ERA Energy Resources of Australia Ltd

10 Closure monitoring and maintenance

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FIGURES

Cover photograph: Surface water monitoring station in Magela Creek

TABLES

APPENDICES

GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Airborne radiometric survey	Estimation of the concentration of radioactive elements in the surface of the landform via the detection of gamma radiation using low flying aircraft.
Closure criteria	Direct, measurable and quantifiable target values or tiered assessment processes, developed to demonstrate achievement of the closure objectives
Contaminated Land Risk Register	Register of all sites where activities have occurred that have the potential to contaminate land on the RPA.
Constituents of potential concern	Chemical elements identified by the Supervising Scientist Division as being of potential concern to the receiving environment
Diameter at breast height	Measurement of tree diameter taken at 1.3 m above ground level (an adult's approximate breast height).
Digital Elevation Modelling	Digital representation of the land topography
ERICA Assessment	Exposure/dose/effect assessment for radiological risk to terrestrial, freshwater and marine biota.
Groundwater conceptual model	Calibrated numerical groundwater flow model encompassing all hydrogeologic elements governing groundwater flow and transport at the Ranger Mine to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions.
Groundwater solute transport modelling	Prediction of the temporal and spatial mobilisation of constituents of potential concern from the Ranger Project Area to the surrounding environment through groundwater using the Groundwater conceptual model.
Hydrolithologic unit	A grouping of soil or rock units or zones based on common hydraulic properties.
Hydrolithologic Zones	Groupings of hydolithologic units based on similar geological and groundwater flow and transport characteristics.
Landscape denudation	Reduction in elevation and relief of the land surface due to various eroding processes
Landscape Evolution Model	Numerical model that simulates the change in landscape over time in response to various parameters.
LiDAR	Remote sensing technique using pulsed laser to measure distances
Long Lived Alpha Activity	Abbreviated to LLAA. The presence, generally in airborne dust, of any of the alpha emitting radionuclides in uranium ore, except for the short lived alpha emitting radon decay products.

Key term	Definition
Mirarr	Mirarr is a patrilineal descent group. Descent groups are often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Monitoring and maintenance phase	Period after 8 January 2026 Completion criteria monitoring (and maintenance rehabilitation works if required) Site access pending.
Monitoring Evaluation and Research Review Group	Comprised of members of ERA and SSB, as well as subject matter experts as required, the group is tasked with the ongoing development and refinement of research and monitoring programs during the progressive rehabilitation period
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321%.
Pit 1 Progressive Rehabilitation Monitoring Framework	Overarching framework of environmental monitoring for the rehabilitation of Pit 1
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Potential Alpha Energy Concentration	The concentration of the total alpha energy emitted in air during the decay of radon-222 progeny. Usually measured in $\mu J\ m^{-3}$.
Radon exhalation	Activity of radon gas leaving the surface of the landform
Trigger, Action, Response Plan	Abbreviated to TARP. Plan of tasks to be undertaken should monitoring detect a change in parameters of a level that requires preventative or remedial action.

ABBREVIATIONS & ACRONYMS

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

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
ARRTC	Alligator Rivers Region Technical Committee
BACIP	Before-After Control-Impact Paired sampling
COPC	Constituents of Potential Concern
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DWPZ	Deeps Water Producing Zone
EC	Electrical Conductivity
ERICA	Environmental Risk from Ionising Contaminants: Assessment and management
GAC	Gundjeihmi Aboriginal Corporation
GCC	Gulungul Creek Control
GCLB	Gulungal Creek water monitoring site
HLU	Hydrolithologic unit
LEM	Landscape Evolution Model
LLAA	Long Lived Alpha Activity
LiDAR	Light Detection and Ranging
MCP	Mine Closure Plan
MCUS	Magela Creek Upstream water monitoring site
MERRG	Monitoring Evaluation Research Review Group
NLC	Northern Land Council
NP	National Park
PAEC	Potential Alpha Energy Concentration
RPA	Ranger Project Area
RWMP	Ranger Mine Water Management Plan
SSB	Supervising Scientist Branch
TARP	Trigger, Action, Response Plan
TPH	Total Petroleum Hydrocarbon
TSF	Tailings Storage Facility
WASWG	Water and Sediment Working Group

10 CLOSURE MONITORING

This section describes the monitoring programs developed for the Ranger mine to assess the trajectory of rehabilitation actions towards meeting the closure criteria (Section 8) and to address the requirements of the Ranger Authorisation. In accordance with clause 13.3 of the Ranger Authorisation: *"… the company must carry out a monitoring program approved by the Supervising Authority or the Minister with the advice of the Supervising Scientist following cessation of operations until such time as a relevant close-out certificate is issued"*.

The closure criteria represent direct, measurable and quantifiable target values or tiered assessment processes, based on industry best practice frameworks to develop suitable monitoring programs. The closure criteria have been developed to demonstrate achievement of the closure objectives and desirable outcomes (Section 8). The monitoring programs discussed within this section apply to the closure and monitoring and maintenance phases as defined in Section 1.3. The monitoring programs discussed below align with the six closure themes described in Section 8.3:

- landform
- radiation
- water and sediment
- soil
- ecosystem (revegetation & fauna), and
- cultural.

Within each closure theme is a description of the proposed monitoring as it will occur during the closure and monitoring and maintenance phases. The proposed closure monitoring programs build on the existing, extensive monitoring regimes established during mining operations at the Ranger Mine. The closure monitoring program is required to assess rehabilitation success, including determination of the protection of potentially impacted ecosystems and environmental values.

