  - aluminium (Al), ammonia (as total ammoniacal nitrogen, TAN; NH_3-N), cadmium (Cd), chromium (Cr^{3+}), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), calcium (as a ratio to Mg; Mg:Ca), manganese (Mn), nickel (Ni), nitrate-N (NO_3-N), radium-226 (^{226}Ra), selenium (Se), sulfate (SO_4), uranium (U), vanadium (V), and zinc (Zn),
- composite source terms (i.e. contaminants from all source terms across the site that were included in the RSWM) and Pit 3 only source terms (contaminants from Pit 3 only), and
- three different groundwater load scenarios (P10, P50 and P90)

The sites are described in 0 and shown in Figure 2.2.

Figure 2.2 Location of Coonjimba Billabong (CB) and assessment sites (red boxes) relative to Pit 3

Table 2.1 Reporting site details

Site ID	On or off the RPA	Description
GS01 or MG001	ON the RPA	Magela Creek upstream of pit 3, downstream of Corridor Creek/Georgetown Billabong.
409 or MG003	ON the RPA	Magela Creek reporting node downstream of Pit 3, upstream of MG005
421 or MG005	ON the RPA	Magela Creek reporting node downstream of Pit 3 and MG003, upstream of Coonjimba Billabong
GS09 or MG009	ON the RPA	Magela Creek downstream of Coonjimba Billabong, upstream of Gulungul Billabong. Current compliance point
End RPA	OFF the RPA	Downstream of all above mentioned sites plus Gulungul Billabong.
Mudginberri Billabong or MB	OFF the RPA	Downstream of End RPA. Upstream of Magela Creek floodplain.

2.4 Assessment criteria

The GVs described in Iles (2023) were used as assessment criteria to assess the risks to human use of water for drinking and recreation, animals drinking water, biodiversity and potential acid sulfate soil formation. These GVs, shown in Table 2.2 were from the following sources.

- Site-specific, or site-adjusted ecotoxicity based guideline values developed by SSB for different species protection levels (SPL) for Cu, Mg, Mn, NH_3-N, U and Zn (Supervising Scientist 2021a – d respectively).
- National default guideline values (DGV) for different SPL for Al, Cd, Cr^{3+}, Ni, Pb, Se, V (ANZG 2018) and NO_3-N (ANZG 2023).
- National drinking guideline values for Al, Cu, Cd, Cr, Fe, Mn, Ni, NO_3, Pb, Se, SO_4, U and Zn from NHMRC, NRMMC (2011; v3.8 updated September 2022).
- National recreational guideline values for the same CoPCs as drinking water, where the health drinking water GV is multiplied by 10 as recommended by NHRMC (2008) and for sulfate from ANZEEC and ARMCANZ (2000).
- Animal (wildlife and/or livestock) drinking water guideline values for Al, Cu, Pb, Se, NO_3-N, and Zn (ANZECC and ARMCANZ 2000), U (long-term) from the British Columbian Ministry of Environment (MECC 2019) and U (acute) from Hink *et al.* (2010).
- The SSB rehabilitation standard of 10 mg/L sulfate in water (Supervising Scientist 2001e) to protect against ASS formation.
- The site-specific ^{226}Ra limit of 14 mBq/L (above background) for aquatic biota (Doering *et al.* 2019).

The most stringent GV for each CoPC is highlighted green. The 99% species protection level GV (99% SPL GV) were more stringent than the GVs for the other categories. For CoPC that do not have species protection GVs the most stringent GVs were for protection against ASS formation (sulfate) and human drinking water (Fe).

Eutrophication risks and those associated with exposure of ASS are being assessed under separate processes.

Table 2.2 Guideline values used as assessment criteria; most stringent GV highlighted green

COPC	Species protection level (%) (SPL)				Drinking water (total)[a]	Recreational water (total)[b]	Australian Livestock drinking water (long-term; total)[c]	International Wildlife/ Livestock drinking water (acute)[d]	Notes
	99	95	90	80					
Aluminium (µg/L) for pH < 6 waters	0.8				2000 aesthetic				ANZG (2018) default GV for unspecified level of species protection. Aesthetic drinking GV based on post-flocculation problems (ANZG, 2022)
Ammonia-N (NH_3-N) (mg/L)	0.4	0.6	0.79	6.81	-	-	-	-	Site specific SPL GV for pH 6.0, T 20°C. pH and temperature dependant (Supervising Scientist, 2021c). Could be more toxic in billabongs with higher pH and temperature.
Cadmium (µg/L)	0.06	0.2	0.4	0.8	2	20	10	-	ANZG (2018) default SPL GVs
Chromium 3+ (µg/L)	3.3				-	-	-	-	ANZG (2018) default GV for unspecified level of species protection. Cr^{3+} is relevant speciation for surface waters in the Ranger study area.
Copper (µg/L)	0.5	0.9	1.1	1.5	2000	2000	400 - 5000	300 (total)	Site specific SPL GV for Magela Creek conditions (Supervising Scientist, 2021d).. Potential to adjust for modifying factors in billabongs.
Iron	-				300 taste		-	-	
Lead (µg/L)	1.0	3.4	5.6	9.4	10	100	100	100	ANZG (2018) default SPL GVs
Magnesium (mg/L)	2.9	5.7	9.4	19	-	-	-	-	Site specific SPL GV applicable when Mg:Ca ≤9:1 (Supervising Scientist, 2021b).
Manganese (µg/L)	73	153	240	443	500	5000	-	-	Site specific SPL GV (Supervising Scientist, 2021a). Potential to adjust for modifying factors. Methods for GV adjustment not yet validated for Australian waters. Aesthetic drinking GV based on taste and staining
Nickel (µg/L)	8	11	13	17	20	200	1000	-	ANZG (2018) default SPL GVs
Nitrate (NO_3-N) (mg/L)	0.64	1.1	1.5	2.3	11.3	113	-	100	Drinking water GV protects bottle-fed infants under 3 months. Adults and children > 3 months can safely drink water with up to 100 mg/L nitrate. Nitrite rapidly oxidised to nitrate so not included separately.
Radium-226 (mBq/L above background)	14				-	-	-	-	Aquatic biota protection (Doering et al. 2019).
Selenium (µg/L)	5	11	18	34	10	100	20	5 / 30	ANZG (2018) default SPL GVs. The MECC (2019) guidelines use their aquatic 99% SPL GV to protect wildlife against accumulation (would be 5 in Australia using this logic). Canadian livestock value is 30 so an order of magnitude higher than their wildlife drinking GV.
Sulfate (SO_4) (mg/L)	-				500	400[c]	1000 - 2000	1000	10 mg/L seasonal average to avoid ASS formation (compare to the 50% exceedance probability concentration) (Supervising Scientist, 2021e).
Uranium (µg/L)	2.8	8.3	13	23	20	200	200	7000	Site-specific SPL GV can be adjusted for DOC conditions (Supervising Scientist, 2021a). Wildlife drinking water GV is acute value for mammals; birds an order of magnitude higher.
Vanadium (µg/L)	6				-	-	-	-	ANZG (2018) default GV for unspecified level of species protection.
Zinc (µg/L)	1.5	4.0	6.8	12.6	3000 taste		20000	2000 (chronic)	Site-adapted SPL GV for Magela Ck conditions (Supervising Scientist, 2021d). Potential to adjust for higher hardness in billabongs.

a) NHMRC, NRMMC, (2011; v3.8) health based GV or aesthetic GV if no health GV available.
b) Based on 10x drinking water GV for health as recommended by NHRMC (2008) and the value for sulfate from ANZEEC and ARMCANZ (2000).
c) ANZEEC and ARMCANZ (2000), Table 4.3.2 Livestock (long-term), update expected in 2020, not yet available.
d) Uranium GV from Hink *et al.* (2010); all other GVs from MECC (2019) except selenium, see notes column.

2.5 Consequences

The consequence descriptors used in this assessment were the same as those described in Iles (2023). A sliding scale approach that is stricter for sites off the RPA is used. The approach is illustrated in Table 2.3 using Mn site specific guideline values for different species protection levels (SPL).

As biodiversity consequences are related to exposure intensity, duration and/or repetition of exposure, the rating of consequences takes these factors into consideration. For species protection, meeting the 99% SPL GV results in very low (nil/negligible) consequences. Exposure to concentrations exceeding any GV for 1% or less of the flow period, or an exceedance of the 95% SPL GV only for less than 10% of the flow period, is characterised as having only a low consequence due to the unlikely adverse impacts associated with such short/infrequent periods of exposure above GV levels. Higher likelihoods of exposure above any of the GVs results in medium to very high species protection consequences depending on the exposure likelihood, the species protection level exceeded, and whether the location is on or off the RPA (Table 2.3).

Table 2.3 Example of a sliding scale consequence descriptor for species protection level.

<table>
<tr><th colspan="8">Predicted MANGANESE in water vs. SSGV; 73, 153, 240, 443 µg/L for 99, 95, 90, 80 % species protection level</th></tr>
<tr><th></th><th colspan="2">Exposure likelihood</th><th colspan="5">Consequence to species</th></tr>
<tr><th rowspan="6">Exceedance Probability predicted by RSWM</th><th>OFFSITE</th><th>ONSITE</th><th>Very Low</th><th>Low</th><th>Medium</th><th>High</th><th>Very High</th></tr>
<tr><td>≤1%</td><td>≤1%</td><td rowspan="5">No GV exceedance

(Mn concentration 0 - 73)</td><td>1% exceedance any GV</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>>1-10%</td><td>74 -153</td><td>154 - 240</td><td>241 - 443</td><td>>443</td></tr>
<tr><td>>1-10%</td><td>>10-25%</td><td rowspan="3">NA</td><td>74 -153</td><td>154 - 240</td><td>>240</td></tr>
<tr><td>>10-25%</td><td>>25-50</td><td rowspan="2">NA</td><td>74 -153</td><td>>153</td></tr>
<tr><td>>25%</td><td>>50%</td><td>NA</td><td>>73</td></tr>
</table>

Table 2.4 shows descriptors for classifying the consequences for human use of water by comparing predicted Mn concentrations to the drinking water GV for health. Recreational water quality is assessed with the same approach as drinking water quality. (Note drinking and recreational water are contributors to human health; a comprehensive human health assessment is reported elsewhere. Aesthetic aspects of water quality are also assessed and reported elsewhere.)

Table 2.4 Example of a sliding scale consequence descriptor for human use of water.

<table>
<tr><th colspan="6">Predicted MANGANESE in water vs. drinking water HEALTH GV (500 µg Mn/L)</th></tr>
<tr><th rowspan="2"></th><th colspan="5">Consequence for human use of water</th></tr>
<tr><th>Very Low</th><th>Low</th><th>Moderate</th><th>High</th><th>Very High</th></tr>
<tr><td>Exceedance Probability predicted by RSWM</td><td>1%</td><td>10% onsite</td><td>25% onsite; 10% offsite</td><td>50% onsite; 25% offsite</td><td>>50% onsite; >25% offsite</td></tr>
</table>

Consequences (and risks) for Community Trust, Compliance and Reputation were not scored in this report.

2.6 Risk classification

Risks were classified using the ERA risk spreadsheet and likelihood/probability and scoring matrices (Table 2.5and Table 2.6).

Table 2.5 ERA probability matrix

LIKELIHOOD	Rare	Unlikey	Probable	Likely	Almost certain
Frequency (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 or probability distribution)	<5%	5-20%	21-50%	51-75%	>75%

Table 2.6 ERA risk classification matrix

	Consequence Severity				
Likelihood	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

Iles (2023) tested the sensitivity of the APRA tool to RSWM predicted concentrations for different groundwater load scenarios using a likelihood that aligned with the different load probabilities and found:

- the risk classification was very sensitive to changes in likelihood, with risks being understated or overestimated when using a likelihood of 10% (P90 loads) and overstated when using a likelihood of 90% (P10 loads), and
- the current combination of consequence descriptors and risk classification was most suited to assessing concentrations associated with P50 groundwater loads.

The risk classification for this assessment therefore focussed on consequences associated with RSWM predicted concentrations for both the P50 and P90 groundwater loads but used a probable likelihood of occurrence for both scenarios.

See Iles (2023) for further information on consequence, probability and risk used in the APRA tool.

3 Consequences of CoPC Concentrations

3.1 Screening for very low and low consequences

If predicted water quality meets the most stringent GV or only exceeds it with a 1% exposure likelihood the consequences were very low or low (see Table 2.3 and Table 2.4). If the most stringent GV was exceeded with a higher likelihood, then the full consequence matrix was applied.

Table 3.1 to Table 3.5 compares predicted CoPC concentrations to the most stringent GV for each CoPC (Table 2.2) at MG003, MG005, MG009, End of RPA and Mudginberri Billabong. Results are presented for multiple load scenarios (P10 loads at select sites, P50 and P90 loads at all sites) and multiple contaminant sources (No Mine, Composite sources, and Pit 3 only contaminant source). Any GV exceedances are highlighted red. If the No Mine scenario concentrations exceed the GV the results are highlighted yellow.

The only CoPC predicted to exceed GVs due to mining contamination was Mn, which exceeded the 99% SPL GV at all sites. The full consequence matrix needs was applied to Mn results (Section 3.2).

All predicted Al concentrations, including for the No Mine scenario, exceeded the SPL GV. Thus the species protection GVs for Al were not suitable and consequences could not be scored using the approach agreed for other CoPCs. ANZG (2018) suggests comparing the median concentration from a reference site (in this case the No Mine scenario) to the 80th percentile concentration at the exposed site, or to the median at the exposed site for high value locations. The reference condition approach for Al was also recommended by the Supervising Scientist (2018). The median Al concentration and percentage increase for each scenario compared to the No Mine scenario are shown in the screening tables (Table 3.1 to Table 3.5). The change in median Al concentrations were greatest the further from the mine the site was. For the P50 scenarios the Al increases were negative at the two sites closest to Pit 3 (MG003 and MG005), up to 3% at MG009, up to 5% at End of RPA and up to 9% at Mudginberri Billabong. Concentrations of Al and increases in the medians were higher for the P90 scenarios but followed the same pattern of increasing with distance from the mine. Therefore consequences associated with mine derived Al were considered to fall into the very low class. The other Al GV is for drinking water (aesthetics). Predicted concentrations were two orders of magnitude lower than the drinking water GV.

There was a 1% exceedance likelihood of the most stringent Mg GV for the P90 composite scenario at MG009; this results in a low consequence for species protection and very low consequences for all other endpoints which have higher GVs (drinking, recreation, wildlife drinking water) from Mg exposure at that site. All other results, including those for sites closer to Pit 3 were below the most stringent Mg GV and so consequences from Mg exposure for all endpoints were classified as very low at those sites.

No other GVs were exceeded so consequences for all other endpoints and CoPCs were classed as very low. Increased concentrations for Cr, V and Ni are shown in Table 3.1 to Table 3.5 and the limitations of the DGV for these CoPC and confidence in the consequence and risk classification are discussed in Section 5.2.

Consequences were very low for all CoPC for drinking water, recreational water, animal drinking water and ASS formation.

Summary tables for predicted concentrations at 10,000 years are shown in Annex A. Manganese exceeds GVs at 10,000 years for the P50 and P90 scenarios at sites on the RPA and the lease boundary. The consequences for both peak and 10,000-year concentrations are shown in Section 3.2.

Table 3.1 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for MG003 (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at MG003																								
Exccedance probability	1%	1690	640	200	174	0.8	74	0.3	0.1	0.01	130	0.6	0.13	0.77	0.32	0.0	106	0.1	4760	3				
	10%	1590	640	3.0	152	0.7	65	0.3	0.1	0.01	120	0.5	0.13	0.67	0.29	0.0	93	0.1	4000	3				
	25%	1570	630	3.0	149	0.7	64	0.3	0.1	0.01	110	0.5	0.13	0.49	0.29	0.0	70	0.1	3830	2				
	50%	840	550	3.0	61	0.3	27	0.2	0.0	0.01	90	0.5	0.11	0.21	0.19	0.0	34	0.1	1690	2	10	-11	31	-11
	75%	630	310	3.0	16	0.0	10	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	-0.1	8.5	0.1	549	2				
	90%	330	200	3.0	12	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	281	1				
	99%	230	160	3.0	7	0.017	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	168	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at MG003																								
Exccedance probability	1%	1350	590	200	144	0.3	55	0.3	0.1	0.01	120	0.5	0.13	0.77	0.30	0.0	106	0.1	3380	3				
	10%	1310	590	3.0	128	0.2	49	0.3	0.1	0.01	110	0.5	0.12	0.67	0.28	0.0	93	0.1	2740	2				
	25%	1290	590	3.0	122	0.2	48	0.3	0.1	0.01	100	0.5	0.12	0.49	0.27	0.0	70	0.1	2530	2				
	50%	790	540	3.0	49	0.1	21	0.2	0.0	0.01	80	0.4	0.11	0.21	0.18	0.0	34	0.1	1210	2	8	-13	29	-11
	75%	550	290	3.0	10	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	8.3	0.1	380	1				
	90%	310	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at MG003																								
Exccedance probability	1%	2110	690	200	265	1.1	108	0.4	0.2	0.01	140	0.7	0.16	0.78	0.53	0.1	107	0.1	6830	3				
	10%	1960	680	3.1	228	1.0	94	0.3	0.2	0.01	120	0.7	0.15	0.68	0.47	0.0	94	0.1	5790	3				
	25%	1930	670	3.1	224	0.9	92	0.3	0.2	0.01	110	0.7	0.15	0.50	0.46	0.1	71	0.1	5620	3				
	50%	900	550	3.1	90	0.4	38	0.3	0.1	0.01	90	0.5	0.120	0.23	0.26	0.0	36	0.1	2350	2	17	-4	49	-5
	75%	730	320	3.0	24	0.0	13	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	0.0	12	0.1	667	2				
	90%	350	210	3.0	16	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.1	0.1	354	2				
	99%	230	170	3.0	8	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	206	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG003																								
Exccedance probability	1%	1590	600	200	203	0.5	77	0.4	0.2	0.01	120	0.6	0.15	0.78	0.44	0.0	107	0.1	4520	3				
	10%	1520	600	3.0	180	0.4	68	0.3	0.2	0.01	110	0.6	0.14	0.68	0.40	0.0	94	0.1	3800	3				
	25%	1490	600	3.0	172	0.4	66	0.3	0.2	0.01	100	0.6	0.14	0.50	0.39	0.0	71	0.1	3590	2				
	50%	790	540	3.0	67	0.2	27	0.3	0.1	0.01	80	0.5	0.11	0.22	0.23	0.0	35	0.1	1580	2	12	-8	42	-7
	75%	610	300	3.0	11	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.11	0.13	-0.1	11	0.1	445	1				
	90%	320	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				

Table 3.1 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at MG003																								
Exceedance probability	1%	2470	710	200	334	1.7	138	0.4	0.3	0.01	150	0.9	0.19	0.80	0.71	0.2	111	0.1	8610	4				
	10%	2280	700	3.1	292	1.5	121	0.4	0.3	0.01	120	0.8	0.18	0.70	0.64	0.1	97	0.1	7400	3				
	25%	2240	690	3.1	285	1.4	118	0.3	0.3	0.01	110	0.8	0.18	0.52	0.62	0.1	74	0.1	7150	3				
	50%	960	550	3.1	111	0.5	48	0.3	0.1	0.01	90	0.5	0.13	0.24	0.31	0.1	39	0.1	2890	3	23	2	59	3
	75%	770	330	3.0	22	0.0	13	0.2	0.0	0.01	80	0.4	0.11	0.14	0.15	0.1	18	0.1	671	2				
	90%	370	210	3.0	15	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.0	0.1	319	2				
	99%	230	170	3.0	8	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	211	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG003																								
Exceedance probability	1%	1900	620	200	289	1.0	108	0.4	0.3	0.01	120	0.8	0.18	0.79	0.65	0.0	110	0.1	6170	3				
	10%	1800	620	3.1	256	0.9	96	0.4	0.3	0.01	110	0.7	0.17	0.69	0.59	0.0	97	0.1	5320	3				
	25%	1760	620	3.1	245	0.8	92	0.3	0.3	0.01	100	0.7	0.17	0.51	0.57	0.0	74	0.1	5020	3				
	50%	800	540	3.0	93	0.3	37	0.3	0.1	0.01	80	0.5	0.12	0.23	0.29	0.0	38	0.1	2090	2	19	-1	55	2
	75%	670	300	3.0	12	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.13	0.13	0.0	17	0.1	518	1				
	90%	340	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG003																								
Exceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.100	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Legend
Above GV
No mine scenario above GV
Below GV

Table 3.2 Predicted peak CoPC concentrations (P50, P90 load scenarios) compared to the most stringent GVs for MG005

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P50 scenario at MG005																								
Exceedance probability	1%	2100	690	200	263	1.1	107	0.4	0.2	0.01	130	0.7	0.16	0.78	0.52	0.1	107	0.1	6790	3				
	10%	1960	680	3.1	227	1.0	93	0.3	0.2	0.01	120	0.7	0.15	0.68	0.47	0.0	94	0.1	5750	3				
	25%	1930	670	3.1	223	0.9	91	0.3	0.2	0.01	110	0.7	0.15	0.51	0.46	0.1	71	0.1	5590	3				
	50%	900	550	3.1	89	0.4	38	0.3	0.1	0.01	90	0.5	0.12	0.23	0.26	0.0	36	0.1	2340	2	17	-4	49	-5
	75%	720	320	3.0	24	0.0	13	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	0.0	12	0.1	665	2				
	90%	350	210	3.0	16	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.1	0.1	354	2				
	99%	230	160	3.0	8	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	199	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG005																								
Exceedance probability	1%	1580	600	200	201	0.5	76	0.4	0.2	0.01	120	0.6	0.15	0.78	0.43	0.0	107	0.1	4500	3				
	10%	1510	600	3.0	179	0.4	68	0.3	0.2	0.01	110	0.6	0.14	0.68	0.40	0.0	94	0.1	3790	3				
	25%	1490	600	3.0	171	0.4	66	0.3	0.2	0.01	100	0.6	0.14	0.50	0.39	0.0	71	0.1	3570	2				
	50%	790	540	3.0	66	0.2	27	0.3	0.1	0.01	80	0.5	0.11	0.22	0.22	0.0	35	0.1	1570	2	12	-8	42	-7
	75%	610	300	3.0	11	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.11	0.13	-0.1	11	0.1	444	1				
	90%	320	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted peak concentrations for COMPOSITE_P90 scenario at MG005																								
Exceedance probability	1%	2450	710	200	333	1.7	137	0.4	0.3	0.01	150	0.9	0.19	0.80	0.71	0.2	111	0.1	8550	4				
	10%	2270	700	3.1	290	1.5	120	0.4	0.3	0.01	120	0.8	0.18	0.70	0.63	0.1	97	0.1	7360	3				
	25%	2230	690	3.1	283	1.4	118	0.3	0.3	0.01	110	0.8	0.18	0.52	0.62	0.1	74	0.1	7110	3				
	50%	960	550	3.1	110	0.5	47	0.3	0.1	0.01	90	0.5	0.13	0.24	0.31	0.1	39	0.1	2870	3	23	2	58	3
	75%	770	330	3.0	22	0.0	13	0.2	0.0	0.01	80	0.4	0.11	0.14	0.15	0.1	18	0.1	669	2				
	90%	370	210	3.0	15	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.0	0.1	319	2				
	99%	230	160	3.0	8	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	208	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG005																								
Exceedance probability	1%	1890	620	200	288	1.0	107	0.4	0.3	0.01	120	0.8	0.18	0.79	0.64	0.0	110	0.1	6140	3				
	10%	1790	620	3.1	254	0.9	95	0.4	0.3	0.01	110	0.7	0.17	0.69	0.58	0.0	97	0.1	5290	3				
	25%	1760	620	3.1	244	0.8	92	0.3	0.3	0.01	100	0.7	0.17	0.51	0.57	0.0	74	0.1	4990	3				
	50%	800	540	3.0	93	0.3	37	0.3	0.1	0.01	80	0.5	0.12	0.23	0.29	0.0	38	0.1	2080	2	19	-1	55	2
	75%	670	300	3.0	12	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.13	0.13	0.0	17	0.1	516	1				
	90%	330	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG005																								
Exceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Legend
Above GV
No mine scenario above GV
Below GV