Both the monitoring programs and closure criteria are subject to review as the outcomes of studies and/or new information become available and stakeholder feedback is considered. As such, some aspects of post-closure monitoring require finalisation of the closure criteria to develop further. This is an adaptive management process designed to remove uncertainty and meet the closure objectives. Where necessary, amendments will be incorporated into future iterations of the Mine Closure Plan (MCP).

10.1 Closure monitoring program

Monitoring to evaluate performance against closure criteria begins as progressive rehabilitation activities are undertaken during operations and continue into closure. The closure monitoring program will enable an adaptive management approach to site rehabilitation to inform performance strategy. The monitoring program will provide ongoing feedback of the site rehabilitation performance allowing for the refinement of rehabilitation strategies before broad scale rehabilitation.

Operational monitoring programs will provide input into the closure monitoring programs, as required. Technical working groups, and programs that have taken place over recent years, have also informed the development of the monitoring programs outlined in this section. In recognition of the interrelationship between closure related studies undertaken by both Energy Resources of Australia Ltd (ERA) and Supervising Scientist Branch (SSB), the Monitoring Evaluation and Research Review Group was established in 2019. The group, represented by members of ERA and the SSB, as well as subject matter experts as required, is tasked with the ongoing development and refinement of research and monitoring programs during the progressive rehabilitation period.

Monitoring programs associated with closure studies will also continue throughout the operation and closure phases. The research related monitoring programs are captured within the summary of each research project in Section 5.

A Ranger Mine Rehabilitation Monitoring Workshop was held on 4 September 2018 to ‘agree on high-level monitoring, to avoid missing information that is needed to inform the progressive rehabilitation process’ (SSB 2018).

An overarching framework for the monitoring of Pit 1 was developed in mid-2019: *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1). The framework outlines the two phases of Pit 1 rehabilitation; construction and ecosystem rehabilitation. Monitoring plans will be developed for the two phases as rehabilitation of Pit 1 progresses. The monitoring plan for the construction phase (ERA 2020) was developed by the Monitoring Evaluation and Research Review Group (MERRG) and initiated in early 2020. The monitoring plan to be implemented during the ecosystem rehabilitation phase is currently under development. Success of the Pit 1 rehabilitation will be driven by adaptive management, research and monitoring to establish the overarching framework for ongoing rehabilitation across the Ranger Mine. A number of stakeholders, including the SSB and Alligator Rivers Region Technical Committee (ARRTC), have provided recommendations towards the Pit 1 monitoring objectives and requirements.

10.2 Monitoring and maintenance period program

The monitoring and maintenance program is initiated following the successful completion of decommissioning and rehabilitation. This monitoring phase will occur after January 2026 when the site is progressing towards the development of a long-term stable landform and self-sustaining ecosystem that meets the closure objectives. The adaptive management approach implemented during the transitional monitoring phase (from operations to closure to post-closure) will continue, whereby the monitoring program will provide ongoing feedback of the site rehabilitation performance, identify any issues and inform maintenance activities. However, under the current legislative framework, (*Atomic Energy Act* 1953 - section 41c (5) of the Authority (Nov 1999) (Section 3.1.2) the access of ERA to the Ranger Project Area (RPA) ceases on 8 January 2026. Discussions are currently underway with key stakeholders to enable ongoing access to the RPA after this date, to undertake monitoring and, if required, minor remedial or maintenance works (Section 3.1.5.1).

The monitoring program following the closure period will commence in 2026 and continue until results of the monitoring demonstrate that the site has met the required closure objectives and relinquishment of the RPA is achieved. As this length of time is unknown, ERA have currently assumed a 25 year period of monitoring and maintenance.

During this phase, the landform may settle over time and there is also the potential for subsidence and/or erosion to occur. Revegetation must also progress towards a self-sustaining ecosystem. Potential remedial management practices to ensure continued progress towards a stable landscape and self-sustaining ecosystem in this phase are described in Table 10-1.

Monitoring the rehabilitation progress of site access tracks and service corridors (the ‘linear infrastructure’ domain) will be assessed by aerial photography, as it will not be practical to undertake traditional monitoring in the field once tracks are removed. Remedial action will be undertaken, where necessary.

Table 10-1: Examples of maintenance work that may be required during the closure and/or post-closure phases

Action	Description
Minor earthworks	• Will be undertaken to repair any ongoing erosion or other stability issues, identified by landform monitoring. • May include localised maintenance of passive water management structures or sediment basins.
Infill planting	• Highest rates of plant mortality will most likely occur soon after initial planting and routine monitoring will allow for timely remediation through infill planting (timed to occur with annual wet seasons). Infill planting will be undertaken where high mortality of ‘initial’ tubestock is observed in the first 6-24 months. • ‘Secondary’ introductions of additional species will occur once suitable conditions develop. • May also be required when an unplanned large-scale event such as a fire or cyclone causes significant additional mortality.
Weed control	• Weeds may out-compete and smother tubestock, or may increase the risk of fire, and thus increase mortality. • ERA will monitor and maintain a weed control buffer zone around the rehabilitated site. Targeted weed monitoring, as well as the routine revegetation monitoring will identify and record any weed infestations on the rehabilitated landform. • Weed control methods will be situation and species-specific, with the most effective controls determined from ERA experience and input from specialists. Weeds are likely to be controlled by a combination of chemical and physical methods (including application of residual or short acting chemicals, seed head cutting and burning, or fuel-load reduction by fire).

Action	Description
Fire management	• Fire is a part of the current land management of Kakadu NP but is a risk to the initial development of rehabilitation; and therefore, needs to be controlled. • In an effort to avoid fire in revegetated areas, only low-biomass native grasses and herbs will be introduced, along with trees and shrubs, at initial establishment. Fire will be excluded for the first 5-8 years until revegetated species have established a level of resilience (defined in the Ranger Mine Revegetation Strategy, (Section 5) and after which low intensity 'cool burns' will be promoted in the wet and early dry seasons.
Application of fertiliser	• Some of the growth media to be used in rehabilitation may be deficient in nutrients. To improve optimum growing conditions, tubestock will be planted with fertiliser pellets and, approximately 6-12 months later, a second application of fertiliser will be applied. • Plant health and development will be the primary indicator of soil and plant nutrition, however five-yearly soil monitoring will assist with interpretation, and amelioration, of any determined nutrient deficiency, if required (e.g. addition of further fertiliser inputs).
Pest control	• High levels of insect damage can cause plant mortality; young plants may also be impacted by native and feral vertebrate fauna (e.g. wallabies or pigs). • Routine vegetation monitoring will identify impacts from the range of potential pest species. • Management of pests may involve spraying with insecticides, temporary fencing, or direct management of feral vertebrate fauna (carried out in accordance with the ERA Fauna Management Plan and in accordance with relevant licences and permits).
Water management	• Passive water and sediment management ponds may require maintenance. • Structures may also need to be decommissioned when no longer required.

10.3 Landform monitoring

A number of landform studies have been undertaken to address key closure issues and risks, and to inform the design parameters of the final landform. A trial landform was constructed in 2009, and studies on the trial landform have been used to validate design attributes such as landform stability, erosion, topography and visual amenity; and inform the current landform model predictions (Appendix 5.1). The outcomes of these studies have resulted in a final landform topography that incorporates low elevation and slopes to enhance landform stability and visual aesthetics to blend with the surrounding landscape.

Landform monitoring will begin during progressive rehabilitation and continue throughout the closure and monitoring and maintenance phases to assess the condition of the landform. Specific landform parameters are monitored during and after construction to assess stability and suitability for revegetation. The primary objective of monitoring during construction is to assess adherence to the planned landform design; including material transfer and placement. Following construction, parameters such as settlement and subsidence performance; surface topography; surface ripping; erosion and erosion controls; bedload and sediment control; and suspended sediment will be monitored. Further detail on these parameters are included in the Table 10-2.

The design of the landform, including erosion and drainage control, will minimise the development of gully erosion. Sediment basins and drainage channels will be inspected after each wet season to confirm that the basins and channels continue to operate according to design. Inspections will identify any unplanned gully erosion and channels and inform subsequent maintenance, if required, as well as validate modelling outputs. The SSB has indicated that whilst it is expected that gullies will form on the landform within the modelled 10,000 years, the tailings will be below the natural landscape and are therefore not expected to be exposed (Supervising Scientist 2017). It is expected that maintenance requirements will progressively decrease as the landform stabilises and dynamic equilibrium is reached. The outcome criterion will be achieved when drainage channels are considered to have reached, or are trending towards functional dynamic equilibrium. At functional dynamic equilibrium, there will be no unplanned gully erosion and the landform will be comparable to the surrounding landscape.

An important parameter for assessment of site-wide erosion is event load suspended sediment, tracked on a whole of wet season basis. Suspended sediment loads from the landform are expected to reduce over time, trending towards background suspended sediment loads. The SSB has demonstrated turbidity can be used as an indicator for suspended sediment (Moliere & Evans 2010). A comparison of turbidity levels upstream and downstream of the RPA will be applied as a measure of suspended sediment loads leaving the landform and entering Magela Creek or Gulungul Creek. As sediment loads are expected to decrease over time, achievement of the outcome criterion will be based on a trend towards background loads. Inspections for bedload in Magela Creek and Gulungul Creek will also be conducted following every wet season to assess the presence and extent of erosion and inform maintenance.

Changes in geotechnical conditions will be monitored to identify the presence, and measure the extent of subsidence, slumping, deformation and/or settlement. This will provide a mechanism to track progress towards the closure objectives. Maintenance will be undertaken, where necessary. Settlement plates at the interface between the consolidating tailings and the overlying waste rock were installed during placement of the pre-load as part of the backfill of Pit 1. The monitoring plates enable regular verification and updating of the consolidation model. Ongoing measurements of tailings settlement have been undertaken on a monthly basis and confirm that the model is still valid. Use of Satellite based synthetic Aperture Radar is likely to be used to monitor tailings settlement in Pit 3. This will be confirmed in the Pit 3 closure application. Tailings will be monitored for excess pore water pressures via vibrating piezometers.

Monitoring to measure progress towards landform closure criteria will also include final landform topography after completion. It is expected that either airborne and/or terrestrial LiDAR (or equivalent) technology will be used to survey and capture the final landform topography. If the final landform varies significantly from the design, the topography will be used to rerun the 10,000 year landscape evolution model. Specific details on which LiDAR techniques will be utilised have yet to be determined; and new information will be incorporated into future iterations of the MCP. Landform monitoring for closure and the monitoring and maintenance period is presented in Table 10-2 and Table 10-3, respectively.