Table 3.3 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for MG009 (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at MG009																								
Excedance probability	1%	2060	700	200	185	0.8	73	0.3	0.1	0.01	140	0.6	0.14	0.77	0.33	0.6	106	0.1	6130	3				
	10%	1890	680	5.6	163	0.7	64	0.3	0.1	0.01	120	0.6	0.13	0.68	0.30	0.2	94	0.1	5130	3				
	25%	1760	660	5.0	157	0.7	63	0.3	0.1	0.01	110	0.6	0.13	0.51	0.30	0.3	72	0.1	4720	3				
	50%	1010	550	4.1	78	0.3	32	0.2	0.0	0.01	90	0.5	0.11	0.24	0.21	0.3	38	0.1	2580	2	12	3	38	1
	75%	650	290	3.3	18	0.1	10	0.2	0.0	0.01	80	0.4	0.10	0.10	0.14	0.3	8.7	0.1	806	2				
	90%	350	200	3.0	12	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	288	1				
	99%	230	160	3.0	7	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	201	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at MG009																								
Excedance probability	1%	1330	590	200	141	0.3	54	0.336	0.1	0.01	120	0.5	0.13	0.77	0.30	0.0	106	0.1	3320	2				
	10%	1290	590	3.2	125	0.2	48	0.3	0.1	0.01	110	0.5	0.12	0.67	0.28	0.0	93	0.1	2720	2				
	25%	1280	590	3.0	119	0.2	47	0.3	0.1	0.01	100	0.5	0.12	0.50	0.27	0.0	71	0.1	2480	2				
	50%	790	540	3.0	58	0.1	24	0.2	0.0	0.01	80	0.4	0.11	0.24	0.19	0.0	38	0.1	1380	2	9	1	33	1
	75%	490	270	3.0	13	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.09	0.14	-0.1	8.3	0.1	546	1				
	90%	300	190	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.0997	49.9	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at MG009																								
Excedance probability	1%	2690	780	200	304	1.1	109	0.4	0.3	0.01	180	0.8	0.17	0.78	0.61	1.7	107	0.1	9040	4				
	10%	2420	750	8.2	268	1.0	96	0.3	0.2	0.01	140	0.8	0.16	0.69	0.55	0.9	95	0.1	7600	3				
	25%	2240	720	7.1	249	1.0	93	0.3	0.2	0.01	130	0.7	0.16	0.52	0.52	0.8	73	0.1	6940	3				
	50%	1250	560	5.1	127	0.5	46	0.3	0.1	0.01	110	0.6	0.13	0.26	0.32	0.6	39	0.1	3730	3	23	9	60	5
	75%	770	310	3.5	26	0.1	13	0.2	0.0	0.01	90	0.4	0.11	0.13	0.16	0.5	12	0.1	906	2				
	90%	390	210	3.0	17	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.15	-0.1	6.1	0.1	366	2				
	99%	230	170	3.0	9	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	253	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG009																								
Excedance probability	1%	1550	600	200	198	0.5	75	0.4	0.2	0.01	120	0.6	0.15	0.78	0.43	0.0	107	0.1	4440	3				
	10%	1500	600	3.25	176	0.4	67	0.3	0.2	0.01	110	0.6	0.14	0.68	0.39	0.0	95	0.1	3750	3				
	25%	1470	600	3.03	168	0.4	64	0.3	0.2	0.01	100	0.6	0.14	0.51	0.38	0.0	72	0.1	3510	2				
	50%	800	540	3.02	80	0.2	32	0.3	0.1	0.01	80	0.5	0.12	0.25	0.24	0.0	39	0.1	1830	2	15	4	47	3
	75%	540	270	3	14	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.11	0.14	0.0	11	0.1	622	1				
	90%	310	200	3	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	50	1				

Table 3.3 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at MG009																								
Excedance probability	1%	3000	820	200	403	1.7	140	0.4	0.6	0.01	200	1.1	0.21	0.81	0.88	2.9	112	0.1	11500	4				
	10%	2720	780	12.9	352	1.5	123	0.4	0.5	0.01	160	1.0	0.20	0.71	0.78	1.7	98	0.1	9690	4				
	25%	2530	750	10.8	326	1.5	120	0.3	0.4	0.01	140	0.9	0.19	0.53	0.72	1.4	76	0.1	8850	3				
	50%	1380	560	6.83	165	0.7	58	0.3	0.2	0.01	120	0.7	0.15	0.27	0.43	0.9	42	0.1	4670	3	31	14	70	11
	75%	790	320	3.86	28	0.1	13	0.3	0.0	0.01	100	0.4	0.11	0.16	0.17	0.6	18	0.1	996	2				
	90%	400	210	3.01	15	0.0	9	0.2	0.0	0.01	60	0.4	0.10	0.07	0.14	0.0	6.0	0.1	325	2				
	99%	230	170	3	10	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	230	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG009																								
Excedance probability	1%	1860	620	200	283	1.0	105	0.4	0.3	0.01	120	0.8	0.18	0.79	0.63	0.0	110	0.1	6030	3				
	10%	1770	620	3.27	250	0.8	94	0.4	0.3	0.01	110	0.7	0.17	0.70	0.58	0.0	97	0.1	5210	3				
	25%	1740	610	3.07	240	0.8	90	0.3	0.3	0.01	100	0.7	0.16	0.52	0.56	0.0	75	0.1	4920	3				
	50%	920	540	3.05	112	0.4	44	0.3	0.1	0.01	80	0.5	0.13	0.26	0.32	0.0	41	0.1	2460	2	23	9	60	9
	75%	610	280	3	16	0.1	8	0.3	0.0	0.01	60	0.4	0.10	0.14	0.15	0.0	17	0.1	700	2				
	90%	320	200	3	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG009																								
Excedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6.2	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6.0	0.1	50	1				

Legend
- Above GV
- No mine scenario above GV
- Below GV

Table 3.4 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for End of RPA (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at End of RPA																								
Exccedance probability	1%	1940	690	197	165	0.7	64	0.3	0.1	0.01	130	0.6	0.13	0.77	0.30	0.4	106	0.1	5400	3				
	10%	1860	680	8.6	159	0.7	63	0.3	0.1	0.01	120	0.6	0.13	0.70	0.30	0.2	96	0.1	4950	3				
	25%	1760	660	5.2	148	0.6	59	0.3	0.1	0.01	110	0.6	0.13	0.51	0.29	0.3	71	0.1	4570	3				
	50%	1310	510	4.7	110	0.5	44	0.3	0.1	0.01	90	0.5	0.12	0.25	0.24	0.4	39	0.1	3500	3	17	5	47	3
	75%	590	280	3.8	43	0.2	18	0.2	0.0	0.01	80	0.4	0.11	0.10	0.17	0.4	13	0.1	1560	2				
	90%	350	200	3.3	19	0.1	9	0.2	0.0	0.01	80	0.4	0.10	0.10	0.14	0.4	9	0.1	835	2				
	99%	250	170	3.1	8	0.0	6	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	0.4	8	0.1	272	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at End of RPA																								
Exccedance probability	1%	1290	590	197	121	0.2	47	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2890	3				
	10%	1270	590	8.2	118	0.2	46	0.3	0.1	0.01	110	0.5	0.12	0.69	0.27	0.0	96	0.1	2460	3				
	25%	1240	580	3.0	110	0.2	43	0.3	0.1	0.01	100	0.5	0.12	0.50	0.26	0.0	71	0.1	2340	3				
	50%	940	450	3.0	82	0.2	33	0.2	0.1	0.01	80	0.5	0.11	0.25	0.22	0.0	39	0.1	1890	3	12	4	42	3
	75%	450	260	3.0	34	0.1	14	0.2	0.0	0.01	60	0.4	0.11	0.09	0.16	0.0	13	0.1	1030	2				
	90%	310	200	3.0	16	0.0	8	0.2	0.0	0.01	50	0.4	0.10	0.09	0.14	0.0	8	0.1	543	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	8	0.1	161	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at End of RPA																								
Exccedance probability	1%	2500	760	197	276	1.0	96	0.4	0.3	0.01	160	0.8	0.17	0.78	0.57	1.3	106	0.1	8010	3				
	10%	2380	740	10.1	261	1.0	94	0.3	0.2	0.01	140	0.8	0.16	0.71	0.54	0.9	98	0.1	7370	3				
	25%	2230	720	7.6	241	0.9	87	0.3	0.2	0.01	130	0.7	0.16	0.52	0.51	0.8	73	0.1	6780	3				
	50%	1650	560	6.4	178	0.7	65	0.3	0.2	0.01	120	0.6	0.14	0.26	0.40	0.8	**40**	0.1	5110	3	29	10	68	6
	75%	700	290	4.6	66	0.2	25	0.3	0.1	0.01	100	0.5	0.11	0.13	0.22	0.7	17	0.1	2100	2				
	90%	390	210	3.6	27	0.1	11	0.2	0.0	0.01	90	0.4	0.10	0.13	0.16	0.6	12	0.1	1030	2				
	99%	260	170	3.1	10	0.0	6	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	0.5	11	0.1	357	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at End of RPA																								
Exccedance probability	1%	1480	600	197	170	0.4	65	0.3	0.2	0.01	120	0.6	0.14	0.77	0.39	0.0	106	0.1	3850	3				
	10%	1470	600	8.2	166	0.4	64	0.3	0.2	0.01	110	0.6	0.14	0.70	0.38	0.0	97	0.1	3470	3				
	25%	1420	600	3.0	155	0.4	60	0.3	0.1	0.01	100	0.6	0.14	0.51	0.36	0.0	72	0.1	3280	3				
	50%	1070	460	3.0	115	0.3	45	0.3	0.1	0.01	80	0.5	0.13	0.25	0.30	0.0	**39**	0.1	2560	3	20	6	57	5
	75%	490	260	3.0	45	0.1	18	0.2	0.0	0.01	60	0.4	0.11	0.11	0.19	0.1	15	0.1	1250	2				
	90%	320	200	3.0	19	0.1	9.2	0.2	0.0	0.01	60	0.4	0.10	0.11	0.15	0.1	11	0.1	641	2				
	99%	240	170	3.0	8	0.0	5.7	0.2	0.0	0.01	40	0.4	0.10	0.09	0.13	0.1	10	0.1	192	1				

Table 3.4 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at End of RPA																								
Excedance probability	1%	2800	800	197	365	1.5	124	0.4	0.5	0.01	180	1.0	0.20	0.79	0.81	2.2	109	0.1	10200	4				
	10%	2670	770	14.5	343	1.5	121	0.4	0.4	0.01	160	1.0	0.20	0.72	0.76	1.6	100	0.1	9420	3				
	25%	2500	750	11.5	316	1.4	112	0.3	0.4	0.01	140	0.9	0.19	0.53	0.71	1.5	75.5	0.1	8650	3				
	50%	1850	580	9.3	232	1.0	83	0.3	0.3	0.01	130	0.8	0.16	0.28	0.55	1.2	43	0.1	6450	3	39	15	76	13
	75%	770	300	6.0	85	0.4	31	0.3	0.1	0.01	110	0.5	0.12	0.16	0.27	0.9	21	0.1	2560	3				
	90%	410	210	4.2	33	0.1	13	0.3	0.0	0.01	100	0.4	0.11	0.15	0.18	0.7	18	0.1	1190	2				
	99%	260	170	3.2	12	0.0	7	0.2	0.0	0.01	80	0.4	0.10	0.12	0.14	0.5	15	0.1	415	2				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at End of RPA																								
Excedance probability	1%	1750	620	197	243	0.8	91	0.4	0.3	0.01	120	0.7	0.17	0.78	0.56	0.1	108	0.1	5200	3				
	10%	1730	620	8.2	237	0.8	89	0.3	0.3	0.01	110	0.7	0.16	0.71	0.55	0.1	99	0.1	4850	3				
	25%	1660	610	3.1	222	0.7	84	0.3	0.2	0.01	100	0.7	0.16	0.52	0.53	0.1	75	0.1	4570	3				
	50%	1250	470	3.1	163	0.6	62	0.3	0.2	0.01	80	0.6	0.14	0.26	0.42	0.1	42	0.1	3490	3	30	11	69	11
	75%	550	260	3.0	61	0.2	24	0.3	0.1	0.01	70	0.5	0.11	0.14	0.23	0.2	20	0.1	1560	2				
	90%	340	200	3.0	24	0.1	11	0.2	0.0	0.01	60	0.4	0.10	0.13	0.16	0.2	16	0.1	767	2				
	99%	240	170	3.0	9	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.10	0.13	0.2	14	0.1	235	1				
Predicted peak concentrations for NO MINE scenario at End of RPA																								
Excedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Legend
- Above GV
- No mine scenario above GV
- Below GV

Table 3.5 Predicted peak CoPC concentrations (P50, P90) compared to the most stringent GVs for Mudginberri Billabong

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stingent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	8	1.6	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1860	770	150	142	0.6	56	0.3	0.1	0.01	140	0.7	0.16	0.79	0.40	0.6	108	0.1	3870	3				
	10%	1740	720	6.6	133	0.5	52	0.3	0.1	0.01	120	0.7	0.15	0.56	0.37	0.6	80	0.1	3600	2				
	25%	1680	700	6.0	127	0.5	49	0.3	0.1	0.01	120	0.6	0.15	0.35	0.36	0.6	53	0.1	3420	2				
	50%	1500	630	5.8	115	0.4	45	0.3	0.1	0.01	110	0.6	0.14	0.18	0.33	0.6	30	0.1	3060	2	20	14	56	9
	75%	800	360	4.9	63	0.2	24	0.3	0.1	0.01	100	0.5	0.12	0.13	0.23	0.5	18	0.1	1900	2				
	90%	430	230	3.7	29	0.1	12	0.2	0.0	0.01	90	0.4	0.11	0.11	0.16	0.4	13	0.1	1070	2				
	99%	280	180	3.1	12	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	0.3	9.6	0.1	406	2				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1300	680	150	89	0.2	39	0.3	0.1	0.01	120	0.6	0.15	0.78	0.30	0.0	108	0.1	1790	2				
	10%	1220	640	4.4	83	0.2	36	0.3	0.1	0.01	110	0.6	0.14	0.55	0.28	0.0	79	0.1	1640	2				
	25%	1180	620	3.5	79	0.2	34	0.3	0.1	0.01	90	0.5	0.13	0.35	0.27	0.0	53	0.1	1560	2				
	50%	1050	550	3.4	71	0.2	31	0.3	0.1	0.01	80	0.5	0.13	0.17	0.25	0.0	29	0.1	1410	2	13	9	43	7
	75%	590	330	3.3	41	0.1	18	0.2	0.0	0.01	70	0.4	0.11	0.11	0.19	0.0	17	0.1	1010	2				
	90%	350	220	3.0	21	0.1	10	0.2	0.0	0.01	70	0.4	0.10	0.10	0.15	0.0	12	0.1	658	2				
	99%	250	170	2.9	9	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.0	8.9	0.1	224	1				
Predicted peak concentrations for COMPOSITE_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	2080	790	150	186	0.8	71	0.4	0.3	0.01	150	0.8	0.18	0.79	0.53	1.1	109	0.1	5160	3				
	10%	1940	740	9.2	175	0.8	66	0.3	0.2	0.01	130	0.8	0.17	0.56	0.49	1.0	81	0.1	4810	3				
	25%	1870	720	8.4	167	0.7	63	0.3	0.2	0.01	130	0.8	0.16	0.36	0.47	1.1	55	0.1	4570	3				
	50%	1670	640	8.0	150	0.7	56	0.3	0.2	0.01	120	0.7	0.16	0.19	0.43	1.0	32	0.1	4080	3	28	20	67	15
	75%	880	370	6.3	81	0.3	30	0.3	0.1	0.01	110	0.5	0.12	0.14	0.28	0.7	21	0.1	2410	2				
	90%	460	240	4.4	36	0.2	15	0.3	0.0	0.01	90	0.4	0.11	0.13	0.18	0.5	16	0.1	1260	2				
	99%	280	180	3.2	14	0.1	7	0.2	0.0	0.01	80	0.4	0.10	0.11	0.14	0.3	12	0.1	479	2				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1440	690	150	126	0.5	53	0.4	0.2	0.01	130	0.7	0.16	0.79	0.39	0.1	109	0.1	2480	2				
	10%	1350	650	4.4	118	0.4	49	0.3	0.1	0.01	110	0.6	0.15	0.56	0.37	0.1	80	0.1	2290	2				
	25%	1310	630	3.5	112	0.4	46	0.3	0.1	0.01	90	0.6	0.15	0.35	0.35	0.1	54	0.1	2160	2				
	50%	1170	560	3.4	100	0.4	42	0.3	0.1	0.01	80	0.6	0.14	0.18	0.33	0.1	31	0.1	1940	2	20	15	56	13
	75%	650	330	3.3	56	0.2	23	0.3	0.1	0.01	70	0.5	0.12	0.13	0.22	0.1	20	0.1	1300	2				
	90%	370	220	3.0	26	0.1	12	0.2	0.0	0.01	70	0.4	0.10	0.11	0.16	0.1	15	0.1	798	2				
	99%	260	180	2.9	10	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.10	0.14	0.1	11	0.1	276	1				
Predicted peak concentrations for NO MINE scenario at Mudginberri Billabong																								
Exccedance probability	1%	940	660	149	15	0.0	6	0.3	0.0	0.01	120	0.5	0.13	0.78	0.16	-	107	0.1	892	1				
	10%	880	620	4.3	8	0.0	6	0.3	0.0	0.01	110	0.5	0.12	0.55	0.15	-	78	0.1	536	1				
	25%	860	600	3.5	5	0.0	6	0.3	0.0	0.01	90	0.5	0.11	0.33	0.15	-	51	0.1	164	1				
	50%	760	530	3.4	5	0.0	6	0.2	0.0	0.01	80	0.4	0.11	0.16	0.15	-	27	0.1	56	1				
	75%	450	320	3.2	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.10	0.13	-	15	0.1	52	1				
	90%	300	220	3.0	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.08	0.13	-	10	0.1	50	1				
	99%	240	170	2.9	4	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-	6.9	0.1	45	1				

Legend
- Above GV
- No mine scenario above GV
- Below GV

3.2 Species protection consequences for Mn

The predicted Mn concentrations and species protection consequence classifications at each of the Magela Creek sites are shown in Table 3.6.

Peak consequences

The species protection consequences for P50 load peak concentrations were High or Very High at all sites downstream of Pit 3 for both the Composite source and Pit 3 only scenarios. Although the concentrations for the Pit 3 only source were predicted to be lower, the consequence classification was the same.

Concentrations, and in some cases consequences, increase for P90 loads (Table 3.6).

- At MG003 and MG005, the two sites closest to Pit 3, Mn concentrations and consequences were predicted to be almost identical. These Mn concentrations were higher than the site upstream of Pit 3 (MG001).
- At MG009 (downstream of Coonjimba Billabong):
  - The peak Composite source scenario concentrations increase as expected.
  - The concentrations for the peak Pit 3 only source were lower except for the 50 and 75% exceedance probabilities.
  - The consequences were higher for the Composite source scenarios (High for P10 and P50 to Very High for P90) than for the Pit 3 only scenarios (Very Low for P10 to High for P50 and P90).
- At End RPA the concentrations were lower than at MG009 for the 1- 25% exceedance probabilities but higher for the other exceedance probabilities.
- Mn concentrations at Mudginberri Billabong were lower than other Pit 3 receiving water sites, but consequences for the billabong were classified as High to Very High for the P50 and P90 scenarios. The High consequences for the Pit 3 only P50 were a result of a 25% exceedance of the 99% species protection GV by 5%. For the P90 scenario the GV was exceeded by higher percentage with greater probability.

10,000-year consequences

The P10 scenarios for both source combinations has Very Low consequences at all sites.

At MG003, MG005 and MG009 the species protection consequences were:

- Low and Very Low for Pit 3 only P10 and P50 scenarios.
- Medium for the P50 and P90 Composite source and the P90 Pit 3 only sources.

At End of RPA consequences for the P50 Pit 3 only source were Very Low, and Very High for the other P50 and P90 scenarios. At Mudginberri Billabong the consequences were rated as Very Low for all scenarios.

Table 3.6 Predicted three day rolling average manganese peak concentrations (µg/L) in Magela Creek and species protection consequences; full season results

		Consequence to species		Very Low		Low		Medium		High		Very High		
Location	**Exceed-ance probability**	**No Mine**	**Peak P10 Composite UA**	**Peak P50 Composite UA**	**Peak P90 Composite UA**	**Peak P10 Pit 3 Only UA**	**Peak P50 Pit 3 Only UA**	**Peak P90 Pit 3 Only UA**	**10k P10 Composite UA**	**10k P50 Composite UA**	**10k P90 Composite UA**	**10k P10 Pit 3 Only UA**	**10k P50 Pit 3 Only UA**	**10k P90 Pit 3 Only UA**
GS01/MG001 (Magela upstream of pit 3)	**1%**	14.4	42.6	75.8	59.7	14.4	14.4	14.4	23.5	30.8	29.1	14.4	14.3	14.4
	10%	11.5	32.9	57.9	45.8	11.5	11.5	11.5	16.5	22.0	20.8	11.5	11.3	11.5
	25%	6.67	29.9	52.4	41.6	6.67	6.67	6.67	14.50	18.8	17.8	6.67	6.54	6.67
	50%	4.50	20.0	33.0	26.7	4.50	4.50	4.50	11.00	13.1	12.7	4.50	4.50	4.50
	75%	4.50	12.6	17.4	14.9	4.50	4.50	4.50	6.66	7.62	7.42	4.50	4.50	4.50
	90%	4.49	8.39	10.5	9.60	4.49	4.49	4.49	5.50	6.00	5.89	4.49	4.49	4.49
	99%	4.45	4.50	4.50	4.50	4.45	4.45	4.45	4.50	4.50	4.50	4.45	4.45	4.45
409/MG003 (Magela mid-stream, d/s of Pit 3)	**1%**	14.4	174	265	334	144	203	289	68.2	106	155	56.1	86.0	137
	10%	11.6	152	228	292	128	180	256	57.3	89.8	133	48.1	76.2	122
	25%	6.89	149	224	285	122	172	245	54.8	86.3	130	45.7	72.4	116
	50%	4.50	60.5	89.5	111	48.5	66.5	93.2	25.8	37.4	52.4	21.6	30.9	46.4
	75%	4.50	16.3	24.3	22.4	10.4	11.4	12.3	8.31	9.92	11.0	7.49	8.80	10.3
	90%	4.49	11.8	16.0	14.5	4.50	4.50	4.50	5.78	6.45	6.38	4.50	4.50	4.50
	99%	4.47	6.78	7.76	8.16	4.47	4.47	4.47	5.20	5.58	5.60	4.47	4.47	4.47
421/MG005 (Magela mid-stream, d/s of Pit 3)	**1%**	14.4	173	263	333	143	201	288	67.7	105	154	55.8	85.6	136
	10%	11.6	151	227	290	127	179	254	57.0	89.2	132	47.9	75.8	121
	25%	6.91	148	223	283	121	171	244	54.5	85.9	129	45.4	72.0	115
	50%	4.50	59.9	88.5	110	48.1	66.1	92.8	25.6	37.1	51.9	21.4	30.7	46.1
	75%	4.50	16.2	24.2	22.3	10.4	11.3	12.3	8.28	9.88	10.9	7.47	8.78	10.2
	90%	4.49	11.7	15.9	14.5	4.50	4.50	4.50	5.78	6.45	6.37	4.50	4.50	4.50
	99%	4.47	6.75	7.69	8.06	4.47	4.47	4.47	5.19	5.56	5.59	4.47	4.47	4.47
GS09 (MG009, downstream of CB on lease)	**1%**	14.4	185	304	403	141	198	283	66.2	103	151	54.9	84.3	134
	10%	11.7	163	268	352	125	176	250	56.0	87.5	130	47.2	74.6	119
	25%	7.23	157	249	326	119	168	240	53.9	84.9	127	44.8	70.9	113
	50%	4.50	78.0	127	165	57.9	79.8	112	29.5	44.0	62.5	24.4	36.2	55.3
	75%	4.50	17.7	26.4	28.3	13.0	14.1	15.9	10.6	12.3	13.6	9.56	11.2	12.8
	90%	4.49	11.9	17.1	15.3	4.50	4.50	4.50	5.73	6.37	6.29	4.50	4.50	4.50
	99%	4.49	7.22	8.89	9.54	4.49	4.49	4.49	5.16	5.53	5.57	4.49	4.49	4.49
EndRPA (OFF the RPA)	**1%**	14.4	165	276	365	121	170	243	58.1	89.6	130	47.6	73.0	115
	10%	12.3	159	261	343	118	166	237	54.0	84.9	126	44.3	70.1	112
	25%	7.21	148	241	316	110	155	222	51.0	79.6	118	42.0	66.1	105
	50%	4.50	110	178	232	82.4	115	163	40.2	61.3	88.9	33.2	50.5	78.7
	75%	4.50	42.9	66.0	84.7	33.6	44.8	60.6	19.6	26.3	35.5	17.7	23.2	32.5
	90%	4.50	19.4	27.0	33.0	15.5	18.9	23.7	10.9	13.6	16.4	9.74	12.2	15.1
	99%	4.49	8.04	10.4	12.1	6.82	7.73	8.97	5.64	6.27	7.06	5.38	5.91	6.71
Mudginberri Billabong	**1%**	14.5	NA	142	186	NA	88.7	126	NA	48	69	NA	39	61
	10%	8.42	NA	133	175	NA	83.2	118	NA	45	65	NA	37	57
	25%	5.09	NA	127	167	NA	79.3	112	NA	43	62	NA	35	55
	50%	4.90	NA	115	150	NA	71.1	100	NA	39	56	NA	32	49
	75%	4.77	NA	63	81	NA	40.9	56	NA	24	33	NA	21	30
	90%	4.53	NA	29	36	NA	20.8	26	NA	14	18	NA	13	16
	99%	4.37	NA	12	14	NA	8.7	10	NA	7	8	NA	6	7

4 Risk Evaluation

Risks for the combinations of sites, scenarios, and values shown in Table 4.1 were evaluated using the ERA risk spreadsheet and classification schemes discussed above.

The risk evaluation and classification for cultural use of water based on drinking and recreational water quality and for animal drinking water quality for all CoPCs with relevant GVs is shown in Table 4.2 and Table 4.3 respectively. The consequences were very low so the risks were all Class I which is the lowest risk rating possible.

The risk evaluation and classification for biodiversity, based on comparison of modelled data to aquatic ecosystem species protection levels, is shown in Table 4.4.

The risk of ASS formation, not shown in the tables, was also Class I as the SO_4 GV was not exceeded.

The risk spreadsheet showing additional detail is provided in Annex B. The risk classifications are discussed in Section 5.1. Limitations of inputs to the risk evaluation and confidence or material effect of the limitations on the risk assessment are discussed in Section 5.2.

Table 4.1 Combinations of scenarios, sites, and values classified in the ERA risk spreadsheet

	Contaminant source sceanrios, vlaues and CoPCs assessed for risk classification			
Sites	**Composite sources PEAK, P50**	**Pit3 only PEAK, P50**	**Composite sources 10,000 Yr, P50**	**Pit 3 only 10,000 Yr, P50**
ON the RPA (MG001, MG003, MG005, MG009)	Drinking water (all CoPCs)			
	Recreational water (all CoPC)			
	Animal drinking water (all CoPC)			
	Acid sulfate soil formation (SO_4)			
	Aquatic species protection (Mn)			
	Aquatic species protection (all other CoPC)			
OFF the RPA (EndRPA, Mudginberri BB)	Drinking water (all CoPCs)			
	Recreational water (all CoPC)			
	Animal drinking water (all CoPC)			
	Acid sulfate soil formation (SO_4)			
	Aquatic species protection (Mn)			
	Aquatic species protection (all other CoPC)			

Table 4.2 Risk evaluation for cultural water use based on drinking and recreational GVs; applies to all CoPC with relevant GVs

Ref.				Risk Description		Evaluation			Rating		
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 32 of 32 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Risk Management Class
T	J	02		Land use (cultural use of water for drinking & recreation)							
T	J	02	01	Water not suitable for drinking due to mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	02	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	02	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	02	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	02	05	Water not suitable for recreation due mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	02	06		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	02	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	02	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	02	09	Water not suitable for drinking due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	02	10		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	02	11		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	02	12		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I
T	J	02	13	Water not suitable for recreation due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	02	14		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	02	15		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	02	16		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

Table 4.3 Risk evaluation for animal drinking water; applies to all CoPC with relevant GVs

Ref.				Risk Description		Evaluation			Rating		
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 32 of 32 risks (0 Remaining) / Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Likelihood - Probability	Animal drinking OFF the RPA	Animal drinking ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	06		**Flora & fauna (animal drinking water)**							
T	J	06	01	Water not suitable for animal drinking water due to mine contaminants OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	06	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	06	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	06	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	06	05	Water not suitable for animal drinking water due to mine contaminants ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	06	06		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	06	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	06	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

Table 4.4 Risk evaluation for biodiversity, based on species protection GVs; applies to all CoPC with relevant GVs

Ref.				Risk Description		Evaluation		Rating			
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Likelihood - Probability	Biodiversity OFF the RPA	Biodiversity ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Risk Management Class
T	J	07		Biodiversity & ecosystems (aquatic species protection)							
T	J	07	01	Elevated Mn in water (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VH		IV		IV
T	J	07	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VH		IV		IV
T	J	07	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	H		IV		IV
T	J	07	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	07	05	Poor water quality for CoPC except Mn (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	07	06		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	07	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	07	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	07	09	Elevated Mn in water (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		H		IV	IV
T	J	07	10		Contaminated by **Pit 3 (PEAK, P50)**	P		H		IV	IV
T	J	07	11		Contaminated by **Composite sources (10,000 Yr, P50)**	P		M		III	III
T	J	07	12		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		L		II	II
T	J	07	13	Poor water quality for CoPC except Mn (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	07	14		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	07	15		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	07	16		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

5 Discussion

5.1 Risk profile

The risk profile for ON and OFF the RPA for the P50 load scenarios is shown in Figure 5.1.

Class I is the lowest risk possible. A risk that results in Class III or Class IV is considered a material risk that requires active management and consideration of additional control measures.

Location (Sites)	Value and CoPC assessed	Risk classes for P50 contaminant source sceanrios (based on worst case for any site at the location)			
		Composite sources PEAK, P50	Pit3 PEAK, P50	Composite sources 10,000 Yr, P50	Pit 3 10,000 Yr, P50
ON the RPA (MG001 / MG003 / MG005 / MG009)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	III	II
	Aquatic species protection (all other CoPC)	I	I	I	I
OFF the RPA (Mudginberri Billabong / EndRPA)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	IV	I
	Aquatic species protection (all other CoPC)	I	I	I	I

Risk ranking is based on consequences for the full season data. If based on recessional flow data only the only change would be biodiversity protection at MG009 for the 10,000 year composite sceanrio increases from a class III to a class IV risk.

Figure 5.1 Risk profile for ON and OFF the RPA

Cultural water use and

The consequences for cultural water use (based on drinking and recreational water quality GVs for all CoPCs) were very low resulting in Class I risks at all sites; the lowest risk rating possible (Table 4.2 and Figure 5.1).

Wildlife drinking water and acid sulfate soil formation

Wildlife drinking water and acid sulfate soil formation risks were Class I at all sites.

Species protection

The risk classification for biodiversity (Table 4.3), was Class I for all CoPCs except Mn. Based on Mn ecotoxicity species protection GVs, the species protection risks were (Figure 5.1):

- Class I risks OFF the RPA for the 10,000-year Pit 3 only scenario.

- Class II risks ON the RPA for the 10,000-year Pit 3 only scenario.
- Class III risk ON the RPA for the 10,000-year composite sources scenario.
- Class IV risks both ON and OFF the RPA for both the peak composite and peak Pit 3 only scenarios.
  - For the two sites closest to Pit 3 the risk would be Class III but at MG009 risk is Class III for the Pit 3 only scenario and Class IV for the composite source scenario.

5.2 Limitations

Guideline values for aquatic ecosystem species protection

Site-specific, or site adjusted, GVs based on aquatic species sensitivity distributions (SSDs) protection were used in this assessment for Cu, Mg, Mg:Ca, Mn, NH_3-N, U and Zn. The reliability of the Cu and Zn GVs under the criteria recommended by Warne et al. (2018) is moderate (Supervising Scientist 2021d). There is a high level of confidence in the Mg GV (Supervising Scientist 2021b). The level of confidence or reliability for the GVs for Mn, U and NH_3-N is not stated in the rehabilitation standards where they are published (Supervising Scientist 2021a and 2021c respectively) however the Supervising Scientist has stated the level of confidence for these site-specific GVs is high (Supervising Scientist 2021g).

The Supervising Scientist (2018) found the same species protection DGV used in this assessment for Cd and Pb were suitable to apply to Magela Creek providing high confidence in these DGVs. They recommended that local GVs for Al, Cr, and V be based on reference site data to account for local background water quality conditions

Small increases in Al were predicted were predicted at sites immediately downstream of Pit 3. There was a trend of increasing concentrations above the reference condition with distance from the mine (Table 3.1 to Table 3.5). It was assumed therefore that the mine contribution to Al was small and the consequences to species protection were ranked as very low resulting in a Class I risk. The same assumptions applied to V as the trend for V concentrations above the reference condition was similar to that for Al.

Modelling predicted moderate increases above the reference condition for Cr with 12% to 23% increases for the P50 and P90 scenarios at the two sites immediately downstream of the Pit increasing to 20% to 30% at End of RPA (Table 3.1 to Table 3.5). Despite the moderate increases the concentrations remained less than an order of magnitude lower than the DGV for Cr^{3+}. A review of Magela Creek water quality data shows that the highest predicted Cr concentrations are less than double the reporting limit. It was therefore assumed these moderate increases would result in very low consequences and a Class 1 risk for species protection.

If the assumptions for Cr, V and Al are not valid the species protection consequences and risk may be higher.

Nickel was not included in the Supervising Scientist (2018) DGV assessment. The ANZG (2018) Ni DGV was used in this assessment in line with the method reported in Iles (2023). Nickel did not exceed the DGV, however it is important to note:

- the Supervising Scientist has suggested that the ANZG (2018) Ni DGV may be too high for Magela Creek

- the predicted proportional increase in Ni concentrations relative to background (i.e. the No mine scenario) was greater than predicted for other metals except Mn.

It is therefore plausible that the very low consequences and Class I risk may be underestimated.

The bioavailability and toxicity of Ni is dependent on several (often interactive) physico-chemical processes, which can be predicted based on generalised models. Stauber *et. al.* (2021) report Ni GVs adjusted for bioavailability in Australian and New Zealand waters using two biotic ligand models (BLM), two multiple linear regression (MLR) models and datasets for temperate, tropical, and combined temperate-tropical data. For Magela Creek the 99% protection GV varied between 9.9 and 0.48 µg Ni/L (Table 5.1) compared to the 8 µg Ni/L used in this assessment.

The two MLR based 99% SPL GVs for Magela Creek reported by Stauber et al. (2021) were exceeded by the Ni concentrations at sites downstream of Pit 3. The two BLM based GVs were not exceeded.

Stauber *et al.* (2021) report limitations for all four modelled approaches. Personal comments from Dr. Andrew Harford (Supervising Scientist) indicate more work would be required if a site-specific/adjusted GV for Ni is deemed necessary. Information and advice in Stauber *et al*. (2021) could be used to derive a site-specific/adjusted GV for Ni which may be lower than the GV used in this assessment and the predicted Ni concentrations.

Table 5.1 Species protection GVs for Ni (µg/L)

Species protection level				Reference and notes
99%	95%	90%	80%	
National water type				
8	11	13	17	ANZG 2018 default GVs (DGV)
0.4	3.0	5.4	14	Bioavailability adjusted GVs for pH 7.5, DOC 0.5 mg/L, hardness 30 mg $CaCO_3$/L. Stauber *et al*. 2021 main report and Tables S6-9.
Soft water or Magela reek water				
1.6	8.4	17	44	Bioavailability based GVs adjusted for pH 6.0, DOC 3 mg/L, hardness 12 mg $CaCO_3$/L, Ca 2 mg/L, Mg 1.6 mg/L. Closest to Magela Creek conditions of pH 6.1, DOC 3, Hardness 2, Ca 0.25, Mg 0.25 in Stauber *et al.* 2021 lookup tables S6-9. Toxicity in the softer Magela Creek could be higher.
1.9	3.4	-	-	Softwater BLM; Magela Creek. Stauber *et al.* 2021 Table 7.
0.48	2.5	5.0	10	Trophic-level-specific MLR; Magela Creek. Stauber *et al.* 2021 Table S5.
0.62	1.7	2.8	4.7	Pooled MLR; Magela Creek. Stauber *et al.* 2021 Table S5.
9.9	15	-	-	EU BLM; Magela Creek. Stauber *et al.* 2021 Table 7.

Confidence in the species protection consequence and risk classifications for Al, Cr, V and Ni is lower than for the other parameters. This will not pose a risk to the environment as the management actions required to mitigate the risks associated with Mn will also mitigate the risks from these CoPC.

Guideline value for the prevention of acid sulfate soil

The GV for prevention of ASS was recommended by the Supervising Scientist (2021e). It was based on a review of local water quality conditions believed to have caused ASS to form at Ranger and is identical to the nationally recommended guideline value to prevent the formation of ASS. No level of confidence is stated in Supervising Scientist (2021e) but it is stated that additional site-specific knowledge may lead to further refinement of this standard. If the GV is lowered then the consequences and risks may be higher than reported in this assessment.

Guideline values for animal drinking water

The GVs for animal drinking water are based on livestock drinking water and a limited number of reports in the international literature. These may not be protective of native species so the consequences and risks for this endpoint may be higher than stated. This should not pose a real risk as the management actions required to mitigate the risks associated with Mn being higher than GV for species protection will improve water quality.

Predicted water quality

Uncertainty analyses for the ground and surface water models have been reported elsewhere (INTERA, 2021; Water Solutions 2021). The models have been shown to have multiple layers of conservatism for concentrations, loads and flows.

Concentrations for 10%, 50% and 90% probability groundwater load input scenarios were assessed in this report. GVs were exceeded more frequently as the Px groundwater loads increase but the difference in concentrations between the P50 and P90 (the two highest loads) scenarios were not material to classifying consequences and risks as shown by Iles 2023.

Predicted Mn concentrations were conservative as Mn was treated as a non-reactive element. Parry (2023) reported studies of mine water mixed with Magela Creek/billabong waters where a large proportion (up to 50%) of Mn did not remain in the bioavailable fraction. The Supervising Scientist feedback was that other studies do not support this finding. This assessment assumed all Mn was bioavailable, so was conservative however it is noted that even a 50% reduction in Mn concentrations at End RPA would still constitute a Class IV risk under P50 load scenarios

Cumulative impacts

This study assesses the risks of multiple CoPC individually, as such cumulative impacts were not considered explicitly. However:

- cumulative impacts from a combination of CoPC above GV are not expected. Trenfield *et al.* (2021) studied the toxicity of Ranger mine waters with multiple CoPC present at above GV values. They found that antagonistic effects lowered the expected toxicity and concluded that "*existing individual GVs for contaminants would be adequately protective for ecosystems downstream of the mine in the event of exposure to a mixture of the contaminants of concern*", and
- only one CoPC (Mn) was predicted to be above the 99% SPL GV in the Magela creek sites assessed.
- Several studies have looked at the cumulative risks in the Ranger surface water pathway either explicitly or implicitly (i.e. looked at endpoints that would be effected directly or indirectly by exposure to multiple contaminants).
  - Harford *et al.* (2022) reported on the project Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (aquatic pathways)

- Bartolo *et al.* (2018) looked at cumulative impacts on ecological processes in different aquatic habitats and hydrological regimes.

- Field investigations at sites impacted by multiple CoPC (e.g. Chandler *et al.* 2021; SSB 2020; Batterham and Overall 2001, and several instances of biological monitoring that included sites with high Mn concentrations). These studies are being reviewed as part of the Mn VAF (BMT 2023).

Studies are planned to investigate multiple processes and stressors in Coonjimba Billabong and in the Magela Creek hyporheic zone (e.g. ASS, eutrophication).

Microbial and biogeochemical processes

Detrital pools, the role of microbial assemblages in organic matter decomposition, and biogeochemical cycles in general, were identified as a knowledge gaps in the APRA (Wong and Bolton 2023).

Microbially-mediated processes will be important in assessing some CoPCs, especially ammonia and sulfate. Direct effects upon microbes and decomposition processes can indirectly affect higher trophic levels. For example, Forrow and Moltby (2000) report that the rate limiting step in detritus decomposition was shredding by detritivore macroinvertebrates. Pre-processing (microbial conditioning) of detritus by microbes can make it more palatable to macroinvertebrates. Contaminant accumulation in detritus can also make it less palatable to detritovores.

Microbial and biogeochemical processes are now included in the conceptual model as a regulating (Intermediary) process. Wong and Bolton (2023) requested that the findings of this risk assessment discuss these issues.

The APRA is a screening tool used to assess modelled CoPC predictions in the surface water column against GVs for toxicity, and (sulfate) ASS risk. ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered.

Two of the site-specific GVs take biogeochemical and microbial impacts into consideration:

- Field impacts on billabong macroinvertebrates was used in developing the site-specific GV for Mg in water (Humphrey and Chandler, 2018). This line of evidence integrates impacts to a higher trophic level from biogeochemical and microbial processes.

- The site specific GV for U in sediments was based on field effects on sediment communities including bacteria and archaea (prokaryotes), and micro- and macro-invertebrates (eukaryotes) (Supervising Scientist, 2021f). McMaster *et al.* (2020) found that by meeting the site-specific water quality GV for U the sediment GV would also be met. This assessment found no exceedances of the U water GV therefore, the U sediment GV would also be met, protecting the benthic community.

Studies or assessments are being/have been conducted separately on Mn, ammonia and sulfate, CoPCs that are microbially mediated, and on potential impacts in the surface-ground water interface:

- Increased ammonia loads may cause eutrophication. Professor Perran Cook (Monash University) reviewed the eutrophication risk associated with Pit 3 closure and made recommendations on assessment approaches which will be reported elsewhere by ERA. His review considered microbially mediated transformation of nutrients.

- Biogeochemical reactions drive the speciation and therefore bioavailability of Mn. Parry (2023) summarises local studies that showed a reduction in dissolved Mn when mine impacted water was mixed with Magela creek/billabong waters. This risk assessment is conservative as it considers all Mn is bioavailable. A separate project will assess the ecosystems vulnerability to elevated Mn concentrations in the waters at/near the RPA.

- Increased sulfate concentrations may increase the propensity for ASS to develop from shallow groundwater sources for the which the surface water GV may not necessarily apply. ERA is in the process of investigating this.
- Sediment studies being conducted separately will compare contamination levels to ANZG (2018) GVs based on protecting benthic communities. There is no such GV for Mn in sediments. Previous studies at Ranger mine have shown sediments overlain by waters with elevated Mn (even the sediments of wetlands used to treat contaminated water) contained Mn concentrations within the background range (Iles *et al.* 2010, Parry 2016, Esslemont and Iles 2017). Local concentration factors are available for Mn partitioning and could be used in a separate assessment to calculate the potential sediment concentrations of Mn for the predicted water column concentrations. The calculated median sediment concentrations could be compared to the median calculated by the same method for the No Mine scenario and the regional background concentrations.

Bartolo *et al.* (2018) identifies Magela Creek as a sandy channel water type with riparian zones fringing the creek. They define chemical processes as the '*interactions and associations between chemical substances and physical attributes of an ecosystem which affect the way that biota interact and function. Incorporates all biogeochemical processes*". Among the components listed under chemical process several were relevant to this issue i.e. nutrient and carbon cycling, nitrogen dynamics, energy and nutrient dynamics, microbial activity as purification service, physical, chemical and biological interactions. They report (in their Figure 4) that chemical processes are a low activity in sandy channels year-round but a high activity in the riparian zones, and in the lowland billabongs it was low in the wet and high in the dry season. The findings on relative activity concur with the observation by Wong and Bolton (2023) that processes associated with detrital pools were especially important for billabongs.

The sandy channel habitat and activity levels of chemical processes described by Bartolo *et al.* (2018) may not apply to residual pools in the creek channels or the hyporheic zone in Magela Creek which is anaerobic throughout the year (pers. comm. Chris Humphrey, SSB). Chandler *et al.* (2021) reported changes in microbial communities along a gradient of contamination in the Magela Creek hyporheic zone. Some of these changes occurred at concentrations within background variability and focused on ions causing salinity change. The risk to, and the importance of these processes, from other CoPC in the residual pools and hyporheic zone is a knowledge gap. SSB is conducting a study in the 2023 dry season on pools in Magela Creek which will help address this issue.

6 Conclusions

ERA provided predicted peak and 10,000-year surface water concentrations of 20 CoPC for P10, P50 and P90 groundwater loads at sites on the Magela Creek upstream and downstream of Pit 3.

The APRA tool was used to screen and classify risks in surface water pathway by comparing the predicted concentrations of 18 CoPC (Mg, Mg:Ca, Mn, NH_3-N, U, Al, Cd, Cu, Cr, Fe, Ni, Pb, Se, V, Zn, NO_3-N, SO_4 and ^{226}Ra) against GVs to protect (i) aquatic biota against chemical and radiological toxicity, (ii) sediments from forming ASS, (iii) cultural uses of water for drinking and recreation, and (iv) the health of wildlife drinking the creek waters.

No human drinking water or recreational water quality GVs were exceeded. Nor were the GVs for ASS formation and radiation protection of aquatic biota was also met for all scenarios.