10.3.1 Pit 1 landform monitoring

As discussed in Section 9.3, Pit 1 will be ready for revegetation early 2021. This provides an opportunity for a number of trials and monitoring programs to be implemented to develop and refine ERA's ecosystem re-establishment approach, thereby aligning with the *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1).

Pit 1 will be divided into four areas as shown in Figure 10-1. Each area will have a different ripping application applied which is intended to create a natural appearance of the surface topography whilst also providing an opportunity to trial revegetation options (refer Section 9.3.1.3).

Surface topography and micro-surface topography monitoring of each area will be undertaken. In summary, this will include:

- Undertaking an annual surface topography survey in various locations on Pit 1;
- Digital Elevation Model (DEM) surveys to be completed year-on-year; and
- Undertaking visual assessment surveys to monitor micro-topography change.

Post survey and modelling results will be compared with historical data to quantify landscape settlement. Micro-topography monitoring will inform landform closure criteria to determine whether the constructed landform meets the optimised landform design.

Landscape denudation and erosion monitoring will also be undertaken of each area. This will include:

- Telemetry stations at the topographical low of each area will be installed to measure turbidity and total suspended solids (TSS); and
- An estimate of discharge via flow measurements.

Opportunistic water grab samples will also be collected and analysed for key COPCs, including nutrients.

A number of vegetation trials will be undertaken on Area WM-1C. For further detail on these trials, see Section 9.3.1.3.

Table 10-2: Landform closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Material placement*	Material characteristics and volume.	Dynamic mine model with associated tracking methods. Within landform levels during construction.	Whole of final landform via tracking system.	Ongoing	Until landform is built.	*Pit 1 Progressive Rehabilitation Monitoring Framework*
Subsidence or slumping, deformation and/or settlement	Geotechnical monitoring (as described in Section 10.4)	Identify any subsidence or deformation of landform areas.	TSF, pits and landfill walls.	Quarterly	Until final landform is on a stable trajectory to meet final criteria.	L1
Surface topography*	Topography survey	Comparison of DEM and survey to planned landform.	Whole of final landform.	Once. When practical upon completion of final landform.	Not applicable.	L1
	Quantify landform settlement	Year on year DEM change and topographic survey.	Whole of final landform.	Annual	Until final landform is on a stable trajectory to meet final criteria.	L1, L4
Surface micro-topography*	Micro-topography survey	Comparison of DEM and survey to planned landform.	Whole of final landform.	Annual	Until final landform is on a stable trajectory to meet final criteria.	L1, L3, L4
		High resolution DEM and field survey.	Whole of final landform.	After land forming and annual after wet season.	Until final landform is on a stable trajectory to meet final criteria.	L1, L3
Surface ripping*	Map ripped areas	Mapping via GPS tracking, field survey or remote sensing.	Planned ripped areas.	Once, after landform creation.	Not applicable.	L4, L5

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Erosion (encapsulated tailings)*	Capture digital elevation model (DEM) of the final constructed landform using either airborne and/or terrestrial LiDAR (or equivalent) technology	Describe the final landform against planned landform. Assess LEM results for critical erosion over tailings areas. Potentially provide updated information to rerun the 10,000 year landscape evolution model (LEM) and confirm LEM predictions for tailings encapsulation.	All disturbed areas.	Once. When practical upon completion of final landform (closure phase).	Not applicable.	L2, L3
Erosion (local scale post-wet season)	Field inspection* of erosion and sedimentation, notes, photographs DEM analysis	Identify significant erosion – rill erosion > 30 cm depth, sheet erosion or prevention of revegetation (>0.1 ha) Identify erosion around drainage channels.	Erosion of drainage channels Sedimentation of sensitive receptors	Annually after wet season	Until final landform is on a stable trajectory to meet final criteria.	L2, L3
Erosion Control Structures*	Confirm erosion control structure function through field inspection.	Ensure erosion structures function effectively.	All erosion control structures.	Annually post-wet season.	Until final landform is on a stable trajectory to meet final criteria.	L3
Bedload (Access Roads and Creeks)	Field inspection* of erosion, notes, photographs	Identify any erosion on roads that may be source of bedload moving offsite.	Access roads Magela and Gulungul creeks	Biannually and after each significant rain event	Until final landform is on a stable trajectory to meet final criteria.	L5
Bedload (sediment traps)*	Quantify sub-catchment bedload sediment movement.	Measurement from sediment traps.	All sediment traps.	Annually post-wet season.	Until final landform is on a stable trajectory to meet final criteria.	L5

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	BACIP analysis (Moliere & Evans 2010) after end wet season. Inform assessment of site denudation rates. Turbidity trajectory transitioning to control environment levels after 5 years.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks).	Continuous turbidity monitoring during wet season.	Until suspended sediment loads are approaching background values.	L6

*Adapted from *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1)