The risk to cultural water use; based on drinking and recreational water quality, is Class I (the lowest risk). The same class risk applies to wildlife drinking water and ASS formation.

Apart from Mn and Al all GVs for protection of aquatic species were met. For all COPC other than Mn the risk was classified as Class I. The species protection GV for Al is exceeded naturally. A comparison of median concentrations for the No Mine scenario against median concentrations for the other scenarios showed no or very small contributions from the mine. Based on the incremental contribution from Ranger related sources, the risk from Al was classified as Class I.

The Cr, V and Ni DGVs for species protection have lower confidence than the other metals considered in this assessment. A comparison of medians for these CoPCs compared to the No Mine scenario median showed:

- No increases in V at the sites downstream of Pit 3 and increasing concentrations with increasing distance from MG009 to Mudginberri Billabong.
- Increased concentration of Cr of 12 – 23% at the two sites downstream of Pit 3 increasing at MG009 and again at End of RPA before reducing at Mudginberri Billabong but still remaining between 13 to 28% above background.
- Increased concentration of Ni of 42 – 59% at the two sites downstream of Pit 3 increasing at MG009 and again at End of RPA before reducing at Mudginberri Billabong but still remaining between 43 to 67% above background.

The trend of enriched Cr and Ni concentrations indicates a mining source and the consequences and risk to species protection might be higher than indicated by assessing these against DGVs. The need for site-specific or site adjusted GVs for these two CoPC needs to be considered. The risk from these two CoPCs will be mitigated by management actions being implemented to manage the high risks from Mn.

Manganese was the only COPC where risks were rated as being higher than Class I. Species protection consequences were assessed for all exceedance probability Mn concentrations predicted by the RSWM. The consequences for the P50 scenarios were used to classify the risks. The resulting risk classifications for species protection from Mn were:

- Class I risks OFF the RPA for the 10,000-year Pit 3 only scenario.
- Class II risks ON the RPA for the 10,000-year Pit 3 only scenario.

- Class III risk ON the RPA for the 10,000-year composite sources scenario.
- Class IV risks both ON and OFF the RPA for both the peak composite and peak Pit 3 only scenarios.
  - For the two sites closest to Pit 3 the risk would be Class III but at MG009 risk is Class III for the Pit 3 only scenario and Class IV for the composite source scenario.

The Mn VAF should be applied to the predicted Mn concentrations at the Magela Creek sites on the RPA.

This assessment assumed that (i) concentrations predicted by the RSWM were accurate, and (ii) that all Mn is present in the bioavailable form. These conservative assumptions may overstate the risks associated with Mn particularly under the assessed 10,000-year scenarios.

ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered.

Biogeochemical and microbial processes are now included in the conceptual model for risks via the surface water pathway. Assessing these is outside the scope of the APRA. As discussed, there are several studies that have addressed or will address these issues.

Whether the predicted concentrations of Mn in the water column will cause sediment Mn concentrations to increase beyond the natural variability is not assessed in this report. Local concentration factors and regional background datasets are available to assess this under a separate process.

7 References

ANZECC and ARMCANZ (2000). Australian and New Zealand guidelines for fresh and marine water quality. Volume 1, The guidelines. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anzguideline

ANZG (2023). Toxicant default guideline values for aquatic ecosystem protection: Nitrate in fresh water. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. CC BY 4.0. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT, Australia. Available at waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/toxicants.

Bartolo RE, Harford AJ, Humphrey CL, George AK, van Dam RA (2018). Defining the importance of ecological processes for monitoring aquatic habitats for conservation and rehabilitation objectives at the Ranger uranium mine, Kakadu Region, Australia. *Marine and Freshwater Research* 69, 1026-1046. https://doi.org/10.1071/MF17256

BMT (2023). Ranger Mine Closure Manganese Vulnerability Assessment - Draft Implementation Report. August 2023.

Chandler L, Harford AJ, Hose GC, Humphrey CL, Chariton A, Greenfield P, Davis J (2021). Saline mine-water alters the structure and function of prokaryote communities in shallow groundwater below a tropical stream. Environmental Pollution, 284, 2021, 117318, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2021.117318.

Doering C, Carpenter J, Orr B, Urban D. (2019). Whole organism concentration ratios in freshwater wildlife from an Australian tropical U mining environment and the derivation of a water radiological quality guideline value. Journal of Environmental Radioactivity. 2019 Mar; 198:27-35. doi: 10.1016/j.jenvrad.2018.12.011. Epub 2018 Dec 19. PMID: 30579144.

ERA (2020). Ranger mine closure plan. Available at Mine Closure Plan - Energy Resources of Australia

ERA (2022). Pit 3 Capping, Waste Disposal and Bulk Material Movement Application Volume 2: Environmental Studies. CDM.03-1321-EY-APP-00003 rev 0. April 2022.

Esslemont G, Iles M. (2017). 2016 Billabong Sediment Sampling Program. Energy Resources of Australia Ltd. August 2017

Forrow DM, Maltby L. (2000). Toward a mechanistic understanding of contaminant-induced changes in detritus processing in streams: Direct and indirect effects on detritivore feeding. Environmental Toxicology and Chemistry, 19: 2100-2106. https://doi.org/10.1002/etc.5620190820

Harford AJ, Bartolo RE, Humphrey CL, Nicholson JD, Richardson DL, Rissik D, Iles M, Dambacher JM. (2022). Resolving ecosystem complexity in ecological risk assessment for mine site rehabilitation. *J Environ Manage*. 2022 Oct 1;319:115488. doi: 10.1016/j.jenvman.2022.115488. Epub 2022 Aug 3. PMID: 35982549.

Hinck J, Linder G, Finger S, Little E, Tillitt D, Kuhne W (2010). Biological Pathways of Exposure and Ecotoxicity Values for Uranium and Associated Radionuclides Hydrological, Geological, and Biological Site Characterization of Breccia Pipe Uranium Deposits in Northern Arizona. USGS professional paper. https://www.sciencedirect.com/science/article/pii/S0269749121009003

Humphrey CL, Chandler L (2018). Use of field-effects information to inform surface water guideline values for magnesium sulfate in Magela Creek. Supervising Scientist Report 212. (Supervising Scientist: Darwin, NT, Australia.). Available at: http:// www.environment.gov.au/science/supervising-scientist/publications/ssr

Iles M, Parry D, Klessa DA (2010). Characterisation of Ranger Wetland and Billabong Sediments: Volume 2: Project-based monitoring of on-site water bodies 2003 – 2006. Prepared by: EWL Sciences Pty Ltd. for: ERA Ltd.

Iles M, Rissik D (2021). Ranger Closure Aquatic Pathway Receptors Risk Assessment, Energy Resources Australia and BMT report, CDM.03–1114-MR-RAS-00001, version 0, Brisbane.

Iles M (2023). ERA Aquatic Pathways Risk Assessment tool. BMT Brisbane. R.B23879.001.00, 3 April 2023.

Iles M (2020). 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. Darwin: Energy Resources of Australia Ltd.

INTERA (2021). Final Report: Groundwater Uncertainty Analysis for Ranger Mine Closure, report for Energy Resources of Australia Ltd.

McMaster SA, Noller BN, Humphrey CL, Trenfield MA, Harford AJ (2020). Speciation and partitioning of uranium in waterbodies near Ranger Uranium Mine. Environmental Chemistry 18 (1) 12-19. https://doi.org/10.1071/en20096.

Ministry of Environment and Climate Change Strategy (MECC) (2019). British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture Summary Report. Water Protection and Sustainability Branch. August 2019. wqg_summary_aquaticlife_wildlife_agri.pdf (gov.bc.ca)

NHMRC (2008). Guidelines for Managing Risks in Recreational Water. National Health and Medical Research Council. February 2008, p 216. https://www.nhmrc.gov.au/guidelines-publications/eh38.

NHMRC, NRMMC (2011). Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Ministerial Council, Commonwealth of Australia, Canberra. p 1309. v3.8 updated September 2022.

Parry D (2016). Review of sediment quality data at Ranger Uranium Mine. Report to Energy Resources of Australia Ltd. Rio Tinto Project code: 590404001561 Report number: 1, Version: Final. June 2016.

Parry D (2023). Manganese speciation in Ranger Project Area surface waters. Prepared by David Parry, Principal Advisor Environment, Rio Tinto Alcan. Final, 14 June 2023.

Stauber J, Golding L, Peters A, Merrington G, Adams M, Binet M, Batley G, Gissi F, McKnight K, Garman E, Middleton E, Gadd J, Schlekat C (2021), Application of Bioavailability Models to Derive Chronic Guideline Values for Nickel in Freshwaters of Australia and New Zealand. Environmental Toxicology and Chemistry, 40: 100-112. https://doi.org/10.1002/etc.4885

Supervising Scientist (2018). Metals in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1) (Withdrawn). Supervising Scientist Branch, Darwin, NT

Supervising Scientist (2020). Impacts associated with a sustained acidification event in Coonjimba Billabong, December 2015 to February 2016: Data summary.

Supervising Scientist (2021a). Uranium and Manganese in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 2). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021b). Magnesium in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 2). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021c). Ammonia in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1.1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021d). Copper and zinc in surface water — Rehabilitation Standard for the Ranger uranium mine (version 1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications /ss-rehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021e). Sulfate in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1.1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021f). Uranium in Sediments — Rehabilitation Standard for the Ranger uranium mine (version 1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021g). Supervising Scientist Review Comments - Ranger closure aquatic pathway receptors risk assessment. 15 November 2021.

Trenfield MA, Pease CJ, Walker SL, Humphrey C, van Dam R, Markich S, Harford AJ (2021). Assessing the toxicity of mine-water mixtures and the effectiveness of water quality guideline values in protecting local aquatic species. Environmental Toxicology and Chemistry, 40, 2334-2346. doi:DOI: 10.1002/etc.5103

Warne MS, Batley GE, Van Dam RA, Chapman J, Fox D, Hickey C & Stauber J 2018. *Revised method for deriving Australian and New Zealand water quality guideline values for toxicants*. Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). Department of Science, Information Technology and Innovation, Brisbane, Queensland.

Water Solutions (2021). ERA Ranger Mine Closure RSWM - Verification and Updated Calibration. WS210136. Revision 0. October 2021.

Wong V, Boulton A (2023). Close-out notes, ARRTC Meeting 52, June 2023. (Provided by email from Michael Ryan, Umwelt, 26/2/23).

Annex A Summary tables for predicted concentrations at 10,000 years

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at MG003																									
Exccedance probability	1%	1320	640	200	68	0.1	29	15	0.3	0.0	0.01	120	0.5	0.11	0.77	0.20	0.00	106	0.1	1660	2				
	10%	1260	630	3.0	57	0.1	25	2.6	0.3	0.0	0.01	110	0.4	0.11	0.66	0.19	-0.01	92	0.1	1190	2				
	25%	1240	620	3.0	55	0.1	24	2.6	0.3	0.0	0.01	100	0.4	0.11	0.48	0.19	-0.01	69	0.1	917	2				
	50%	800	540	3.0	26	0.0	12	2.5	0.2	0.0	0.01	80	0.4	0.10	0.20	0.15	-0.04	33	0.1	728	2	4	-16	14	-14
	75%	540	310	3.0	8	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.08	0.13	-0.11	6.7	0.1	249	1				
	90%	300	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.18	6.0	0.1	70.2	1				
	99%	220	160	3.0	5	0.006	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.21	6.0	0.1	62	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at MG003																									
Exccedance probability	1%	1030	580	200	56	0.1	23	15	0.3	0.0	0.01	120	0.4	0.11	0.77	0.19	0.00	106	0.1	1530	2				
	10%	1020	570	3.0	48	0.1	21	2.5	0.3	0.0	0.01	110	0.4	0.11	0.66	0.18	-0.01	92	0.1	1070	2				
	25%	1010	570	3.0	46	0.1	20	2.5	0.3	0.0	0.01	100	0.4	0.11	0.48	0.18	-0.01	69	0.1	792	2				
	50%	780	530	3.0	22	0.0	11	2.5	0.2	0.0	0.01	80	0.4	0.10	0.20	0.15	-0.04	33	0.1	646	2	3	-17	13	-14
	75%	460	290	3.0	7	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-0.11	6.7	0.1	226	1				
	90%	280	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.18	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.21	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG003																									
Exccedance probability	1%	1480	650	200	106	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2340	2				
	10%	1400	640	3.0	90	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	0.0	92	0.1	1810	2				
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.25	0.0	69	0.1	1570	2				
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	912	2	7	-13	25	-13
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	7	0.1	313	1				
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	69.5	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	61.6	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG003																									
Excceedance probability	1%	1110	580	200	86	0.2	35	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2210	2				
	10%	1080	580	3.0	76	0.1	31	2.5	0.3	0.1	0.01	110	0.5	0.12	0.67	0.23	0.0	92	0.1	1660	2				
	25%	1070	570	3.0	72	0.1	30	2.5	0.3	0.1	0.01	100	0.5	0.12	0.49	0.23	0.0	69	0.1	1430	2				
	50%	780	530	3.0	31	0.1	14	2.5	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	870	2	5	-15	22	-13
	75%	480	290	3.0	9	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	-0.1	7	0.1	295	1				
	90%	290	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG003																									
Excceedance probability	1%	1750	670	200	155	0.3	60	15.1	0.3	0.1	0.01	120	0.6	0.14	0.77	0.36	0.1	106	0.1	3270	3				
	10%	1640	650	3.1	133	0.3	52	3.5	0.3	0.1	0.01	120	0.6	0.13	0.67	0.33	0.0	93.7	0.1	2650	3				
	25%	1610	640	3.0	130	0.3	51	3.5	0.3	0.1	0.01	100	0.6	0.13	0.49	0.33	0.0	71	0.1	2440	3				
	50%	810	540	3.0	52	0.1	22	3.0	0.2	0.0	0.01	80	0.5	0.11	0.22	0.20	0.0	35	0.1	1210	2	10	-10	36	-8
	75%	650	310	3.0	11	0.0	7	2.6	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	381	1				
	90%	330	200	3.0	6	0.0	6	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	78.7	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	67	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG003																									
Excceedance probability	1%	1310	590	200	137	0.3	52	15	0.3	0.1	0.01	120	0.6	0.13	0.77	0.35	0.0	106	0.1	3050	2				
	10%	1270	580	3.0	122	0.3	46	2.6	0.3	0.1	0.01	110	0.5	0.13	0.67	0.32	0.0	94	0.1	2440	2				
	25%	1250	580	3.0	116	0.3	45	2.6	0.3	0.1	0.01	100	0.5	0.13	0.49	0.32	0.0	71	0.1	2230	2				
	50%	790	530	3.0	46	0.1	20	2.5	0.2	0.0	0.01	80	0.5	0.11	0.21	0.20	0.0	35	0.1	1110	2	9	-11	34	-8
	75%	540	290	3.0	10	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	360	1				
	90%	300	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG003																						Legend			
Excceedance probability	1%	810	560	194	14	0.0	6	15	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	2.7	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	2.5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	2.5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG005																									
Exceedance probability	1%	1470	650	200	105	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2320	2				
	10%	1400	640	3.0	89	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	0.0	93	0.1	1800	2				
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.24	0.0	69	0.1	1560	2				
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	908	2	7	-13	25	-13
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	7	0.1	312	1				
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	69.5	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	61.6	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG005																									
Exceedance probability	1%	1100	580	200	86	0.2	34	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2200	2				
	10%	1080	580	3.0	76	0.1	31	2.5	0.3	0.1	0.01	110	0.5	0.12	0.67	0.23	0.0	93	0.1	1660	2				
	25%	1070	570	3.0	72	0.1	30	2.5	0.3	0.1	0.01	100	0.5	0.12	0.49	0.23	0.0	69	0.1	1420	2				
	50%	780	530	3.0	31	0.1	14	2.5	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	868	2	5	-15	22	-13
	75%	480	290	3.0	9	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	-0.1	7	0.1	294	1				
	90%	290	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG005																									
Exceedance probability	1%	1740	660	200	154	0.3	60	15.1	0.3	0.1	0.01	120	0.6	0.14	0.77	0.36	0.1	106	0.1	3250	3				
	10%	1640	650	3.1	132	0.3	52	3.5	0.3	0.1	0.01	120	0.6	0.13	0.67	0.33	0.0	93.7	0.1	2640	3				
	25%	1610	640	3.0	129	0.3	50	3.5	0.3	0.1	0.01	100	0.6	0.13	0.49	0.33	0.0	71	0.1	2430	3				
	50%	810	540	3.0	52	0.1	22	3.0	0.2	0.0	0.01	80	0.5	0.11	0.22	0.20	0.0	35	0.1	1200	2	10	-10	36	-8
	75%	650	310	3.0	11	0.0	7	2.6	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	379	1				
	90%	330	200	3.0	6	0.0	6	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	78.7	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	67	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG005																									
Exceedance probability	1%	1300	590	200	136	0.3	52	15	0.3	0.1	0.01	120	0.6	0.13	0.77	0.35	0.0	106	0.1	3040	2				
	10%	1260	580	3.0	121	0.3	46	2.6	0.3	0.1	0.01	110	0.5	0.13	0.67	0.32	0.0	94	0.1	2430	2				
	25%	1250	580	3.0	115	0.3	44	2.6	0.3	0.1	0.01	100	0.5	0.13	0.49	0.32	0.0	71	0.1	2210	2				
	50%	790	530	3.0	46	0.1	19	2.5	0.2	0.0	0.01	80	0.5	0.11	0.21	0.20	0.0	35	0.1	1100	2	9	-11	34	-8
	75%	530	290	3.0	10	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	359	1				
	90%	300	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG005																									
Exceedance probability	1%	810	560	194	14	0.0	6	15	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	2.7	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	2.5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	2.5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Legend

- Above GV
- No mine scenario above GV
- Below GV

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stingent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at MG009																								
Excedance probability	1%	1400	690	200	66	0.1	28	0.3	0.0	0.01	120	0.46	0.11	0.77	0.2	0.0	106	0.1	1630	2				
	10%	1330	670	3.2	56	0.1	25	0.3	0.0	0.01	110	0.45	0.11	0.67	0.2	0.0	93	0.1	1190	2				
	25%	1290	650	3.0	54	0.1	24	0.3	0.0	0.01	100	0.45	0.11	0.50	0.2	0.0	71	0.1	900	2				
	50%	810	550	3.0	30	0.1	14	0.2	0.0	0.01	80	0.42	0.10	0.23	0.2	0.0	37	0.1	766	2	4	-1	17	-1
	75%	510	290	3.0	11	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.08	0.1	-0.1	6.8	0.1	362	1				
	90%	300	200	3.0	6	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	69.1	1				
	99%	220	160	3.0	5	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0997	61.9	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at MG009																								
Excedance probability	1%	1020	580	200	55	0.1	22	0.306	0.0	0.01	120	0.44	0.11	0.77	0.2	0.0	106	0.1	1510	2				
	10%	1010	570	3.2	47	0.1	20	0.3	0.0	0.01	110	0.44	0.11	0.67	0.2	0.0	93	0.1	1080	2				
	25%	1000	570	3.0	45	0.1	20	0.3	0.0	0.01	100	0.44	0.11	0.50	0.2	0.0	71	0.1	783	2				
	50%	790	540	3.0	24	0.1	12	0.2	0.0	0.01	80	0.42	0.10	0.23	0.2	0.0	37	0.1	673	2	3	-1	15	-1
	75%	420	260	3.0	10	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.08	0.1	-0.1	6.8	0.1	316	1				
	90%	280	190	3.0	5	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0996	49.9	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG009																								
Excedance probability	1%	1610	710	200	103	0.2	39	0.3	0.1	0.01	120	0.50	0.12	0.77	0.3	0.0	106	0.1	2290	2				
	10%	1520	680	3.3	88	0.1	34	0.3	0.1	0.01	110	0.49	0.12	0.67	0.2	0.0	93	0.1	1800	2				
	25%	1450	660	3.0	85	0.1	34	0.3	0.1	0.01	100	0.49	0.12	0.50	0.2	0.0	71	0.1	1540	2				
	50%	840	550	3.0	44	0.1	18	0.2	0.0	0.01	80	0.44	0.11	0.24	0.2	0.0	37	0.1	990	2	8	1	29	-1
	75%	560	290	3.0	12	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.09	0.1	0.0	7	0.1	455	2				
	90%	320	200	3.0	6	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	68.5	1				
	99%	220	160	3.0	6	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0997	61.5	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG009																								
Excceedance probability	1%	1090	580	200	84	0.2	34	0.3	0.1	0.01	120	0.49	0.12	0.77	0.2	0.0	106	0.1	2170	2				
	10%	1080	580	3.24	75	0.1	30	0.3	0.1	0.01	110	0.48	0.12	0.67	0.2	0.0	93	0.1	1670	2				
	25%	1070	570	3.01	71	0.1	29	0.3	0.1	0.01	100	0.47	0.11	0.50	0.2	0.0	71	0.1	1400	2				
	50%	790	540	3.01	36	0.1	16	0.2	0.0	0.01	80	0.43	0.11	0.24	0.2	0.0	37	0.1	920	2	6	0	25	-1
	75%	440	270	3	11	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.09	0.1	0.0	7	0.1	431	1				
	90%	280	190	3	5	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG009																								
Excceedance probability	1%	1910	720	200	151	0.3	59	0.3	0.1	0.01	120	0.58	0.14	0.77	0.4	0.1	106	0.1	3180	3				
	10%	1780	700	3.25	130	0.3	51	0.3	0.1	0.01	120	0.55	0.13	0.68	0.3	0.0	94	0.1	2620	3				
	25%	1700	680	3.04	127	0.3	50	0.3	0.1	0.01	100	0.55	0.13	0.51	0.3	0.0	72	0.1	2390	3				
	50%	960	550	3.03	63	0.1	26	0.2	0.1	0.01	80	0.47	0.11	0.24	0.2	0.0	39	0.1	1360	2	12	3	40	3
	75%	620	300	3	14	0.0	7	0.2	0.0	0.01	70	0.41	0.10	0.10	0.1	0.0	10	0.1	547	2				
	90%	340	210	3	6	0.0	6	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	77.2	1				
	99%	220	160	3	6	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	66.9	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG009																								
Excceedance probability	1%	1280	580	200	134	0.3	51	0.3	0.1	0.01	120	0.56	0.13	0.77	0.3	0.0	106	0.1	3000	2				
	10%	1250	580	3.25	119	0.3	45	0.3	0.1	0.01	110	0.54	0.13	0.68	0.3	0.0	94	0.1	2430	2				
	25%	1240	580	3.03	113	0.3	44	0.3	0.1	0.01	100	0.53	0.13	0.51	0.3	0.0	72	0.1	2180	2				
	50%	790	540	3.02	55	0.1	23	0.2	0.1	0.01	80	0.46	0.11	0.24	0.2	0.0	39	0.1	1250	2	11	2	39	3
	75%	480	270	3	13	0.0	7	0.2	0.0	0.01	60	0.41	0.10	0.10	0.1	0.0	10	0.1	520	1				
	90%	290	190	3	5	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	0.0	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG009																								
Excceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.40	0.10	0.77	0.1	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.40	0.10	0.68	0.1	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.40	0.10	0.49	0.1	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.40	0.10	0.24	0.1	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.40	0.10	0.07	0.1	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-	6.2	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-	6.0	0.1	50	1				

Legend

- Above GV
- No mine scenario above GV
- Below GV

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at End of RPA																								
Exccedance probability	1%	1350	670	197	58	0.1	25	0.3	0.0	0.01	120	0.4	0.11	0.77	0.19	0.0	106	0.1	1470	2				
	10%	1320	660	8.2	54	0.1	24	0.3	0.0	0.01	110	0.4	0.11	0.69	0.19	0.0	96	0.1	1090	2				
	25%	1270	650	3.0	51	0.1	23	0.3	0.0	0.01	100	0.4	0.11	0.50	0.18	0.0	71	0.1	889	2				
	50%	970	500	3.0	40	0.1	18	0.2	0.0	0.01	80	0.4	0.11	0.24	0.17	0.0	38	0.1	809	2	7	2	23	1
	75%	460	270	3.0	20	0.0	9	0.2	0.0	0.01	70	0.4	0.10	0.08	0.14	0.0	12	0.1	593	2				
	90%	310	200	3.0	11	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.08	0.13	0.0	7	0.1	341	2				
	99%	240	170	3.0	6	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	7	0.1	99.8	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at End of RPA																								
Exccedance probability	1%	1010	570	197	48	0.1	20	0.3	0.0	0.01	120	0.4	0.11	0.77	0.18	0.0	106	0.1	1360	3				
	10%	1000	570	8.2	44	0.1	20	0.3	0.0	0.01	110	0.4	0.11	0.69	0.18	0.0	96	0.1	1010	3				
	25%	990	570	3.0	42	0.1	19	0.3	0.0	0.01	100	0.4	0.11	0.50	0.18	0.0	71	0.1	761	3				
	50%	760	440	3.0	33	0.1	15	0.2	0.0	0.01	80	0.4	0.11	0.24	0.16	0.0	38	0.1	685	3	5	2	21	1
	75%	390	250	3.0	18	0.0	8	0.2	0.0	0.01	60	0.4	0.10	0.08	0.14	0.0	12	0.1	515	2				
	90%	280	200	3.0	10	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7	0.1	302	2				
	99%	230	160	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	7	0.1	89.7	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at End of RPA																								
Exccedance probability	1%	1540	690	197	90	0.1	35	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2030	2				
	10%	1500	680	8.2	85	0.1	34	0.3	0.1	0.01	120	0.5	0.12	0.69	0.24	0.0	96	0.1	1540	2				
	25%	1430	660	3.0	80	0.1	32	0.3	0.1	0.01	100	0.5	0.12	0.50	0.24	0.0	71	0.1	1490	2				
	50%	1090	510	3.0	61	0.1	24.5	0.2	0.0	0.01	80	0.5	0.11	0.24	0.21	0.0	**38**	0.1	1270	2	11	3	37	2
	75%	500	280	3.0	26	0.1	12	0.2	0.0	0.01	70	0.4	0.10	0.09	0.16	0.0	12	0.1	820	2				
	90%	320	200	3.0	14	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.09	0.14	0.0	8	0.0999	434	2				
	99%	240	170	3.0	6	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7	0.0999	126	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at End of RPA																								
Exccedance probability	1%	1070	580	197	73	0.1	30	0.3	0.1	0.01	120	0.5	0.12	0.77	0.23	0.0	106	0.1	1910	2				
	10%	1070	580	8.2	70	0.1	29	0.3	0.1	0.01	110	0.5	0.11	0.69	0.23	0.0	96	0.1	1410	2				
	25%	1040	570	3.0	66	0.1	28	0.3	0.1	0.01	100	0.5	0.11	0.50	0.22	0.0	71	0.1	1340	2				
	50%	800	450	3.0	51	0.1	21	0.2	0.0	0.01	80	0.4	0.11	0.24	0.20	0.0	38	0.1	1170	2	9	3	33	2
	75%	410	250	3.0	23	0.1	11	0.2	0.0	0.01	60	0.4	0.10	0.09	0.15	0.0	12	0.1	759	2				
	90%	290	200	3.0	12	0.0	6.8	0.2	0.0	0.01	50	0.4	0.10	0.08	0.14	0.0	8	0.1	408	1				
	99%	230	170	3.0	6	0.0	5.3	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	7	0.1	118	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at End of RPA																								
Exccedance probability	1%	1810	710	197	130	0.3	51.2	0.3	0.1	0.01	120	0.6	0.13	0.77	0.33	0.0	106	0.1	2810	3				
	10%	1760	690	8.2	126	0.3	49.7	0.3	0.1	0.01	120	0.5	0.13	0.70	0.32	0.0	96.8	0.1	2360	3				
	25%	1670	680	3.0	118	0.3	46.6	0.3	0.1	0.01	100	0.5	0.13	0.51	0.31	0.0	72	0.1	2260	3				
	50%	1260	520	3.0	89	0.2	36	0.2	0.1	0.01	80	0.5	0.12	0.25	0.26	0.0	39.2	0.1	1840	2	17	6	50	4
	75%	560	280	3.0	36	0.1	15	0.2	0.0	0.01	70	0.4	0.11	0.10	0.17	0.1	15	0.1	1020	2				
	90%	340	200	3.0	16	0.0	8	0.2	0.0	0.01	60	0.4	0.10	0.10	0.14	0.1	10	0.1	539	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.1	10	0.1	160	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at End of RPA																								
Exccedance probability	1%	1250	580	197	115	0.3	44	0.3	0.1	0.01	120	0.5	0.13	0.77	0.32	0.0	106	0.1	2610	2				
	10%	1240	580	8.2	112	0.3	43	0.3	0.1	0.01	110	0.5	0.13	0.70	0.31	0.0	97	0.1	2160	2				
	25%	1200	580	3.0	105	0.3	41	0.3	0.1	0.01	100	0.5	0.12	0.50	0.30	0.0	72	0.1	2060	2				
	50%	920	450	3.0	79	0.2	31	0.2	0.1	0.01	80	0.5	0.12	0.25	0.25	0.0	39	0.1	1690	2	15	5	48	4
	75%	440	260	3.0	33	0.1	14	0.2	0.0	0.01	60	0.4	0.11	0.10	0.17	0.1	15	0.1	964	2				
	90%	300	200	3.0	15	0.0	8	0.2	0.0	0.01	50	0.4	0.10	0.10	0.14	0.1	10	0.1	507	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.1	10	0.1	149	1				
Predicted 10,000 year concentrations for NO MINE scenario at End of RPA																					Legend			
Exccedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at Mudginberri Billabong																								
Exceedance probability	1%	1360	740	150	48	0.1	22	0.3	0.0	0.01	130	0.6	0.14	0.78	0.23	0.0	108	0.1	1090	2				
	10%	1270	690	4.4	45	0.1	21	0.3	0.0	0.01	110	0.5	0.13	0.55	0.21	0.0	79	0.1	816	2				
	25%	1230	670	3.5	43	0.1	20	0.3	0.0	0.01	90	0.5	0.12	0.34	0.20	0.0	51.7	0.1	738	2				
	50%	1100	600	3.4	39	0.1	18	0.2	0.0	0.01	80	0.5	0.12	0.16	0.20	0.0	28	0.1	686	2	7	4	26	2
	75%	610	350	3.3	24	0.1	11	0.2	0.0	0.01	70	0.4	0.11	0.11	0.16	0.0	16	0.1	568	2				
	90%	360	230	3.0	14	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	10	0.1	400	2				
	99%	250	180	2.9	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7.5	0.1	140	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at Mudginberri Billabong																								
Exceedance probability	1%	1090	670	150	39	0.1	19	0.3	0.0	0.01	120	0.5	0.13	0.78	0.22	0.0	108	0.1	1070	2				
	10%	1020	630	4.4	37	0.1	18	0.3	0.0	0.01	110	0.5	0.13	0.55	0.20	0.0	79	0.1	769	2				
	25%	990	610	3.5	35	0.1	17	0.3	0.0	0.01	90	0.5	0.12	0.34	0.20	0.0	52	0.1	666	2				
	50%	880	540	3.4	32	0.1	16	0.2	0.0	0.01	80	0.5	0.12	0.16	0.19	0.0	28	0.1	616	2	6	4	23	2
	75%	500	320	3.2	21	0.1	10	0.2	0.0	0.01	70	0.4	0.11	0.10	0.15	0.0	16	0.1	521	2				
	90%	320	220	3.0	13	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	10	0.1	369	1				
	99%	240	170	2.9	6	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7.5	0.1	130	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at Mudginberri Billabong																								
Exceedance probability	1%	1510	750	150	69	0.2	31.3	0.3	0.1	0.01	130	0.6	0.14	0.78	0.27	0.0	108	0.1	1300	2				
	10%	1410	700	4.4	65	0.2	29	0.3	0.1	0.01	110	0.5	0.13	0.55	0.25	0.0	79	0.1	1160	2				
	25%	1370	680	3.5	62	0.1	28	0.3	0.1	0.01	100	0.5	0.13	0.34	0.24	0.0	52	0.1	1100	2				
	50%	1220	600	3.4	56	0.1	25	0.3	0.1	0.01	80	0.5	0.13	0.17	0.23	0.0	29	0.1	1010	2	10	8	37	6
	75%	670	350	3.3	33	0.1	15	0.2	0.0	0.01	80	0.4	0.11	0.11	0.17	0.0	17.2	0.1	781	2				
	90%	380	230	3.0	18	0.1	9	0.2	0.0	0.01	70	0.4	0.10	0.10	0.15	0.0	12	0.1	523	2				
	99%	260	180	2.9	8	0.0	6	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	0.1	8.76	0.1	181	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at Mudginberri Billabong																								
Exceedance probability	1%	1180	670	150	61	0.2	27	0.3	0.1	0.01	120	0.6	0.14	0.78	0.26	0.0	108	0.1	1220	2				
	10%	1100	630	4.4	57	0.2	25	0.3	0.1	0.01	110	0.5	0.13	0.55	0.24	0.0	79	0.1	1050	2				
	25%	1070	610	3.5	55	0.1	24	0.3	0.1	0.01	90	0.5	0.13	0.34	0.24	0.0	52	0.1	994	2				
	50%	950	540	3.4	49	0.1	22	0.3	0.1	0.01	80	0.5	0.12	0.17	0.22	0.0	29	0.1	918	2	10	7	35	6
	75%	540	320	3.3	30	0.1	13	0.2	0.0	0.01	70	0.4	0.11	0.11	0.17	0.0	17	0.1	721	2				
	90%	330	220	3.0	16	0.1	8	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	12	0.1	487	2				
	99%	250	170	2.9	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.1	9	0.1	167	1				
Predicted 10,000 year concentrations for NO MINE scenario at Mudginberri Billabong																					Legend			
Exceedance probability	1%	940	660	149	15	0.0	6	0.3	0.0	0.01	120	0.5	0.13	0.78	0.16	-	107	0.1	892	1	Above GV			
	10%	880	620	4.3	8	0.0	6	0.3	0.0	0.01	110	0.5	0.12	0.55	0.15	-	78	0.1	536	1				
	25%	860	600	3.5	5	0.0	6	0.3	0.0	0.01	90	0.5	0.11	0.33	0.15	-	51	0.1	164	1	No mine scenario above GV			
	50%	760	530	3.4	5	0.0	6	0.2	0.0	0.01	80	0.4	0.11	0.16	0.15	-	27	0.1	56	1				
	75%	450	320	3.2	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.10	0.13	-	15	0.1	52	1				
	90%	300	220	3.0	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.08	0.13	-	10	0.1	50	1	Below GV			
	99%	240	170	2.9	4	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-	6.9	0.1	45	1				

Annex B Populated risk spreadsheet

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	02		Land use (cultural use of water for drinking & recreation)																			
T	J	02	01	Water not suitable for drinking due to mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	Restricted land use, decline in human health. Community trust and reputation. Closure criteria not met.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and times when water naturally not suitable for drinking/recreation not considered; need information on that if GVs not met.	Drinking and recreation GVs vs predicted CoPCNo GV s exceeded	P	VL						I						I
T	J	02	02		Contaminated by **Pit 3 (PEAK, P50)**					P	VL						I						I
T	J	02	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P	VL						I						I
T	J	02	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P	VL						I						I
T	J	02	05	Water not suitable for recreation due mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P	VL						I						I
T	J	02	06		Contaminated by **Pit 3 (PEAK, P50)**					P	VL						I						I
T	J	02	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P	VL						I						I
T	J	02	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P	VL						I						I
T	J	02	09	Water not suitable for drinking due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P		VL						I					I
T	J	02	10		Contaminated by **Pit 3 (PEAK, P50)**					P		VL						I					I
T	J	02	11		Contaminated by **Composite sources (10,000 Yr, P50)**					P		VL						I					I
T	J	02	12		Contaminated by **Pit 3 (10,000 Yr, P50)**					P		VL						I					I
T	J	02	13	Water not suitable for recreation due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P		VL						I					I
T	J	02	14		Contaminated by **Pit 3 (PEAK, P50)**					P		VL						I					I
T	J	02	15		Contaminated by **Composite sources (10,000 Yr, P50)**					P		VL						I					I
T	J	02	16		Contaminated by **Pit 3 (10,000 Yr, P50)**					P		VL						I					I

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	06		Flora & fauna (animal drinking water)																			
T	J	06	01	Water not suitable for animal drinking water due to mine contaminants OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	Wildlife health impacted with potential flow on impacts to biodiversity, cultural practices, spiritual beliefs, community trust and reputation.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and all CoPC assumed to be in a bioavailable form.	Wildlife GVs vs predicted CoPC. No GV s exceeded	P					VL						I		I
T	J	06	02		Contaminated by **Pit 3 (PEAK, P50)**					P					VL						I		I
T	J	06	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P					VL						I		I
T	J	06	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P					VL						I		I
T	J	06	05	Water not suitable for animal drinking water due to mine contaminants ON the RPA	Contaminated by **Composite sources (PEAK, P50)**					P						VL						I	I
T	J	06	06		Contaminated by **Pit 3 (PEAK, P50)**					P						VL						I	I
T	J	06	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P						VL						I	I
T	J	06	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P						VL						I	I

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	07		**Biodiversity & ecosystems (aquatic species protection)**																			
T	J	07	01	Elevated Mn in water (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	Aquatic toxicity with potential flow on impacts to biodiversity, cultural practices, spiritual beliefs, community trust and reputation.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and all CoPC assumed to be in a bioavailable form.	Based on highest species protection consequences for predicted Mn at End of RPA or Mudginberri Billabong vs. the site-specific Mn GVs	P			VH						IV				IV
T	J	07	02		Contaminated by **Pit 3 (PEAK, P50)**					P			VH						IV				IV
T	J	07	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P			H						IV				IV
T	J	07	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P			VL						I				I
T	J	07	05	Poor water quality for CoPC except Mn (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**				SPL GV met except for Al. Al above background (no mine scenario) increased with distance from mine sources so assumed not mine related.	P			VL						I				I
T	J	07	06		Contaminated by **Pit 3 (PEAK, P50)**					P			VL						I				I
T	J	07	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P			VL						I				I
T	J	07	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P			VL						I				I
T	J	07	09	Elevated Mn in water (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**				Based on highest species protection consequences for predicted Mn at MG003, MG005 or MG009 vs. the site-specific Mn GVs	P				H						IV			IV
T	J	07	10		Contaminated by **Pit 3 (PEAK, P50)**					P				H						IV			IV
T	J	07	11		Contaminated by **Composite sources (10,000 Yr, P50)**					P				M						III			III
T	J	07	12		Contaminated by **Pit 3 (10,000 Yr, P50)**					P				L						II			II
T	J	07	13	Poor water quality for CoPC except Mn (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**				SPL GV met except for Al. Al above background (no mine scenario) increased with distance from mine sources so assumed not mine related.	P				VL						I			I
T	J	07	14		Contaminated by **Pit 3 (PEAK, P50)**					P				VL						I			I
T	J	07	15		Contaminated by **Composite sources (10,000 Yr, P50)**					P				VL						I			I
T	J	07	16		Contaminated by **Pit 3 (10,000 Yr, P50)**					P				VL						I			I

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Level 5
348 Edward Street
Brisbane
QLD 4000
Australia
+61 7 3831 6744

Registered in Australia
Registered no. 010 830 421
Registered office
Level 5, 348 Edward Street,
Brisbane QLD 4000 Australia

For your local BMT office visit www.bmt.org

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APPENDIX 9.1: REVEGETATION STRATEGY FOR SAVANNA WOODLAND CONCEPTUAL REFERENCE ECOSYSTEM

Ecosystem Establishment Strategy for the Proposed Savanna Woodland Conceptual Reference Ecosystem

Ranger Mine Closure Plan 2024

Unique Reference: PLN007
Revision: 1.23.2

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1 ECOSYSTEM ESTABLISHMENT STRATEGY FOR THE PROPOSED SAVANNA WOODLAND CONCEPTUAL REFERENCE ECOSYSTEM

The sections below summarise key aspects of the current ecosystem establishment strategy, based on a range of research trials, as outlined in the Ranger Mine Closure Plan.

The Ranger Project Team continues to partner with Kakadu Native Plant Supplies Pty Ltd (KNPS), a local Indigenous business owned and managed by Dr Peter Christophersen. KNPS specialise in cultural-led land management and have a deep understanding of local ecology and environmental conditions. KNPS have been engaged to undertake land management activities (e.g. weed and fire management) on the RPA and the adjacent Jabiluka mining lease since 2005, extending to seed collection, tubestock propagation, planting and irrigation management. KNPS also regularly provides advice on ecosystem establishment and assists with stakeholder consultations.

In collaboration with KNPS, the Ranger Project Team have developed a Species Establishment Research Program (SERP) database. The SERP is vital to the revegetation strategy and includes information on:

- seed management – including species phenology and seed collection, storage longevity, viability and germinability;
- propagation – including seed treatments, inoculation, nursery germination rates, plant growth, seasonality of propagation and alternative propagation methods; and
- establishment methods – including relevant substrates, initial tubestock planting, direct seeding, secondary introduction, natural colonisation, persistence, expected growth and development at key stages, flowering, fruiting and recruitment.

A comprehensive research project on local flora seed biology by Bellairs and McDowell (2012) provided a foundation for the SERP, which has been continuously updated with available information from published literature, ongoing revegetation trials and traditional knowledge.

The current ecosystem establishment strategy is largely based on SERP data.

1.1 Construction of the Final Landform Growth Substrate

Waste rock backfill methodology

The surface layer of the waste rock landform is required to support the establishment of proposed vegetation communities, of which the Savanna Woodland Conceptual Reference Ecosystem (CRE) is most widespread. This CRE is characterised by a dominant overstorey of larger *Eucalyptus* trees. In natural systems, the root systems of these trees extend to at least 5 or 6 m below the surface, enabling access to water over the prolonged dry season (Hutley *et al.,* 2000).

Figure 2 shows an indicative depth of waste rock across the final landform. To facilitate root development, for areas of the waste rock landform that that will be filled with a depth of waste rock exceeding 6 m (i.e. not overlying natural ground), a 'vegetation growth layer' will be constructed to a depth of approximately 6 m. Like the methodology used in the construction of the TLF (Daws and Poole, 2010) and Pit 1, the vegetation growth layer will be constructed in two relatively thick layers, to a depth of 6 m, using techniques known as tip-head and paddock dumping.

As illustrated in Figure 1, tip-head dumping will be used for the lower layer, to achieve a consolidated boundary layer, which blocks preferential flow paths, slows water percolation and improves water-holding capacity. Paddock dumping will be used for the upper (surface) layer and contoured in alignment with the final landform design, with an acceptable construction tolerance in the order of +/- 1 m.

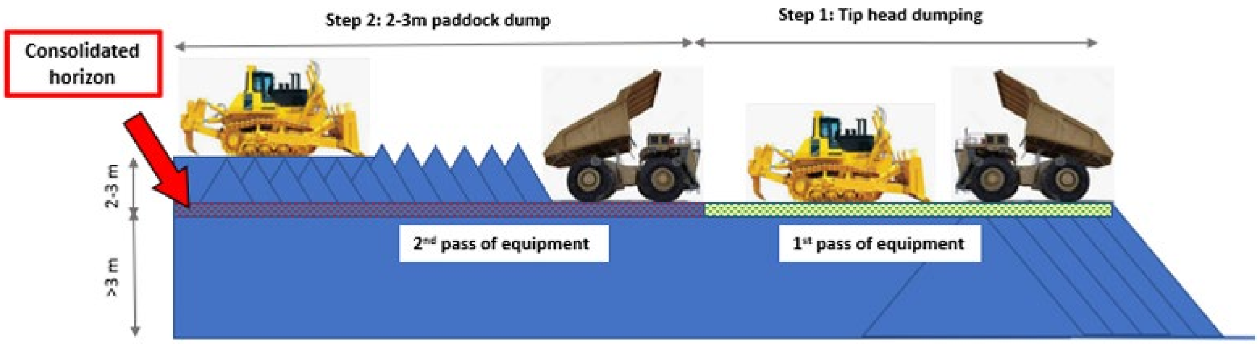

Figure 1: Construction method for final landform vegetation growth layer

Following construction of Pit 1 (completed in 2020) and initial planting, differential settlement of waste rock and the consolidation of tailings have contributed to localised depressions and variations across the Pit 1 surface, which was expected. During a visit in March 2023, Traditional Owners indicated that the areas of subsidence on Pit 1 are not a major concern at their current size and depth, and suggested certain flora species that may perform better in such conditions. It was noted however that large areas of subsidence across the landform would not be desirable. During another visit held in September 2023, there was further consultation with Traditional Owners around the acceptability of potential co-occurrence of *Melaleuca viridiflora* and *Eucalyptus sp.* on the final landform in some areas. A naturally occurring ecotonal community in adjacent areas on the RPA was also visited as a potential reference.

The final landform surface and the development of such localised depressions and variations at Pit 1 and other areas will be monitored and will influence the composition of any required infill planting, which may be more closely associated with the Seasonally inundated Savanna and Ecotones CRE.