Table 10-3: Landform monitoring and maintenance

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Erosion (local scale post-wet season)	Field inspection* of erosion and sedimentation, notes, photographs	Identify significant erosion – rill erosion > 40 cm depth, sheet erosion or prevention of revegetation (>0.1 ha) Identify erosion around drainage channels.	Erosion of drainage channels Sedimentation of sensitive receptors	Annually after wet season	Until final landform is on a stable trajectory to meet final criteria.	L3
Erosion (general)	Field inspection* of erosion, notes, photographs	General inspection for localised scouring and damage.	All disturbed areas	Biannually	2026-2031**	L3
				Annually	2031-2051**	L3
Bedload (Access Roads and Creeks)	Field inspection* of erosion, notes, photographs	Identify any erosion on roads that may be source of bedload moving offsite.	Access roads Magela and Gulungul creeks	Biannually and after each significant rain event	Until final landform is stable and has met final criteria	L5
Bedload (Sediment Basins)	Field inspection* of sediment control basins, notes, photographs	Sediment volumes in sediment control basins. Structural integrity of sediment control basins.	All sediment control basins	Quarterly	2026-2029**	L5
				Biannually	2030-2051**	L5
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	BACIP analysis (Moliere and Evans 2010) after end wet season Inform assessment of site denudation rates. Turbidity trajectory transitioning to control environment levels after 5 years.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks)	Continuous turbidity monitoring during wet season	Until suspended sediment loads are approaching background values	L6

*Erosion field study methodology to be developed prior to closure and being trialled as part of the Pit 1 Rehabilitation Monitoring Strategy.

**Assuming access to the landform is permitted after 2026

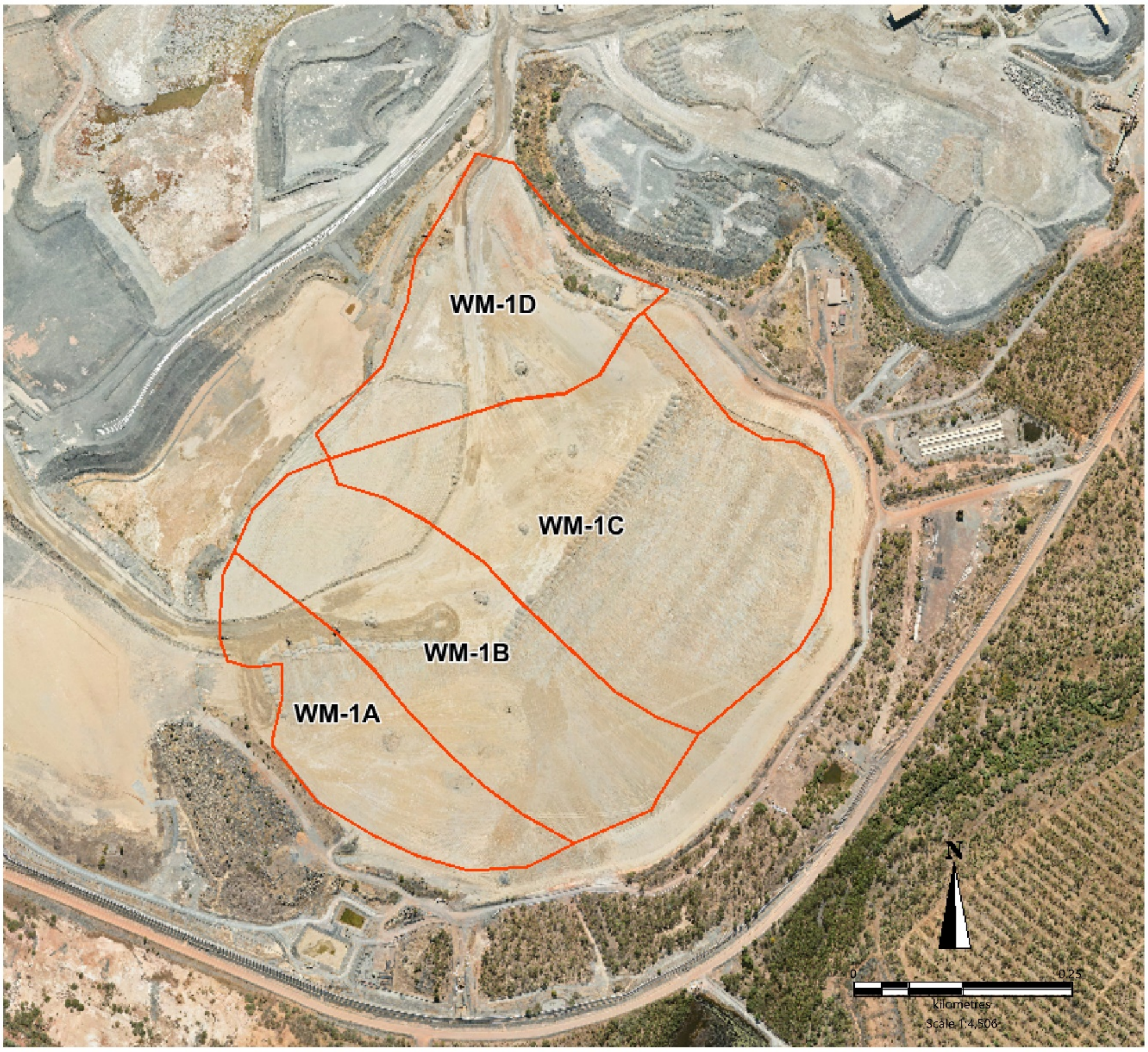

Figure 10-1: Pit 1 ecosystem reconstruction areas

10.4 Water and sediment monitoring

10.4.1 Surface water and sediments

10.4.1.1 Closure monitoring

Surface water monitoring is currently undertaken at a number of sites within and outside the RPA. Monitoring is undertaken by ERA, the SSB and the Northern Territory Department of Industry, Tourism and Trade (DITT). The ERA surface water monitoring program is reviewed and updated annually in the Ranger Mine Water Management Plan (RWMP). The RWMP is subject to a stakeholder review and approval process each year. The program includes monitoring for both compliance and operational purposes, i.e. active water management information.

The surface water compliance monitoring program and interpretation and reporting framework is very mature (Turner *et al.* 2015). The compliance monitoring program consists of continuous monitoring of electrical conductivity (EC) and turbidity, weekly grab samples for a range of key variables and event-based auto-sampling upstream and mid/downstream of the mine on Magela Creek and Gulungul Creek.

Water quality results are compared to a three-tier system of management and compliance trigger values; this approach aligns with the National Water Quality Management Framework. The upper tier *Limit*, which represents the water quality objective for high-level ecosystem protection, is the compliance value. The framework also includes *Focus*, *Action* and *Guideline* values which prompt management and reporting actions. These lower tier management trigger values also provide criteria to assess the acceptability of, or suitable conditions for, planned active discharges of water from the Ranger Mine site to Magela Creek. This program will continue during the closure phase.

Once the mine enters the post-closure phase, discharges of water from the rehabilitated site will be passive so the three-tiered approach with discharge management responses will not be the most appropriate regime to implement. Monitoring will instead be interpreted against closure criteria at the locations agreed to for each criteria Table 10-4.

10.4.1.2 Monitoring and maintenance period

Monitoring in the post-2026 period is required to assess rehabilitation success including identifying any unexpected events or concentrations of constituents of potential concern (COPC) (compared to model predicted results), and assessing the protection of ecosystems, human health and environmental values by comparison of water quality against closure criteria.

Groundwater solute transport modelling has predicted long time lags between closure of the mine and delivery of peak solute loads to the creek system. The delivery time frames are dependent on the source of the contaminant, and transport pathway (Section 5).

Timeframes for the peak loads from the different source terms (INTERA 2016) and (INTERA 2020 – TSF modelling) are:

- waste rock runoff – < 20 years
- TSF contaminant plume - < 20 years
- waste rock seepage – ~ 270 years
- tailings and brines – ~10,000 years
- expressed process water (pit tailings flux) from Pit 1, removed and treated currently and throughout closure phase (i.e. prior to 2026).

The surface water model (Section 5) predicts concentrations of COPCs the creeks and billabongs will be exposed to as a result of these loads. Accumulation of uranium in sediments will be calculated based on predicted water quality results and the partition model being developed by the SSB.

Figure 10-2: GC2 monitoring station in the dry season

Figure 10-3: GC2 monitoring station in the wet season

This time lag and its relevance to monitoring, and assessing if closure criteria will be met, is recognised in the SSB rehabilitation standard series[2] which states:

> *Given the potentially long timeframe between the completion of rehabilitation and the peak delivery of contaminants to surface water, this Rehabilitation Standard will most likely be used to assess predicted magnesium[3] concentrations from modelled scenarios. Ongoing surface water and groundwater monitoring will be required after rehabilitation to continue to ensure the environment is being protected, and to validate and assess confidence in the models.*

Thus, the aims of the post-2026 surface water monitoring program can be described as:

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

[2] http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards

[3] The same statement is made in the rehabilitation standard for each COPC

The proposed post-closure monitoring program, summarised in Table 10-4 provides a basis for determining if the environment and human health will continue to be protected in the post-closure phase, and if the surface water model predictions for that phase are being met.

Water quality parameters and draft guideline values have been proposed for each of the objectives of the surface water and sediment closure theme (Section 8). These have been developed in consultation with the Water and Sediment Working Group (WASWG). The draft monitoring program to assess if the criteria are being met in the post-closure period will be reviewed by the same group.

The locations and monitoring frequencies for current surface water monitoring forms the basis of the proposed initial post-closure monitoring strategy (Table 10-4). Sub-catchment monitoring exit points will be included as part of surface water monitoring during Pit 1 rehabilitation. Consideration of onsite and sub-catchment exit points will be discussed in future planning meetings with the SSB, with new information included within updates to the MCP. The rationale for monitoring at these locations are:

- Current compliance points MG009 and GCLB, just inside the boundary of the RPA
    - Comparison of water quality at the current compliance points in Magela and Gulungul creeks against agreed water quality objectives will continue to provide the basis of assessing protection of the aquatic environment, human health and recreational values in creeks and billabongs downstream of the RPA.
- Upstream and downstream on Magela and Gulungul creeks
    - Continuous turbidity during the wet season will enable the comparison of suspended sediment with natural distribution (suspended sediment landform criteria and aesthetic values of clarity).
- Onsite billabongs
    - Comparison of water quality and sedimentation in Coonjimba and Georgetown billabongs with criteria accepted as representing impacts that are as low as reasonably achievable (ALARA) (Section 6) will demonstrate acceptable levels of protection for ecosystems and land use on the RPA and
- Comparison of results against model predictions for all of the above sites will be undertaken for validation purposes.

As discussed above, ERA is planning to shift to event-based auto-sampling regime for monitoring, with sample collection triggered by changes in continuous EC data. This approach, currently used by the SSB, should be suitable for the monitoring program after closure and will be considered by WASWG.

The proposed initial monitoring program will evolve based on changes in methods and technology (some currently planned), feedback by WASWG and results collected in the initial years of the post-closure monitoring period. All discussions and improvements to this framework will likely be adapted into the broader site-wide closure monitoring programs as planning progresses. It is anticipated that the post-closure monitoring program could be carried out by a local service provider.