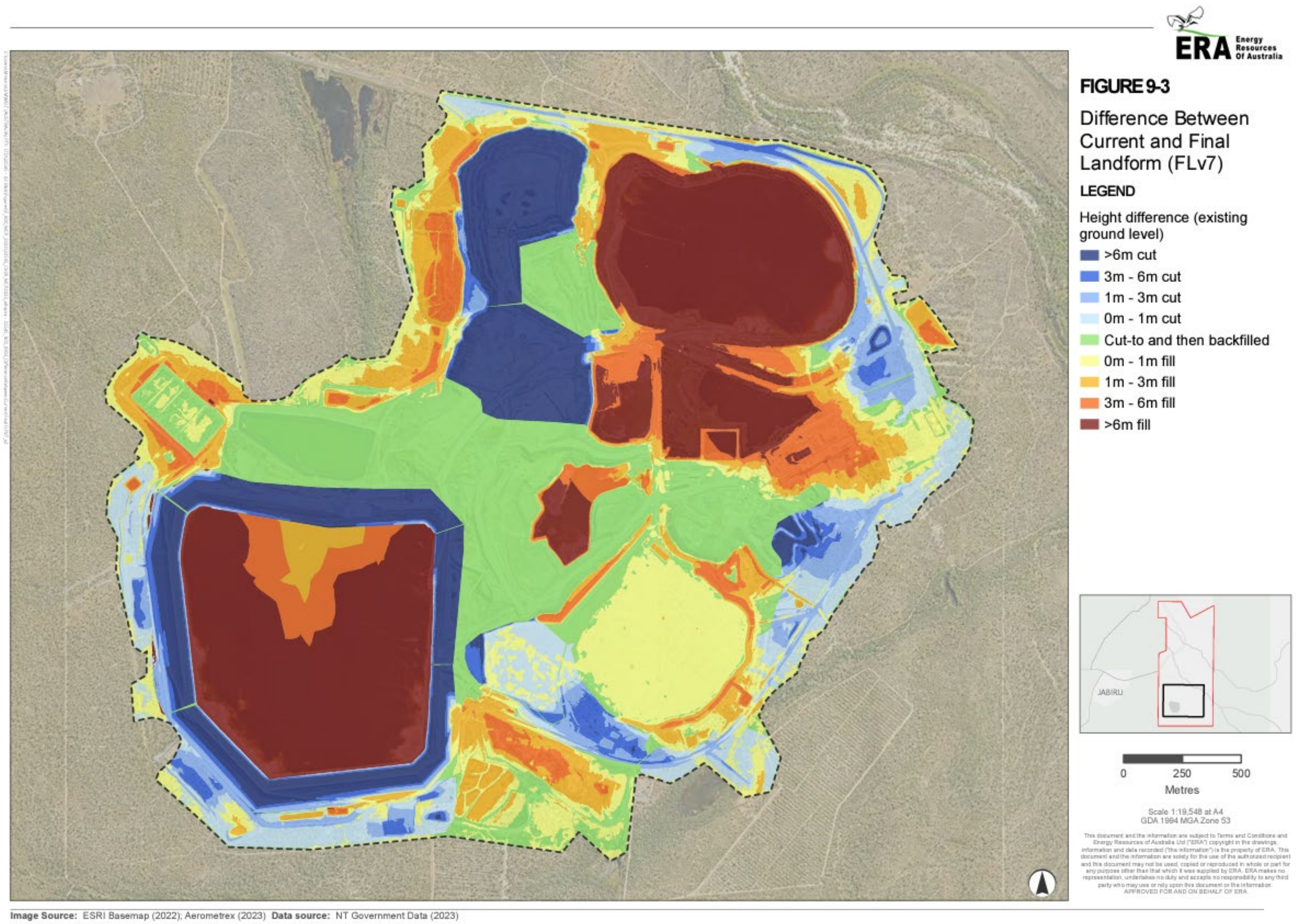

Figure 2: Indicative depth of waste-rock across the final landform

Waste rock backfill material and plant available water

It is necessary to determine if sufficient plant available water will be available in the final landform to support the planned vegetation community (this is the focus of KKN ESR7B, Appendix 5.1 of the MCP). In waste rock, plant available water (PAW) and its capacity to support target ecosystems is of potential concern due to the increased presence of large rock fragments and macropores when compared with natural soils.

Plant available water capacity is influenced by:

- the proportion of fine sediments (<2 mm), referred to below as 'fines'; and
- the total depth of the waste rock.

Studies and modelling for PAW conducted on the TLF, Pit 1 and established reference sites surrounding the disturbance area have indicated that for a waste-rock depth of at least 6 m, a minimum of 25% fines is sufficient to sustain the proposed Savanna Woodland CRE (Lu *et al.,* 2019; Okane, 2021). Conversely, a proportion of fines that is too great may impede drainage, favour weed colonisation and require a different vegetation community type. A subsequent report (Okane, 2024) presents modelling outputs for simulated high risk scenarios (prolonged drought and frequent fires) and their effect on PAW. Further analysis of these modelling outputs and potential implications for long-term substrate suitability is planned.

Particle size distribution sampling conducted by Douglas Partners during the construction of the Pit 1 vegetation growth layer verified that the waste rock substrate contained approximately 30%–40% fines (Miller, 2020). A study conducted on the TLF by Hancock and others (2020) suggested similar proportions of fines, however the larger rocks included in the TLF waste rock appear to have been excluded from analyses. For subsequent areas of the final landform, particle size analysis of waste-rock stockpiles indicates a general range of between 20%–45% fines (Douglas Partners, 2019a, however rocks larger than 150 mm were excluded, meaning that actual proportions of fines may be less).

Where possible, bulk material movement planning and implementation will be designed and managed to ensure that the vegetation growth layer, on average, contains at least 25% fines. To support decision-making on the ground, a visual guide of 'desirable' and 'undesirable' waste rock will be created to help with selection of growth layer material. This should help minimise the extent of areas with excessively coarse or fine waste rock.

Chemical characteristics

The non-mineralised (grade 1) waste rock material proposed for the vegetation growth layer differs from natural soils by having higher pH, electrical conductivity, cation exchange capacity, magnesium, total phosphorus and sulfate concentrations (Ashwath *et al.,* 1993).

. Hutley and others (2021) suggest that elevated levels of $MgSO_4$ can be reasonably classified as a low risk to vegetation growth, however this study is focussed on riparian species only.

For Savanna woodland, earlier studies by Malden and others (1994) indicated a potential impact of $MgSO_4$ to germination from seed. Efflorescence has been observed on the Pit 1 surface, along with poor vegetation growth of Savanna woodland species in some areas. Further investigations are planned to investigate potential impacts of chemical properties of waste rock, including excessive salts, on vegetation establishment, and any constraints this may pose to long-term ecosystem development.

For non-waste rock areas, and particularly LAAs that were irrigated with mildly contaminated pond water for decades, no noticeable impacts to vegetation health have been observed (EcOz, 2022).

Cut-to areas and potential sub-stockpile compaction

The area known as Stage 13.1 is a 4 ha section of final landform that became available for revegetation at the beginning of 2020. The area was cut down from a waste rock stockpile to the designed final landform surface level (i.e. cut-to), leaving an average 3.1 m thick layer of waste rock overlying natural ground.

Generally, the revegetation at Stage 13.1 has performed relatively poorly. Besides compaction, this was attributed to a range of factors as described by Wright and others (2021).

To investigate concerns with compaction of cut-to stockpile areas, dynamic cone penetrometer (DCP) testing was conducted prior to revegetation activities at two locations at Stage 13.1, where the total waste-rock depth measured at 1.7 m and 2.5 m over natural ground (Douglas Partners, 2019b). Similar DCP testing was also conducted on equivalent natural soils during geotechnical investigations for the Jabiru power station (Construction Sciences, 2020). A comparison between the two studies suggests that:

- DCP testing in waste rock is highly variable due to the presence of rocks and may not be the most accurate indicator for compaction; and
- cut-to waste rock may potentially be more compacted than natural ground for at least the first 0.6 m.

Figure 1 illustrates that almost one-third (28%) of the final landform will be cut-to areas (noting that an additional 19% will be cut-to and then backfilled). As such, further investigation into the characteristics of these areas and the treatment that can be applied to maximise plant performance (e.g. deep ripping followed by contouring to create a surface easily traversed on foot) are planned.

1.2 Surface preparation and rock habitat features

Surface preparation

Ripping is a common industry practice used in mine site rehabilitation to aid vegetation establishment. The process improves the success of re-vegetation by promoting infiltration of surface water and assisting in capture of organic material and finer sediments locally.

The entire TLF was ripped at 2 m intervals along the contours to a depth of approximately 50 cm (Daws and Poole, 2010, Plate 1). Over a decade later, the surface has a similar appearance now to what it did immediately after ripping. This has contributed to concerns by Traditional Owners around traversability and they have indicated a preference to minimise ripping wherever possible across the final landform.

As part of a trial, a similar approach was applied at Stage 13.1, albeit during the wet season when ground was soft. This resulted in larger boulders catching the grader tynes, leaving deep linear gouges across the surface (Wright *et al.,* 2021).

With lessons learnt from the TLF and Stage 13.1, a different approach was trialled on the surface of Pit 1. A grader blade was used to apply a light scarification (i.e. shallow 'ripping' using a grader blade with teeth 10 cm deep). Recent inspections suggest that the surface scarification is no longer visible and the surface is easily traversed on foot (Plate 2). At this early stage, the lesser degree of surface preparation has not had a noticeable impact on ecosystem establishment.

Surface scarification, like that for Pit 1, will be conducted for the majority of the final landform. Deeper ripping for the purpose of erosion control will only be implemented if required and in consultation with stakeholders.

Plate 1: Contour ripping on trial landform trial of 2 m interval (2010)

Plate 2: Scarification of the Pit 1 surface as seen in January 2024

Rock habitat features

Nine distinct rocky habitat features were constructed on Pit 1 during 2021 (Plate 3). The rock habitat features were designed by Dr Peter Christophersen (KNPS), in consultation with the Mirarr, as documented by Brady and others (2021), to improve cultural values, landscape heterogeneity, and encourage a diversity of preferential flora and fauna.

For the broader final landform, similar rockpiles are proposed along pre-determined lines (also developed in consultation with the Traditional Owners) that will link the surrounding ecosystem to the final landform (Figure 2) and encourage the return of fauna from the surrounding areas. Excess large rocks will be recovered during bulk material movement and used for this purpose.

Discussions of the links between desired flora and fauna and people's connection to each other and to places, story and cultural practice, have also been held. The selection of plant species that may be actively established for the rocky habitat features will be determined through further engagement, to incorporate traditional ecological knowledge and cultural preferences.

With regards to the benefit of these and similar rocky habitat features for fauna colonisation, ongoing monitoring will provide valuable learning opportunities for future landform design and planning.

Plate 3: Rocky outcrop habitat feature installed on Pit 1

Figure 3: Preliminary plan for rocky habitat feature lines on the final landform

1.3 Additional supplementation of fauna habitat

In 2023, a literature review identified opportunities to artificially or naturally enhance Ranger's rehabilitation areas to ensure that sufficient habitat resources exist (the focus of KKN ESR2B, Appendix 5.1 of the MCP).

The key findings included:

- fire regimes and exotic fauna pose the biggest threats to native fauna populations;
- recolonisation barriers may include poor dispersal capability from source populations, increased competition or predation, limited foraging resources, poor breeding opportunities or absence of mature habitat features.
- important habitat components comprise species rich overstorey and understorey vegetation, with a degree of landscape level heterogeneity;
- appropriate understorey should be established as early as possible, maximising available habitat, resources and refuge from predators;
- successional fauna return is expected as vegetation is established, which may be augmented by artificial habitat structures;
- caution should be exercised with early establishment of artificial habitat structures prior to development of a mature vegetation structure (15–20 years), which may contribute to an ecological trap for returning species, where foraging resources are lacking and/or predation is favoured; and
- habitat creation and enhancement should be iterative and adaptive.

Habitat features such as leaf litter, stag trees, coarse woody debris and hollows are expected to form naturally over varying timeframes. Of these, hollows are the slowest, with studies suggesting that it may take up to 100 years or more before the formation of tree hollows provides suitable habitat for some species (Taylor *et al.,* 2003; Goldingay, 2009; Goldingay, 2011). To aid relatively short-term recruitment of fauna, several feasible options for artificial habitat enhancement have been identified. The knowledge base for each of these is described below.

Artificial nest boxes

A large-scale nest box trial is currently active on the RPA. This includes the installation of approximately 90 nest boxes using five distinct designs to accommodate different faunal groups (small mammals, medium-sized mammals, small birds, medium-sized birds, micro-bats). The boxes are fixed to trees on the TLF, disturbed remnant vegetation on-site and natural reference sites. The trial design is documented in an implementation plan (SLR, 2022) which was endorsed by stakeholders at ARRTC 50. Monitoring by camera traps will be conducted for a minimum total period of 12 months. Outcomes will be presented to stakeholders for further discussion and inclusion in future iterations of the MCP.

Transplantation of leaf litter and humus from surrounds

This has multiple benefits including habitat for invertebrates and foraging resources for vertebrates. However, practical feasibility for a site wide strategy requires further consideration.

1.4 Seed collection and storage

The approved provenance zone for seed collection is based on assessment of environmental factors, species distributions, taxonomy, present and past gene flow, and species traits known to influence genetic variation in plants. Findings are presented in Zimmermann (2013) and Zimmermann and Lu (2015), with the GAC approved 'conservative provenance zone' clipped to the boundary of Kakadu National Park, as shown on Figure 3.

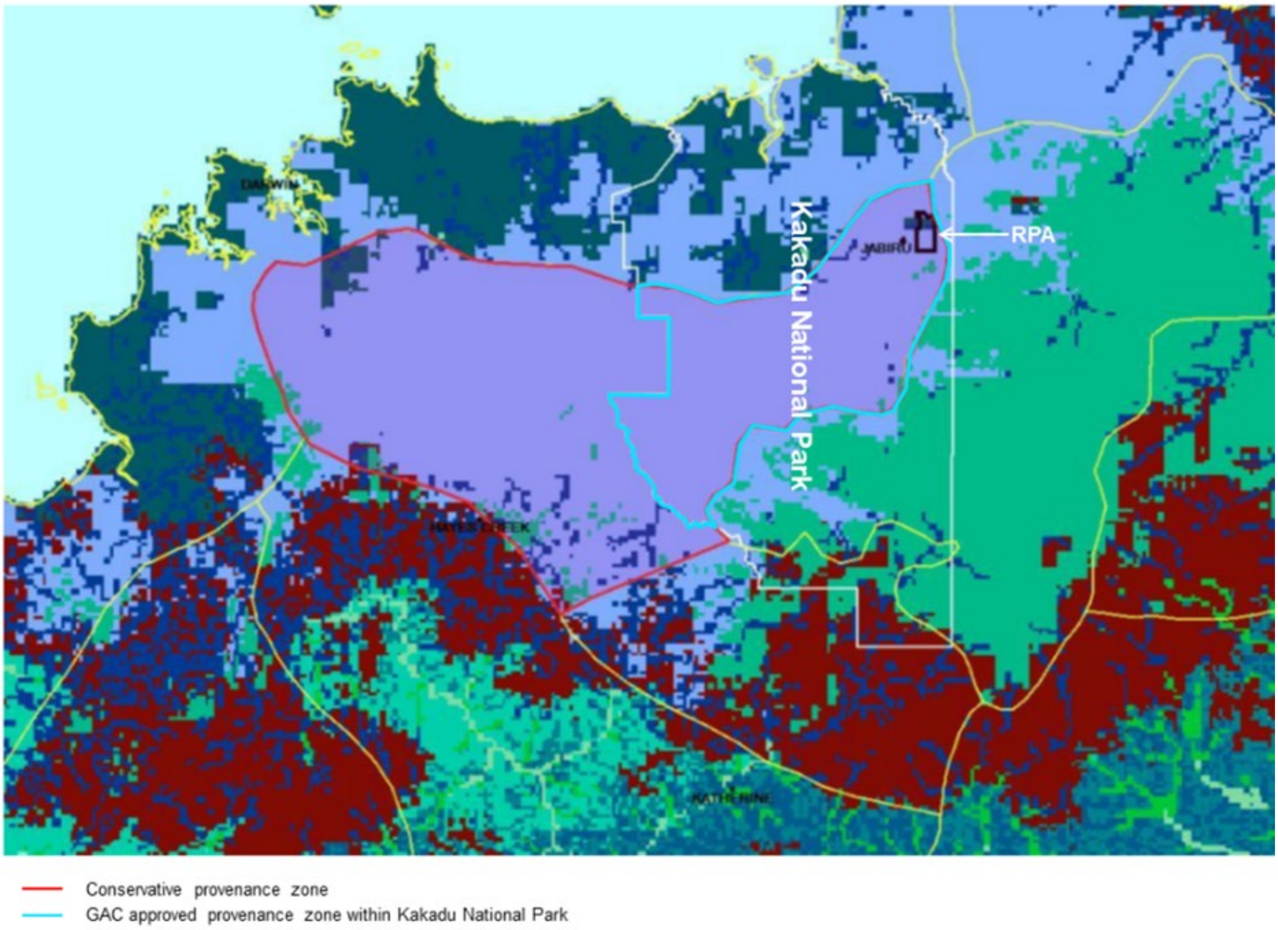

Figure 4: Proposed conservative provenance zone (bordered by the red line) and the GAC approved provenance zone within Kakadu National Park (bordered by the blue line)

Kakadu Native Plant Supplies Pty Ltd (KNPS) collect seeds within the established provenance zone as per the terms and conditions agreed with Kakadu National Park. The permit and approved provenance zone assist in ensuring:

- the genetic make-up of the revegetation and resilience is consistent with locally adapted populations of each species and provides a buffer for adapting to future climate change;

- seeds collected are well adapted to the environmental conditions and promote sufficient genetic diversity to prevent inbreeding; and
- the impact of seed collection to the natural and cultural values of Kakadu National Park are managed.

Seed availability for collection may be influenced by various environmental factors, including repeated 'poor' wet seasons, herbivory by fauna (e.g. cockatoos) or fire. For this reason, the collection program is designed with a degree of flexibility and allows for and encourages early collection for species with adequate storage life. Regular reconnaissance, field testing and knowledge of the landscape ensures that seed is collected at maximum viability. After collection, vegetative material is carefully processed according to industry standards and traditional knowledge for individual species, with relatively pure seed lots dried to maintain viability for long-term storage.

Seed storage principles are based on minimising temperature, moisture content and oxygen. To achieve these conditions, dried seed lots are vacuum-packed and managed for long-term storage. Vacuum-packing minimises exposure to oxygen, humidity and limits the impacts from pests. A consistent temperature of 21°C minimises the effects of condensation when seed lots are exposed to ambient temperatures in a tropical climate. Unprocessed plant material and bulk grass seed is stored separately to avoid transfer of pests.

This process has so far proven to be effective. In 2019, CDU was engaged to conduct seed viability and germination testing for 80 selected seed lots across 49 species with a range of collection dates. The results were used to validate the storage process and facilities, whilst determining acceptable storage timeframes for various species and groups. The Ranger Project Team is in the processes of setting up an ongoing, periodical seed testing campaign, which will further inform collection and storage requirements.

The majority of dominant species (e.g. Eucalypts, Corymbias and Acacias) have a proven seed longevity of at least 8-10 years, and a large portion of required seeds have already been collected and are in storage. Other species with limited storage life will require collection closer to the time of planting.

A seed management database is maintained, which includes and is progressively updated to include:

- relevant information for each seed lot, including collection details, estimated storage life, estimated viability and quantity of available seed;
- area based target planting densities, considering predicted ecosystem development and designed to achieve relevant CRE's; and
- a derived annual plan for seed collection, considering previous experience.

1.5 Tubestock propagation

For many rehabilitated mine sites, most flora species are established by direct seeding. Results can be variable and are often supplemented with tubestock planting, particularly in the case of hard-rock mines. At Ranger, the harsh conditions and absence of available topsoil have led to historic direct seeding trials indicating poor outcomes, particularly when assessed against environmental requirements for rehabilitation and criteria. With historic revegetation trials and more recently the Trial Landform (TLF), planted tubestock areas have out-performed direct-seeded areas in terms of plant survival, growth, stem density and species composition (Daws and Gellert, 2011; additional unreported data). In addition, the increased rates of germination under nursery conditions allow a significant reduction in the volume of seed required to achieve the same densities. This is favourable considering the restricted seed collection provenance zone and permit limitations within Kakadu National Park.

Understory species have seen similar results. Parry and others (2022) found that several understorey species planted from tubestock demonstrated increased growth, persistence, recruitment and spread, compared to individuals that were directly seeded, resulting in larger, more robust plants.

With tubestock being the preferred establishment method for the majority of species, the production capacity of the Ranger plant nursery is an important consideration. The nursery has capacity for approximately 100,000 tubestock at any one time, with an average tubestock growth time for most species of around two to three months. If scheduling requires year round planting then it may be feasible to produce three rounds of propagation annually, with an annual capacity of around 300,000 tubestock. However, planting in the late wet or early dry season (typically April/May) (with provision of suitable irrigation) will be prioritised for a number of reasons, including:

- maximum availability of species with perishable seed, allowing propagation of a greater species richness;
- avoidance of dormancy issues with some species that occurs when propagated over the dry season and planted during the build-up;
- optimal access to planting areas by heavy machinery and vehicles;
- minimal impacts from wind, heavy rain and erosion;
- minimal early impacts from weeds, pests and disease in cooler weather;
- controlled conditions for irrigation; and
- relatively cooler temperatures more favourable for planters and for reducing planting shock.

For planting in other seasons, trials have indicated that variations in germination and growth for most species can be accounted for with particular techniques, including the use of a naturally heated greenhouse, longer propagation periods and increased initial planting densities.

Records are maintained for nursery production and will be used to inform nursery production for the final landform. The records include species specific details of:

- optimal propagation period for different seasons;

- optimal germination methods (e.g. seed trays or required seed quantities per pot); and
- commentary on susceptibility to fungus, influence of seed age, seasonal variations, etc.

To maintain tubestock quality, a tubestock standard has been developed for Ranger Mine Nursery, based on industry best practice, field trials, observations and local knowledge. This is presented in Table 1.

Table 1: Tubestock standard for Ranger Mine Nursery

Standard	Description
Pot type	Seedling supplied in standard plastic tube, unless otherwise directed, without significant damage.
Potting mix	Potting mix with appropriate water holding capacity, and incorporated slow-release fertiliser and microbial additives, to a level within 5 mm of pot lip.
Genetic diversity	Sufficient genetic diversity.
Size and age	Seedling is appropriate size and age as verified by reference material and/or Ranger Project Team supervisor, i.e. with multiple sets of leaves and holding potting mix without major signs of root bounding.
General health	Leaf colour and size is true to species form, without signs of active pests, disease, dieback or injury.
Seedling structure	Seedlings should be growing in accordance with natural habit (i.e. free standing where applicable without staking or tip pruning).
Stem position	The seedling stem base should be at least 10 mm from the edge of the pot.
Arrangement	Prior to planting, seedlings must be arranged into planting trays as specified by the area-specific planting plan.

Pot type

Standard plastic nursery tubes are the commercial standard and were used for all revegetation trials at Ranger prior to 2017. Biopots have since been used in revegetation trials since 2018. The biopots are made from a compacted rice-hull and are a similar shape to the standard tubes. So far, the biopots have proven to be suitably durable under irrigation regimes and provide the added benefit of allowing tubestock to be planted whilst remaining in the pots. However, when compared to standard plastic tubes, the biopots planted on Stage 13.1 and Pit 1 demonstrated poorer survival rates. In addition, the decomposition rates of biopots planted within waste-rock are uncertain and may result in poor root formation and restrict the movement of water and nutrients. With consideration of the above risks, standard plastic nursery tubes are specified as the preferred pot type and can be sterilised for repeat use. The use of biopots may still be considered for smaller planting areas.

Seed cannot be stored for particular species (e.g. *Planchonia careya*). In these cases, tubestock has previously been propagated when seed is available and then held for an extended period of time before planting, with transfer into larger pots to reduce root bounding. Although this method has proven successful, larger plants are more difficult to handle during planting and require larger holes, therefore will be avoided as much as possible.

Potting mix and microorganism inoculation

Microorganism inoculation, often with commercially produced microbial additives, has become standard practice in many commercial nurseries due to the vital role that microbes perform in plant nutrient acquisition. Reddell and Zimmermann (2002) suggest that inoculation can be achieved using ectomycorrhizal fungi collected from surrounding areas. This was done for tubestock planted on the TLF and Stage 13.1.

For Stage 13.1, trial outcomes indicated that seedlings inoculated with locally sourced and/or commercial microbes were more robust than control seedlings. Furthermore, the better performing areas on Pit 1 suggest that commercially sourced microbial additives are generally suitable.

Commercial microbial additives will be included in the standard potting mixes used for subsequent areas.

Promotion of genetic diversity

Sufficient genetic diversity of tubestock will improve the overall resilience to external threats and prevent issues associated with inbreeding. Each delivered seed lot is made up from several individual plants and will include a degree of genetic diversity.

Tubestock size and age

With regard to tubestock size and age, trials have indicated that tubestock with a larger ‘root to shoot’ ratio are less prone to root bounding, more resilient and have a reduced initial water demand after planting.

1.6 Provision of suitable irrigation

Due to harsh environmental conditions and unreliable rainfall, initial irrigation for up to six months has proven to be essential for successful establishment of tubestock on waste rock, as indicated by historic trials and more recently at the TLF (Daws and Gellert, 2010, Daws and Gellert, 2011), Stage 13.1 and Pit 1. These trials have included networks of raised rotational sprinklers and a travelling large-scale pivot system, both with relatively gentle application so not to displace newly planted seedlings or substantially contribute to erosion of the new landform. Georgetown Creek Median Bund Leveline (GCMBL) was used as the water source for both the Pit 1 and Stage 13.1 trials, with regular water quality testing undertaken to indicate the suitability of water for irrigation.

For the broader final landform, monitoring and maintenance of the irrigation system during plant establishment is imperative. Any damage or malfunctioning of the irrigation equipment must be recognised early to minimise impact upon vegetation. The use of pressure-based alarms and a log recording the operation of each panel will ensure that any incidents are recognised and rectified.

The optimal regime will be unique for each area and influenced by rainfall patterns, season, substrate, temperatures, wind, evaporation, and infiltration rates. Irrigation should aim to optimise survival while ensuring appropriate root development and long-term resilience to drought conditions. Ongoing irrigation regime will be informed by regular monitoring of vegetation response and may require maintenance and operation for up to six months.

Similar to what was applied at Pit 1, the following broad principles will be considered:

- irrigation applied immediately prior, during (if practical) and following planting to cool surface temperatures and minimise planting shock (this may be achieved with a combination of automated irrigation and/or low pressure hoses);
- revegetation areas to receive up to 5 mm of irrigation every 12 hours immediately following planting to maintain moisture levels in the upper substrate profile;
- irrigation gradually reduced to nightly soaks over the course of a few weeks; and
- as plants begin to settle (i.e. post-planting mortality rate is stabilised with plants showing signs of new growth), less frequent, heavier soaks applied over several months, with the upper substrate profile partially drying in between.

1.7 Application of pre-emergent herbicide

For most areas of Stage 13.1 and Pit 1, Cavalier (a pre-emergent herbicide with active ingredient Oxyfluorfen at 240 g/L) was applied evenly at a rate of approximately 1.9 L/ha, either under irrigation or during the wet season, a minimum of two weeks prior to planting. The active ingredient in this herbicide kills seedlings upon germination and can be very effective in preventing colonisation of bare surfaces. To optimise effectiveness, the substrate surface was not disturbed for at least two weeks following application, and germination of the weed seeds was encouraged (via irrigation and/or seasonal rainfall). In areas where this wasn't applied, the effect has been clear, with substantially increased weed cover, competition with establishing vegetation and ongoing management required.

For subsequent areas of the final landform, a similar methodology will be applied during the wet season following construction of the surface layer, and prior to planting. A period of time will need to be allowed between application of a pre-emergent herbicide and planned direct seeding activities. At this stage, considering typical rates of decomposition, a conservative approach of at least four weeks is proposed.

In addition to the application of pre-emergent herbicide, emergent weeds will be treated with appropriate short acting herbicides prior to planting.

1.8 Preparation of planting holes

Preparation of planting holes will utilise a custom-designed auger (designed by KNPS) attached to a small excavator (Plate 4). This method creates a hole approximately 400 millimetres (mm) deep and 150 mm wide. Monitoring data for areas where this was previously implemented (Stage 13.1 and Pit 1) suggests that this approach is suitable.

Plate 4: Small excavator with auger attachment

1.9 Fertiliser application for establishment

A slow-release tabular and/or granular fertiliser (suitable for native plants) will be applied to the base of each planting hole during planting, and mixed with the backfilled substrate, which has proven to be a suitable approach.

Re-application of a similar granular fertiliser has been applied during the following wet season to the base of establishing plants, however further refinement regarding the methodology and timing for this may be conducted.

1.10 Tubestock planting

Appropriate planting zones will be clearly defined across the final landform, including a network of access tracks to support initial planting, irrigation, monitoring and maintenance. As with previous revegetation trials at Pit 1, for 1,000 tubestock per hectare, these will be planted at a spacing of approximately 2–4 m in a non-uniform pattern.

Plants will be carefully removed from plastic pots and placed into the planting hole to minimise loss of potting mix. Holes will be backfilled manually with the surrounding loosened substrate, focusing on contact with fines and removal of large rocks. The surface of the potting mix should be just below the final surface leaving a very slight depression which will assist with collecting water for the plant (Plate 5).

Plate 5: Planting of tubestock

In non-waste rock areas, planting without irrigation has proven to be successful if it can be timed with the onset of monsoon. In the case where irrigation is not able to be installed, a small handful of pre-soaked water crystals will be added to the base of each planting hole.

Biopots may still be used for some areas and should be lightly crushed at the bottom prior to planting to facilitate root development, and account for uncertainties with pot decomposition rates. The rims of biopots should be buried below the surface to improve thermal insulation of the root ball and prevent moisture wicking.

1.11 Direct seeding (for suitable species only)

Although establishment from tubestock is the preferred method for most species, the benefits from a resourcing and cost perspective have prompted several trials, with reasonable success for some understorey species and a few midstory species.

Key learnings, as described by Parry and others (2022) and applicable to direct seeding under a mature canopy, are described in the following points:

- Germination and persistence from seed is generally increased with the use of surface litter, likely due to retained moisture and reduced surface temperature. The surface litter may also protect the seeds/seedlings from rain wash or uprooting, and predation.
- Under optimal conditions, the use of fertiliser may account for waste rock nutrient deficiency and is found to increase growth, flowering and fruiting.

Further unreported trials at the TLF and Pit 1 have seen some success with direct seeding under warm and wet conditions, whilst heavy rain has been observed to wash away seed from relatively bare areas. A direct seeding approach may be adopted for select species which have proven successful.

1.12 Secondary introductions

Where they require specific environmental conditions (e.g. accumulation of organic matter, surface cover and canopy cover), identified species may be established entirely via secondary introductions. An early study included in Gellert (2014) indicated that *Xanthostemon paradoxus*, a common local tree species, may fall into this category, however more recent investigations on Stage 52 have so far indicated that this limitation may be overcome with suitable initial irrigation and improved quality of tubestock. Remaining species that fall into this category are more likely to include herbaceous forbs and vines, of which the specific methods and optimal timing will be determined with ongoing monitoring and further trials on more mature revegetation (e.g. TLF).

1.13 Proposed Savanna Woodland CRE

The proposed savanna woodland CRE (Table 4 and Table 5) is largely based on data provided by the Supervising Scientist (2021). There are however several species and vegetation groups for which composition/abundance is modified (Table 2).

Table 2: Differentiation of the savanna woodland CRE from reference sites

Species of vegetation group	Description of differentiations in comparison to reference sites and/or previous experience
Understorey (particularly *Sorghum spp.)*	Several regional studies, including those conducted recently by Paramjyoti and others (2024), highlight the effect of frequent fires on the dominance of *Sorghum spp.* in the understorey. These studies suggest that most of the reference sites (which include *Sorghum spp.* as dominant understorey) are influenced by an inappropriate fire regime and should not represent a direct target for a sustainable re-constructed ecosystem, at least with regards to understorey. This concept was discussed at a workshop on the 24th of June 2021, which involved relevant ERA, OSS and NLC personnel, as well as experts from Charles Darwin University and KNPS. One outcome was the adoption of a ‘functional understorey approach’ for understorey composition closure criterion. This allows for a target composition that does not necessarily include a dominance of *Sorghum spp*., will promote a more appropriate fire regime, and improve species richness and diversity. Drawing on outcomes from a workshop in August 2023, a Savanna Woodland CRE ‘functional’ understorey composition and trajectory has been developed and includes shrubs (legume and non-legume), grasses (perennial and annual), forbs and vines (legume and non-legume). A draft list of species is included in Table 5. It is noted that this list is not exhaustive, and some potential naturally recruiting species have only been identified to genus or family level. Proposed establishment methods will be further developed with consideration of trial outcomes and ongoing monitoring.
Acacias	As documented by Paramjyoti and others (2024), the dominance of *Acacia mimula* in surveyed reference sites is attributable to frequent fire. Whilst the CRE will still have *Acacia mimula* as a dominant Acacia, there will also be increased target relative abundance for several other Acacia species which have been identified as ecologically and/or culturally important.
Dry monsoon forest sub-community	Several species that have been identified as culturally significant and do not occur in reference sites (e.g. *Allosyncarpia ternata, Ficus spp*.) are proposed for establishment in ‘clusters’ of forest around rockpiles and/or broad concave slopes, with relatively low average densities across the landform, and in consultation with Traditional Owners.

Table 3 provides commentary for several of the attributes presented in Table 4 and Table 5.

Table 3: Description of the attributes relevant to the savanna woodland CRE

Attribute	Description
Relevance	Indication of relevance with regard to relative density in reference sites, identified cultural species, and/or functional attributes.
Target stems per hectare or percentage ground cover (minimum and maximum)	Prescription of the allowable range, which is derived from, and reflects the high degree of variability between reference sites. This will encourage a variable composition across the landform, which may be tailored to suit localised variations in the topography and structure of the waste rock landform. Default ranges are applied for species that do not occur in reference sites (OSS 2019) but have been identified culturally (Garde 2015) or experienced previous success. Target percentage ground cover for understorey is not yet confirmed and will be included in future iterations of the MCP.
Target stems per hectare or percentage ground cover (minimum average)	Prescription of the minimum average across the final landform, which is derived from average stem densities in reference sites, however reduced proportionately to allow increased species richness without overcrowding. Relatively small minimum average densities are included by default for species that do not occur in reference sites. Target percentage ground cover for understorey is not yet confirmed and will be included in future iterations of the MCP.
Proposed establishment method	By tubestock, direct seeding or natural recruitment, based on research outcomes. Planting methods and timing for active introduction of understorey species is not yet confirmed and will be included in future iterations of the MCP.
Initial planting density (minimum, maximum and average)	Values are estimated based on target stems and trial performance outcomes for each species. Values will be progressively updated with consideration of ongoing monitoring outcomes. through experience and monitoring species ongoing rehabilitation performance. Planting density for understorey is not yet confirmed and will be included in future iterations of the MCP.

Table 4: Proposed Savanna Woodland Vegetation CRE and planting density for midstorey and overstorey species

Species	Growth form	Reference	Target stems per ha. (min)	Target stems per ha. (max)	Target stems per ha. (ave)	Proposed Establishment Method	Initial planting density (stems/ha.) (min)	Initial planting density (stems/ha.) (max)	Initial planting density (stems/ha.) (ave)	Comment
Acacia difficilis	Shrub	Identified cultural species	0	30	15	Tubestock	0	46	23	Success with tubestock. Reduced population in reference sites possibly influenced by fire regime.
Acacia dimidiata	Shrub	Patchy coverage in reference sites, identified cultural species	0	30	15	Tubestock	0	50	25	Success with tubestock. Reduced population in reference sites possibly influenced by fire regime.
Acacia hemignosta	Tree	Sparse in reference sites	0	30	15	Tubestock	0	43	21	Success with tubestock.
Acacia lamprocarpa	Tree	Sparse in reference sites, identified cultural species	0	30	15	Tubestock	0	38	19	Success with tubestock.
Acacia latescens	Shrub	Spare in surrounding environment. High density in Ranger EIS	0	30	15	Tubestock	0	43	21	Success with tubestock. Reduced population in reference sites possibly influenced by fire regime.
Acacia mimula	Shrub	Dominant in reference sites (potentially influenced by inappropriate fire regime)	20	180	60	Tubestock	27	240	80	Success with tubestock.
Acacia oncinocarpa	Shrub	Patchy, sparse coverage in reference sites	0	50	15	Tubestock	0	77	23	Success with tubestock.
Allosyncarpia ternata	Tree	Identified cultural species	0	5	1	Transplant	0	6	1	Success with tubestock. Suitable for dry monsoon sub-community.
Alphitonia excelsa	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	Limited revegetation experience. Suitable for dry monsoon sub-community.
Antidesma ghaesembilla	Shrub	Bush food	0	1	0	Tubestock	0	1	0	Success with tubestock. Also some success with direct seeding into established vegetation. Suitable for dry monsoon sub-community.
Brachychiton diversifolius	Tree	identified cultural species	0	5	1	Tubestock	0	8	2	Success with tubestock.
Brachychiton megaphyllus	Tree	Patchy coverage in reference sites, identified cultural species	0	20	5	Tubestock	0	21	5	Success with tubestock. Propagation difficult in cooler months.
Breynia cernua	Shrub	Bush food	0	1	0	Tubestock	0	1	0	Success with tubestock. Requires fresh seed. Suitable for dry monsoon sub-community. Natural recruits observed.
Buchanania obovata	Tree	Sparse in reference sites, identified cultural species	0	20	5	Tubestock	0	25	6	Success with tubestock. Limited storage life.
Callitris intratropica	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience. Reduced population in reference sites possibly influenced by fire regime.
Calytrix achaeta	Shrub	Sparse, patchy in reference sites	0	5	0	Tubestock	0	10	0	No revegetation experience.
Calytrix brownii	Shrub	identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience.
Calytrix exstipulata	Shrub	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	0	7	1	Success with tubestock.
Carallia brachiata	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience. Suitable for dry monsoon sub-community.
Clerodendrum floribundum	Shrub	Identified cultural species	0	5	1	Tubestock	0	10	2	Success with tubestock.
Cochlospermum fraseri	Shrub	Sparse in reference sites, identified cultural species	0	10	1	Tubestock	0	13	1	Waste rock coloniser and high recruitment. Will only plant sparsely in areas of finer waste rock. Also potential for direct seeding
Coelospermum reticulatum	Shrub	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience.

Species	Growth form	Reference	Target stems per ha. (min)	Target stems per ha. (max)	Target stems per ha. (ave)	Proposed Establishment Method	Initial planting density (stems/ha.) (min)	Initial planting density (stems/ha.) (max)	Initial planting density (stems/ha.) (ave)	Comment
Corymbia bleeseri	Tree	Patchy coverage (shallower soils?) in reference sites, identified cultural species	0	390	60	Tubestock	0	557	86	Success with tubestock.
Corymbia chartacea	Tree	Patchy coverage (shallower soils?) in reference sites	0	100	15	Tubestock	0	125	19	Success with tubestock.
Corymbia disjuncta	Tree	Identified cultural species	0	5	1	Tubestock	0	6	1	Success with tubestock.
Corymbia foelscheana /latifolia	Tree	Common in reference sites, identified cultural species	0	20	2	Tubestock	0	27	3	Success with tubestock.
Corymbia polycarpa	Tree	Identified cultural species	0	5	1	Tubestock	0	6	1	No tubestock experience, however some direct seeding in depressions.
Corymbia polysciada	Tree	Sparse, patchy in reference sites, identified cultural species	0	5	1	Tubestock	0	6	1	Success with tubestock.
Corymbia porrecta	Tree	Dominant in reference sites	0	220	60	Tubestock	0	314	86	Success with tubestock.
Croton arnhemicus	Shrub	Sparse in reference sites	0	10	2	Tubestock	0	20	4	No revegetation experience.
Dolichandrone filiformis	Tree	Sparse in reference sites	0	1	0	Tubestock	0	2	0	Success with tubestock.
Elaeocarpus arnhemicus	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience. Suitable for dry monsoon sub-community.
Erythrophleum chlorostachys	Tree	Common in reference sites, identified cultural species	0	80	20	Tubestock	0	114	29	Success with tubestock.
Eucalyptus miniata	Tree	Dominant in reference sites, identified cultural species	10	200	70	Tubestock	15	308	108	Sensitive to waterlogging.
Eucalyptus phoenicea	Tree	Identified cultural species	0	5	1	Tubestock	0	7	1	Success with tubestock.
Eucalyptus tectifica	Tree	Sparse, patchy in reference sites	0	5	1	Tubestock	0	6	1	Success with tubestock.
Eucalyptus tetrodonta	Tree	Dominant in reference sites, identified cultural species	60	240	110	Tubestock	86	343	157	Success with tubestock.
Ficus platypoda	Tree	Identified cultural species	0	5	1	Tubestock	0	7	1	No revegetation experience. Suitable for dry monsoon sub-community.
Ficus racemosa	Tree	Identified cultural species	0	5	1	Natural	N/A	N/A	N/A	Observed natural recruitment on waste rock. Suitable for dry monsoon sub-community.
Fluggea virosa	Shrub	Bush food	0	1	0	Tubestock	0	1	0	Success with tubestock. Requires fresh seed, suitable for dry monsoon sub-community
Gardenia fucata	Tree	Identified cultural species	0	5	1	Tubestock	0	9	2	Success with tubestock.
Gardenia megasperma	Tree	Common, patchy in reference sites, identified cultural species	0	10	2	Tubestock	0	13	3	Success with tubestock. Reduced population in reference sites possibly influenced by fire regime.
Grevillea decurrens	Tree	Common in reference sites, identified cultural species	0	10	1	Tubestock	0	14	1	Success with tubestock.
Grevillea pteridifolia	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	0	8	2	Success with tubestock. Remaining uncertainty regarding long-term suitability on waste-rock
Hakea arborescens	Tree	Low density in surrounding ecosystem	0	1	0	Tubestock	0	1	0	Success with tubestock.
Jacksonia dilatata	Shrub	Patchy abundance in surrounding ecosystem	0	1	0	Tubestock	0	1	0	Observed natural recruitment on waste rock.
Jasminum molle	Shrub	Low density in surrounding ecosystem	0	1	0	Tubestock	0	5	0	Remaining uncertainty regarding suitability on waste-rock.
Livistona humilis	Palm	Patchy coverage (fire affected?) in reference sites, identified cultural species	0	280	40	Tubestock	0	431	62	Success with tubestock.

Species	Growth form	Reference	Target stems per ha. (min)	Target stems per ha. (max)	Target stems per ha. (ave)	Proposed Establishment Method	Initial planting density (stems/ha.) (min)	Initial planting density (stems/ha.) (max)	Initial planting density (stems/ha.) (ave)	Comment
Livistona inermis	Palm	Previous successes, present on rocky country in surrounding ecosystem	0	1	0	Tubestock	0	1	0	Success with tubestock.
Owenia vernicosa	Tree	Sparse in reference sites, identified cultural species	0	5	1	Direct seeding	N/A	N/A	N/A	Direct seed in clusters near rock piles and ridgelines. Seed potentially germinated following fire.
Pandanus spiralis	Palm	Sparse, patchy in reference sites, identified cultural species	0	10	5	Direct seeding	N/A	N/A	N/A	Good growth on waste rock. Will be direct seeded in minor depressions.
Persoonia falcata	Shrub	Common in reference sites, identified cultural species	0	60	15	Tubestock	0	120	30	Propagation/seeding so far unsuccessful. Some limited recruitment in reveg areas.
Petalostigma pubescens	Tree	Identified cultural species	0	5	1	Tubestock	0	13	3	Success with tubestock.
Planchonella arnhemica	Tree	Sparse in reference sites, identified cultural species	0	10	5	Tubestock	0	20	10	Propagation/seeding so far unsuccessful.
Planchonia careya	Tree	Sparse in reference sites, identified cultural species	0	10	2	Tubestock	0	11	2	Success with tubestock. Requires fresh seed
Stenocarpus acacioides	Tree	Sparse, patchy in reference sites	0	5	1	Tubestock	0	13	3	Success with tubestock.
Sterculia quadrifida	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience. Suitable for dry monsoon sub-community.
Syzygium eucalyptoides subsp. bleeseri	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	0	6	1	Success with tubestock. Requires fresh seed
Syzygium eucalyptoides subsp. eucalyptoides	Tree	Sparse, patchy in reference sites, identified cultural species	0	10	1	Tubestock	0	14	1	Success with tubestock. Requires fresh seed for propagation. suitable for dry monsoon sub-community
Syzygium suborbiculare	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	0	7	1	Success with tubestock. Requires fresh seed
Terminalia carpentariae	Tree	Identified cultural species	0	5	1	Tubestock	0	7	1	Success with tubestock.
Terminalia ferdinandiana	Tree	Common in reference sites, identified cultural species	10	70	30	Tubestock	13	93	40	Success with tubestock. May be suitable for direct seeding, propagation difficult in cooler months.
Terminalia pterocarya	Shrub	Common, patchy in reference sites	0	15	1	Tubestock	0	20	1	Success with tubestock.
Vitex glabrata	Tree	Identified cultural species	0	5	1	Tubestock	0	10	2	No revegetation experience.
Wrightia saligna	Shrub	Previous successes	0	1	0	Tubestock	0	1	0	Success with tubestock.
Xanthostemon paradoxus	Tree	Common in reference sites	0	250	50	Tubestock	0	357	71	Success with tubestock. Remaining uncertainty regarding suitability on waste-rock.