The results from the surface water monitoring program in the monitoring and maintenance period, and any triggered investigations and actions, will be provided to stakeholders with an interpretive report of all results at the end of each wet season. Investigation reports will be provided as completed, rather than at the end of the wet season. The need for more frequent reporting, and appropriate formats and levels of interpretation will be considered by WASWG.

The proposed surface water monitoring program details are summarised in Table 10-4 and is applicable to both the closure and monitoring and maintenance phases. Monitoring during the closure phase will identify the potential opportunity to decrease the monitoring scope during monitoring and maintenance.

Surface water monitoring sites for the Ranger Mine		
Authored: G Landwehr	Date: 13/08/2020	
Prepared by: C Newland	Print Size: A3	
Map Name: Ranger Mine Surface Water Monitoring V3.mxd		
Spatial Data: "A5988_Ranger_50mm_RGB_MGA94z53_14-May-2019.ecw", ERA data , NT Government, ESRI Basemaps		

Ranger Mine

0 500 1,000 1,500 2,000 2,500

Metres

GDA 1994 MGA Zone 53

Scale 1:30,000

Figure 10-4: Statutory and operations surface water monitoring sites at the Ranger Mine

Table 10-4: Parameters and locations for post-closure surface water monitoring to assess compliance with closure criteria

Location	Parameter	Frequency	**Closure criteria** Tables 8-5 & 8-6
MG009, GCLB, MCUS, GCC	Turbidity	Continuous	W3,W5, W6, L6, C7
	EC (proxy for Mg)		W3, W5, C7
	Mn, U, SO_4	Monthly grab sampling during the wet season with frequency reduced over time based on performance and risk review.	W1, W2, W3, W5, C7
The parameter list for MCUS and GCC upstream sites may be reduced in future where criteria does not include comparison against natural distributions.	Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N		W3, W5, C7
	NO_3, NO_2		W1, W2, W5, C7
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.	W6, C7
Georgetown, Coonjimba and Gulungul Billabongs	Turbidity	Continuous	W3, W5,W6, C7
	EC		W5, C7
	U, Mn, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, SO_4	Monthly grab sampling during the wet season with frequency reduced over time based on performance and risk review.	W5, W1, W2, W3, C7
	NO_3, NO_2	Monthly (if recreational and drinking water identified as community value for these sites).	W1, W2, W5, C7
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.	W5, W6, C7
	Sediment concentrations and U	Accumulation in sediments limited by U in water criteria. Sediment sampling to demonstrate current[4] compliance via scheduled projects in closure phase.	W4, W5

[4] See footnote against sediment concentration for onsite billabongs.

Location	Parameter	Frequency	**Closure criteria** Tables 8-5 & 8-6
	Sedimentation	Event-based triggered by results of landform monitoring. TBC in consultation with Landform criteria and Water quality stakeholder groups.	W5, L5

10.4.2 Groundwater

10.4.2.1 Closure monitoring

Environmental Requirement (ER) 2.3 *"… provides for minimum restrictions on the use of the area."* However, it was agreed during the Closure Criteria Working Group meeting of 19 August 2008 that groundwater extraction for purposes other than monitoring would not be allowed on the RPA, post-closure. The minutes of the meeting state: *"… that a constraint on groundwater abstraction from Ranger operational area and some surrounds will be needed to prevent bores being sunk in areas where water may be unsuitable for use."*

In this context, the primary objective of the closure groundwater monitoring program will be to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and the regional groundwater environment remains protected. The results of solute transport modelling (INTERA 2014a, 2014b, 2018) indicate that solutes at depth in the backfilled pits will enter low-permeability hydrolithologic units (non-aquifers) and migrate away from solute sources at very low rates. The modelled flux rates from these units to shallow and deep aquifers and surface water bodies are very low. Therefore, it is not appropriate to set concentration-based groundwater closure criteria for these units. Ongoing monitoring of groundwater will provide data to validate these solute transport model predictions and assumptions.

Monitoring 'envelopes' in the four sub-catchments; Gulungul, Coonjimba, Djalkmarra and Corridor creeks, will be progressively refined during decommissioning. The ‘envelopes’ will comprise new and/or existing monitoring bores.

Groundwater on the RPA is generally described through discrete hydrolithologic units (HLU). These HLUs are defined based on similar geological and groundwater flow and transport characteristics. The HLUs are split into four typical zones and are summarised in Table 10-5.

The groundwater monitoring program has been designed to identify changes in groundwater head and solute concentrations for comparison against expected changes in the groundwater system (i.e. changes in groundwater heads and flow direction and changes in concentrations of selected solutes). This monitoring regime is intended to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and that the receiving environment remains protected.