Note: Pre-2022, *Eucalyptus tintinnans* was included in the standard mix of species planted in Ranger rehabilitation; however, it has since been removed from planting lists as it is not considered a locally occurring species

Table 5: Proposed Savanna Woodland Vegetation CRE for understorey species

Species	Growth form	Proposed Establishment Method	Comment
Acacia gonocarpa	Legume (shrub)	Planted	
Alloteropsis semialata	Grass (perennial)	Planted	
Alternanthera sp.	Forb	Passive	
Ampelocissus acetosa	Vine	Planted	
Amyema sanguinea	Forb	Passive	
Aristida holathera	Grass (perennial)	Mixed (planted and seeded)	
Aristida hygrometrica	Grass (annual)	Passive	
Aristida inaequiglumis	Grass (perennial)	Mixed (planted and seeded)	
Aristida spp.	Grass (annual/perennial)	Passive	At least two additional species observed to recruit in multiple rehab areas
Asteraceae spp.	Forb	Passive	At least three species observed to recruit across multiple rehab areas
Austrodolichos errabundus (may actually be *Vigna vexillata)*	Legume (vine/forb)	Planted	
Blumea sp.	Forb	Passive	
Blumea tenellula	Forb	Passive	
*Boerhavia coccinea**	Vine	Passive	Common recruiter observed across all rehabilitation areas
Boerhavia sp.	Vine	Passive	
Brachyachne convergens	Grass (annual)	Passive	Common recruiter observed across all rehabilitation areas
Buchnera linearis	Forb	Mixed (passive and seeded)	
Buchnera tetragona	Forb	Mixed (passive and seeded)	
Bulbostylis barbata	Grass (annual)	Passive	Common recruiter observed across most of the rehabilitation areas
Cartonema spicatum	Forb	Planted	low field survival - more investigation required as cultural important bushfood
Cayratia trifolia	Vine	Planted	
Chrysopogon fallax	Grass (perennial)	Mixed (planted and seeded)	
Chrysopogon latifolius	Grass (perennial)	Mixed (planted and seeded)	
*Cleome viscosa**	Forb	Passive	Common recruiter observed across all rehabilitation areas
Crotalaria brevis	Legume (vine/forb)	Passive	Common recruiter observed across all rehabilitation areas
Crotalaria montana	Legume (vine/forb)	Passive	Common recruiter observed across all rehabilitation areas
Cucumis melo	Vine	Passive	
Cymbopogon spp.	Grass (perennial)	Mixed (planted and seeded)	
Cyperus exaltatus	Grass (perennial)	Passive	
Cyperus spp.	Grass (annual/perennial)	Passive	At least four additional species observed to recruit across rehabilitated areas
Desmodium brownii	Legume (vine/forb)	Passive	
Desmodium spp.	Legume (vine/forb)	Passive	At least three additional species observed to recruit in multiple rehab areas
Desmodium triflorum	Legume (vine/forb)	Passive	
Dicanthium sp.	Grass (annual/perennial)	Mixed (passive and seeded)	
Digitaria sp.	Grass (annual/perennial)	Passive	Common recruiter observed across all rehabilitation areas
Dioscorea spp.	Vine	Planted	low field survival - more investigation required as cultural important bushfood
Ectrosia leporina	Grass (perennial)	Mixed (passive and seeded)	Common recruiter observed across all rehabilitation areas
Ectrosia schultzii	Grass (annual/perennial)	Passive	

Species	Growth form	Proposed Establishment Method	Comment
Enneapogon spp.	Grass (annual/perennial)	Passive	At least two additional species observed to recruit in multiple rehab areas
Eragrostis cumingii	Grass (annual)	Mixed (passive and seeded)	Common recruiter observed across all rehabilitation areas
Eragrostis schultzii	Grass (perennial)	Mixed (passive and seeded)	
Eragrostis spp.	Grass (annual/perennial)	Mixed (passive and seeded)	At least six additional species observed across rehabilitation areas
Eriachne armittii	Grass (perennial)	Mixed (planted and seeded)	
Eriachne avenacea	Grass (annual)	Passive	
Eriachne ciliata	Grass (annual)	Passive	Common recruiter observed across most rehabilitation areas
Eriachne obtusa	Grass (perennial)	Mixed (planted and seeded)	
Eriachne schultziana	Grass (perennial)	Mixed (planted and seeded)	
Eriachne sp.	Grass (annual/perennial)	Passive	
Eriachne triseta	Grass (perennial)	Mixed (planted and seeded)	
Euphorbia schultzii	Forb	Passive	Common recruiter observed across most rehabilitation areas
Fimbristylis spp.	Grass (annual/perennial)	Passive	At least seven additional species observed across rehabilitation areas
Fimbristylis tetragona	Grass (annual)	Passive	
Galactia megalophylla	Legume (shrub)	Planted	
Galactia tenuiflora	Legume (vine/forb)	Planted	
Geodorum densiflorum	Forb	Passive	
Gomphrena canesens	Forb	Passive	
Gomphrena sp.	Forb	Passive	At least four additional species observed across rehabilitation areas
Gonocarpus leptothecus	Forb	Passive	
Grevillea dryandri	Shrub	Planted	
Grevillea goodii	Shrub	Planted	
Grewia savannicola	Shrub	Planted	
Gymnanthera oblongata	Vine	Passive	Common recruiter observed across all rehabilitation areas
Haemodorum coccineum	Forb	Planted	low field survival - more investigation required as cultural important species
Heterachne abortiva	Grass (annual)	Passive	
Heteropogon contortus	Grass (perennial)	Passive	
Heteropogon triticeus	Grass (perennial)	Mixed (planted and seeded)	
Indigofera linifolia	Legume (vine/forb)	Passive	
Indigofera saxicola	Legume (shrub)	Planted	
Ipomea sp.	Vine	Passive	
Ludwigia spp.	Forb	Passive	At least three species observed across rehabilitation areas
Microstachys chamaelea	Forb	Passive	
Mitrasacme connata	Forb	Passive	
Mnesithea formosa	Grass (annual)	Mixed (passive and seeded)	
Oldenlandia spp.	Forb	Passive	Common recruiter observed across most rehabilitation areas
Panicum sp.	Grass (annual/perennial)	Passive	
Paspalidium rarum	Grass (annual)	Passive	
Petalostigma quadriloculare	Shrub	Planted	
Phyllanthus sp.	Forb	Passive	

Species	Growth form	Proposed Establishment Method	Comment
Physalis angulata	Forb	Passive	Common recruiter observed across most rehabilitation areas
Polygala coralliformis	Forb	Passive	
Portulaca bicolor	Forb	Passive	
Portulaca spp.	Forb	Passive	At least two additional species observed across the rehabilitation areas
Pseudopogonatherum contortum	Grass (annual)	Mixed (passive and seeded)	
Pterocaulon serrulatum	Forb	Passive	Common recruiter observed across most rehabilitation areas
Ptilotus sp.	Forb	Passive	
Rhynchospora spp.	Grass (annual)	Passive	At least four species observed across the rehabilitation areas
Schizachyrium fragile	Grass (annual)	Passive	Common recruiter observed across all rehabilitation areas
Scoparia dulcis	Forb	Passive	Common recruiter observed across most rehabilitation areas
Setaria sp.	Grass (annual/perennial)	Passive	
Sida sp.	Forb	Passive	
*Sorghum intrans**	Grass (annual)	Passive	
Spermacoce spp.	Forb	Passive	At least four species observed across the rehabilitation areas
Sphaeromorphaea littoralis	Forb	Passive	
Sporobolus australasicus	Grass (annual)	Passive	Common recruiter observed across all rehabilitation areas
Stemodia lythrifolia	Forb	Passive	Common recruiter observed across most rehabilitation areas
Stemodia sp.	Forb	Passive	
Stylidium candelabrum	Forb	Passive	
Stylidium semipartitum	Forb	Passive	
Tacca leontopetaloides	Forb	Passive	
Tephrosia oblongata	Legume (shrub)	Planted	
Tephrosia remotiflora	Legume (shrub)	Planted	
Tephrosia spp.	Legume (vine/forb)	Passive	At least four additional species observed across the rehabilitation areas
Tephrosia subpectinata	Legume (shrub)	Planted	
Triodia bitextura	Grass (perennial)	Passive	
Uraria lagopodioides	Legume (vine/forb)	Planted	
*Urochloa pubigera**	Grass (annual)	Passive	Common recruiter observed across most rehabilitation areas
Urochloa sp.	Grass (annual)	Passive	
Vigna adenantha	Legume (vine/forb)	Passive	
Vigna lanceolata var. filiformis	Legume (vine/forb)	Passive	
Vigna radiata var. sublobata	Legume (vine/forb)	Passive	
Xenostegia tridentata	Vine	Passive	

2 REFERENCES

Ashwath, N, Cusbert, PC, Bayliss, B, McLaughlin, M & Hunt, C 1993. Chemical properties of mine spoils and selected natural soils of the Alligator Rivers Region - Implications for establishing native plant species on mine spoils. Proceedings of the Waste Rock Dump Symposium 7–8 October 1993 Darwin NT.

Brady, C, Christopherson, P & O'Brien, J 2021. Incorporating indigenous knowledge in mine closure: Ranger Uranium Mine. Proceedings of the Royal Society of Victoria 133, pp. 18–22. DOI: 10.1071/RS21003.

Construction Sciences (NT) 2020. Geotechnical Investigation Report. Jabiru Redevelopment – Report No. 1. Power Station – Lot 2303. 5057P027. Prepared for Northern Territory Government, 4 July 2020. Available at Geotechnical Investigation Report (nt.gov.au).

Cook, GD 2021. *Fire resilience for ERA Ranger Mine revegetation.* Arafurica Pty Ltd, Australia.

Daws, M & Gellert, C. 2010. Initial (2009) revegetation monitoring on the trial landform. January 2010.

Daws, M & Gellert, C 2011. Ongoing (2010) Revegetation monitoring on the trial landform. April 2011.

Daws, M & Poole, P. 2010. Construction, revegetation and instrumentation of the Ranger uranium mine trial landform: Initial outcomes. Report by Energy Resources of Australia Ltd, Darwin NT. February 2010.

Douglas Partners 2019a. Waste Rock Stockpile Sampling and Testing, Memorandum prepared for ERA, 23 May 2019.

Douglas Partners 2019b. Material Test Reports 677666.01-1 and 677666.01-2. Prepared for ERA, 26 November 2019.

EcOz, 2022. Land Application Area Survey; Ranger Uranium Mine, Energy Resources Australia. EcOz Environmental Consultants, Darwin.

Freeman M. E., Murphy B. P., Richards A. E., Vesk P. A. & Cook G. D. (2018) Facultative and Obligate Trees in a Mesic Savanna: Fire Effects on Savanna Structure Imply Contrasting Strategies of Eco-Taxonomic Groups. Frontiers in Plant Science 9.

Garde, M 2015. Closure Criteria Development – Cultural. ERA Ranger Integrated Tailings, Water & Closure. Confidential report, Northern Territory. April 2015.

Gellert, C. 2014. Ongoing revegetation monitoring on the trial landform 2013. May 2014.

Hancock, G. R., Saynor, M., Lowry, J. B. C., & Erskine, W. D. (2020). How to account for particle size effects in a landscape evolution model when there is a wide range of particle sizes. Environmental Modelling & Software, 124, 104582.

Hutley, LB, O'Grady, AP & Eamus, D 2000. Evapotranspiration from Eucalypt open-forest savanna of Northern Australia. Functional Ecology, 14(2): pp. 183–194.

Hutley, L, Duvert, C, Setterfield, S, Bourke, A, Canham, C, Freestone, F, Cavalieri, O, Alvarez-Cortez, D & Brand, M 2021. Ecohydrology and sensitivity of riparian flora, Magela Creek, Ranger Uranium Mine, Final Report. National Environmental Science Program (NESP) North Australian Hub, Charles Darwin University, Darwin.

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.

Malden, JS, Ashwath, N & Longnecker, N 1994. The effect of magnesium sulphate on the germination of a selection of plant species native to Kakadu National Park. National Workshop of Native Seed Biology for Revegetation (1994), pp. 123–124.

Miller, R, 2020. Mapping PSD Results in Pit 1 - Final Update a Virtual Completion of Pit 1 Backfill. Memorandum to Ping Lu, dated 20 October.

Okane 2021. Geotechnical Material Characterisation - Pit 1 FLF Backfill at the Ranger Mine. Okane ref: 1195-003-03. March 2021.

Okane 2024. Ranger Pit 1 Final Landform (FLF) Field Response Modelling Support (2022-2023). Okane ref: 1195-221-002. May 2024.

Paramjyothi H, Risler J, Loughran A, Whiteside T, Loewensteiner D, Humphrey C & Gardener M 2024. Data collection to inform development of the appropriate fire regime for the rehabilitated Ranger mine. Internal Report (in review), Supervising Scientist, Darwin.

Parry, M. L., Bellairs, S. M., & Lu, P. (2022). Improved native understorey establishment in mine waste rock in Australia's wet–dry tropics. Australian Journal of Botany, 70(3), pp. 248–262.

Reddell, P & Zimmermann, A. 2002. An external review of revegetation research at Ranger Mine: Assessment of field trials and their implications for future rehabilitation practice. EWLS/CSIRO (L&W) report to Ranger Mine.

Supervising Scientist (2021). Technical Advice #041: Updated Conceptual Reference Ecosystem data. Provided to ERA 23 August 2021.

Wright, A, Parry, M & Lu, P. 2021. Memorandum: Stage 13.1 learnings and proposed species composition for Area C. Energy Resources of Australia Ltd, 9 March 2021.

Zimmermann, A 2013. Potential seed provenance for Ranger Mine revegetation. Delineation and recommendations Report by Energy Resources of Australia Ltd, Darwin, NT. November 2013.

Zimmermann, A & Lu, P 2015. A Multilevel Non-genetic Approach to Delineate Provenance Boundaries of Revegetation Species: Ranger Uranium Mine Case Study. In: Proceedings of 3rd Australian Mine Rehabilitation Conference on Innovation in Mine Planning and Rehabilitation workshop, 18–20 August 2015, Adelaide, Australia.

APPENDIX 9.2: VERTEBRATE FAUNA EXPECTED TO RETURN TO THE REHABILITATED SITE

Energy Resources Of Australia

Native Vertebrate Fauna Expected to Occur on the Rehabilitated Landform

Ranger Mine Closure Plan 2024

Unique Reference: PLN007

Revision: 1.23.2

Native mammal, bird, reptile and amphibian species from 35 savanna woodland survey sites (SLR Consulting, 2021) and additional species highlighted by Dr John Woinarski (pers. comm. Woinarski, CDU, May 2024) are listed in Table 1 to Table 4.

Threated species, and frugivorous and/or nectivorous birds, are highlighted due to their relevance to closure criteria and/or role in external exchanges and vegetation dispersal.

The listed species are not exhaustive. The outcomes of recent surveys by OSS (currently unpublished), further survey efforts and more advanced monitoring techniques may be used to further inform an appropriate fauna reference ecosystem and indicative trajectory towards this.

Table 1 – Native mammals expected to occur on the rehabilitated landform

Scientific Name	Common Name
Antechinus bellus	Fawn Antechinus *
Canis dingo	Dingo
Dasyurus hallucatus	Northern Quoll *
Isoodon macrourus	Northern Brown Bandicoot *
Melomys burtoni	Grassland Melomys
Mesembriomys gouldii gouldii	Black-footed Tree-rat (Kimberley and mainland NT) *
Notamacropus agilis	Agile Wallaby
Osphranter antilopinus	Antilopine Wallaroo
Osphranter robustus	Common Wallaroo
Petaurus ariel	Savanna Glider
Pteropus alecto	Black Flying-fox
Saccolaimus saccolaimus nudicluniatus	Bare-rumped Sheath-tailed Bat *,#
Tachyglossus aculeatus	Short-beaked Echidna
Trichosurus vulpecula arnhemensis	Northern Brushtail Possum *

* species listed as threatened under the relevant Commonwealth and NT legislation.

[#] species highlighted by John Woinarski (pers. comm. Woinarski, CDU, May 2024) as potentially present, however not identified by SLR in 2021.

Table 2 - Native birds expected to occur on the rehabilitated landform

Scientific Name	Common Name	Importance of Fruit	Importance of Nectar
Accipiter fasciatus	Brown Goshawk		
Aegotheles cristatus	Australian Owlet-nightjar		
Anhinga novaehollandiae	Australasian Darter		
Aprosmictus erythropterus	Red-winged Parrot	2	2
Artamus cinereus	Black-faced Woodswallow		2
Artamus minor	Little Woodswallow		
Burhinus grallarius	Bush Stone-curlew		
Cacatua galerita	Sulphur-crested Cockatoo	1	
Cacatua sanguinea	Little Corella	1	
Cacomantis variolosus	Brush Cuckoo		
Calyptorhynchus banksii	Red-tailed Black Cockatoo		
Caprimulgus macrurus	Large-tailed Nightjar		
Centropus phasianinus	Pheasant Coucal		
Chalcites minutillus	Little Bronze-Cuckoo		
Chlamydera nuchalis	Great Bowerbird	2	
Circus assimilis	Spotted Harrier		
Cissomela pectoralis	Banded Honeyeater		1
Cisticola exilis	Golden-headed Cisticola		
Climacteris melanurus	Black-tailed Treecreeper		
Colluricincla harmonica	Grey Shrike-thrush		
Colluricincla megarhyncha	Little Shrike-thrush	2	
Conopophila albogularis	Rufous-banded Honeyeater		1
Conopophila rufogularis	Rufous-throated Honeyeater		
Coracina novaehollandiae	Black-faced Cuckoo-shrike		
Coracina papuensis	White-bellied Cuckoo-shrike	2	
Corvus orru	Torresian Crow		
Cracticus nigrogularis	Pied Butcherbird		
Dacelo leachii	Blue-winged Kookaburra		
Dicaeum hirundinaceum	Mistletoebird	1	
Dicrurus bracteatus	Spangled Drongo	2	
Ducula spilorrhoa	Torresian Imperial Pigeon	1	
Edolisoma tenuirostre	Cicadabird	2	
Entomyzon cyanotis	Blue-faced Honeyeater	2	1
Eolophus roseicapilla	Galah		
Ephippiorhynchus asiaticus	Black-necked Stork		

Scientific Name	Common Name	Importance of Fruit	Importance of Nectar
Erythrotriorchis radiatus	Red Goshawk *,#		
Eudynamys orientalis	Eastern Koel	1	
Eurostopodus argus	Spotted Nightjar		
Eurystomus orientalis	Dollarbird		
Falco berigora	Brown Falcon		
Falco cenchroides	Nankeen Kestrel		
Falco longipennis	Australian Hobby		
Geopelia cuneata	Diamond Dove		
Geopelia humeralis	Bar-shouldered Dove	2	
Geopelia placida	Peaceful Dove		
Geophaps smithii smithii	Partridge Pigeon *		
Gerygone chloronota	Green-backed Gerygone		
Gerygone olivacea	White-throated Gerygone		
Grallina cyanoleuca	Magpie-lark		
Haliaeetus leucogaster	White-bellied Sea-Eagle		
Haliastur sphenurus	Whistling Kite		
Hamirostra melanosternon	Black-breasted Buzzard		
Lalage leucomela	Varied Triller	1	1
Lalage tricolor	White-winged Triller		
Lichmera indistincta	Brown Honeyeater		1
Malurus melanocephalus	Red-backed Fairy-wren		
Manorina flavigula	Yellow-throated Miner		2
Megapodius reinwardt	Orange-footed Scrubfowl	1	
Melithreptus albogularis	White-throated Honeyeater		1
Merops ornatus	Rainbow Bee-eater		
Microeca flavigaster	Lemon-bellied Flycatcher		
Milvus migrans	Black Kite		
Myiagra alecto	Shining Flycatcher		
Myiagra rubecula	Leaden Flycatcher		
Myiagra ruficollis	Broad-billed Flycatcher		
Myzomela obscura	Dusky Honeyeater		
Neochmia phaeton	Crimson Finch		
Ninox boobook	Australian Boobook		
Ninox connivens	Barking Owl		
Oriolus flavocinctus	Yellow Oriole	1	
Oriolus sagittatus	Olive-backed Oriole	2	
Pachycephala rufiventris	Rufous Whistler		

Scientific Name	Common Name	Importance of Fruit	Importance of Nectar
Pardalotus striatus	Striated Pardalote		
Philemon argenticeps	Silver-crowned Friarbird	2	1
Philemon buceroides	Helmeted Friarbird	2	1
Philemon citreogularis	Little Friarbird	2	1
Pitta iris	Rainbow Pitta		
Platalea regia	Royal Spoonbill		
Platycercus venustus	Northern Rosella	2	
Podargus strigoides	Tawny Frogmouth		
Poephila acuticauda	Long-tailed Finch		
Poephila personata	Masked Finch		
Pomatostomus temporalis	Grey-crowned Babbler		
Psitteuteles versicolor	Varied Lorikeet		1
Ptilinopus regina	Rose-crowned Fruit-dove	1	
Rhipidura dryas	Arafura Fantail		
Rhipidura leucophrys	Willie Wagtail		
Rhipidura rufiventris	Northern Fantail		
Scythrops novaehollandiae	Channel-billed Cuckoo	1	
Smicrornis brevirostris	Weebill		
Sphecotheres vieilloti	Australasian Figbird	1	
Stizoptera bichenovii	Double-barred Finch		
Stomiopera unicolor	White-gaped Honeyeater	2	1
Struthidea cinerea	Apostlebird		
Synoicus ypsilophora	Brown Quail		
Taeniopygia guttata	Zebra Finch		
Threskiornis spinicollis	Straw-necked Ibis		
Todiramphus macleayii	Forest Kingfisher		
Todiramphus sanctus	Sacred Kingfisher		
Trichoglossus rubritorquis	Red-collared Lorikeet	2	1
Turnix castanotus	Chestnut-Backed Button-Quail		
Tyto novaehollandiae kimberli	Masked Owl (Northern Mainland) *		

***** species listed as threatened under the relevant Commonwealth and NT legislation.

[#] species highlighted by John Woinarski (pers. comm. Woinarski, CDU, May 2024) as potentially present, however not identified by SLR in 2021.

1 Indicates that most of the diet is fruit, or nectar.

2 Indicates that fruit, or nectar is important, but other dietary items are more important.

Table 3 - Native reptiles expected to occur on the rehabilitated landform

Scientific Name	Common Name
Amalosia rhombifer	Zigzag Velvet Gecko
Anilios spp.	Blind Snake
Anilios unguirostris	Claw-snouted Blind Snake
Antaresia childreni	Children's Python
Brachyurophis roperi	Northern Shovel-nosed Snake
Carlia amax	Two-spined Rainbow Skink
Carlia gracilis	Slender Rainbow-skink
Carlia mund	Shaded-litter Rainbow-skink
Carlia triacantha	Desert Rainbow-skink
Chlamydosaurus kingii	Frilled Lizard
Cryptoblepharus cygnatus	Swanson's Snake-eyed Skink
Cryptoblepharus metallicus	Metallic Snake-eyed Skink
Cryptophis pallidiceps	Northern Small-eyed Snake
Ctenotus essingtonii	Port Essington Ctenotus
Ctenotus robustus	Robust Ctenotus
Ctenotus storri	Storr's Ctenotus
Ctenotus vertebralis	Scant-striped Ctenotus
Delma borea	Rusty-topped Delma
Delma tincta	Excitable Delma
Dendrelaphis punctulata	Green Tree Snake
Diporiphora bilineata	Two-lined Dragon
Eremiascincus isolepis	Northern Bar-lipped Skink
Furina ornata	Orange-naped Snake
Gehyra australis	Northern Dtella
Glaphyromorphus darwiniensis	Northern Mulch-skink
Heteronotia binoei	Bynoe's Gecko
Lerista karlschmidti	Karl Schmidt's Lerista
Lialis burtonis	Burton's Snake-lizard
Liasis fuscus	Water Python
Lophognathus gilberti	Gilbert`s Dragon
Menetia greyii	Grey's Menetia
Menetia maini	Northern Dwarf Skink
Morethia storri	Storr's Snake-Eyed Skink
Notoscincus ornatus	Ornate Soil-crevice Skink
Oedura marmorata	Marbled Velvet Gecko
Proablepharus tenuis	Slender Snake-eyed Skink

Scientific Name	Common Name
Tiliqua scincoides intermedia	Northern Blue-tongued Skink *,#
Varanus scalaris	Spotted Tree Monitor
Varanus tristis	Black-headed Monitor

***** species listed as threatened under the relevant Commonwealth and NT legislation.

[#] species highlighted by John Woinarski (pers. comm. Woinarski, CDU, May 2024) as potentially present, however not identified by SLR in 2021.

Table 4 - Native amphibians expected to occur on the rehabilitated landform

Scientific Name	Common Name
Austrochaperina adelphe	Northern Territory Frog
Crinia bilingua	Bilingual Frog
Cyclorana australis	Giant Frog
Limnodynastes convexiusculus	Marbled Frog
Litoria bicolor	Northern Dwarf Tree Frog
Litoria caerulea	Green Tree-Frog
Litoria coplandi	Common Rock Frog
Litoria nasuta	Rocket Frog
Litoria pallida	Pale Frog
Litoria ridibunda	Western Laughing Tree Frog
Litoria tornieri	Black-shinned Rocket Frog
Notaden melanoscaphus	Northern Spadefoot
Platyplectrum ornatus	Ornate Burrowing Frog
Uperoleia lithomoda	Stonemason Toadlet