Table 10-5: Generally identified hydrolithologic units on the RPA

Hydrolithologic Zone	Geological Description and Typical Depth	Hydrological Description
Alluvial HLUs	The surficial alluvial HLUs include the alluvial sediments (sands, gravels and transported sediments). Alluvial HLUs are present in proximity to the creek channels across the RPA. Typical thickness of the alluvial HLUs are between 8 m and 12 m.	Ephemeral wetting in wet season. Hosts the water table in the wet season. Likely to behave as a porous medium with relatively higher permeability.
Shallow Weathered Rock HLUs	Weathered rock is the mantle of parent rock that has decomposed or altered to contain a large fraction of clay or sandy clay. In general, the thickness of weathered rock across the RPA is about 25 to 30 m but it can be thicker or thinner in local areas.	Ephemeral wetting in wet season. Hosts the water table in the wet season. Likely to behave as a porous medium with relatively moderate to high permeability.
Deep Bedrock HLUs	The deep HLUs are not exposed at the surface. The deep HLUs are those located in the fresh bedrock of the Cahill Formation and the Nanambu Complex. In general, these units start at base of the weathered rock HLUs and extend beyond the base of the groundwater model (700 m+ depth).	Fully saturated at all times (unless affected locally by dewatering associated with mine activities). Typically low permeability with the exception of several discrete zones that with moderate to high permeability. These higher permeability zones include the Deeps Water Producing Zone (DWPZ), MBL zone, depressurised upper mine sequence (D-UMS) and Zone C shallow bedrock. The DWPZ is a higher permeability region located below Pit 3 along a geological contact associated with the Deeps Fault Zone. The MBL zone is a higher permeability conceptualised strip of higher yielding rock. This was defined to explain high groundwater yields near the south-eastern edge of Pit 1. The D-UMS is a higher permeability zone that extends to the north of Pit 3. It is defined by an area where groundwater head responses were observed as a result of Pit 3 mining. Zone C is a relatively small zone of higher permeability shallow bedrock to the south of Pit 3. It is defined by an area where groundwater head responses were observed as a result of Pit 3 mining.
Mine Backfill HLUs	Mine backfill HLUs consist of the material used to backfill Pit 1, Pit 3 and the final landform. This material consists waste rock and tailings. The thickness of these HLUs varies greatly	The mine backfill HLUs consist of materials with both high permeability (waste rock) and lower permeability (tailings).

Hydrolithologic Zone	Geological Description and Typical Depth	Hydrological Description
	depending on location, the Pit 1 and Pit 3 backfill. HLUs extend from ground level to the base of the pit excavations whilst the final landform extends from the natural ground surface to the maximum height of the final landform.	

Groundwater monitoring programs for closure for Pit 3 (Djalkmarra catchment), Pit 1 (Corridor Creek), and R3D are included as components of the Ranger Water Management Plan (2020). The programs have been designed to target pathways for transport of solutes into the environment and the various hydrolithologic units defined in the groundwater conceptual model. New bores have been drilled and developed in the vicinity of Pit 1, Pit 3 and R3D as part of the 2019-2020 drilling program.

The Pit 1 groundwater monitoring program is intended to demonstrate that solute transport velocities and concentrations, within each hydrolithologic unit are consistent with modelling predictions, and that the receiving environment is being protected in this area. A number of opportunities and changes have been identified as a result of updated groundwater modelling information. The monitoring bore layout in the Pit 1 area was therefore changed as part of 2019-2020 Drilling Program. Figure 10-5 shows the location of all groundwater monitoring bores in Pit 1, including the new bores drilled in the 2019-2020 Drilling Program.

The Pit 3 groundwater monitoring program monitors changes in groundwater head and solute concentrations, within each hydrogeologic unit, for comparison against expected changes in the groundwater system between Pit 3 and Magela Creek, both during Pit 3 backfilling and after Pit 3 closure. Adjacent to Pit 3, 13 existing bores are monitored biannually to capture pre and post-wet season groundwater quality. Six new monitoring bores, nested with multiple HLUs and across three different locations were drilled as part of 2019-2020 Drilling Program as shown in Figure 10-5 and Table 10-6. These bores are monitored in accordance with the Ranger Water Management Plan (RWMP 2020). An additional seventh monitoring bore will be installed following completion of backfilling of Pit 3 to monitor head and solute concentration changes in the Pit 3 shallow waste rock backfill, which is expected to be a source for constituents of potential concern. The location and screening parameters of the Pit 1 and Pit 3 monitoring bores are provided in Table 10-6, and Figure 10-6

The site-wide post-closure groundwater monitoring network will be based on the existing network as outlined in the 2018/19 Annual Ranger Groundwater Report (ERM 2020). However, bores within the final landform will be decommissioned when no longer required. This program will also include the Pit 1 and Pit 3 monitoring bores identified below.

The R3Deeps groundwater monitoring program monitors changes in groundwater head and solute concentrations within hydrolithologic units adjacent the underground workings. Proximal to the R3Deeps workings, five existing monitoring bores are monitored biannually to capture pre and post-wet season groundwater quality. The location and screening parameters of the R3Deeps monitoring bores are provided in Table 10-6 and Figure 10-6.

Figure 10-5: Location of Pit 1 monitoring bores

Table 10-6: Parameters for monitoring bores for Pit 1,Pit 3 and R3D closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Monitoring
MB-A	Pit 1	274092	8596243	50	44 to 50	Quarterly WQ & SWL
MB-G	Pit 1	273681	8595812	50	44 to 50	Quarterly WQ & SWL
MB-L	Pit 1	273933	8595935	50	14 to 16	Quarterly WQ & SWL*
R1C3-1	Pit 1	273977	8595978	22.25	16.25 to 22.25	Quarterly WQ & SWL
P1_CL_01	Pit 1	273624	8595993	18	10 - 18	Quarterly SWL
P1_CL_02	Pit 1	273965	8595950	8	2 - 8	Quarterly WQ & SWL
P1_CL_03	Pit 1	274174	8596230	9	3 - 9	Quarterly WQ & SWL
P1_CL_04	Pit 1	274175	8596230	18	12 - 18	Quarterly WQ & SWL
P1_CL_05	Pit 1	274176	8596230	35	29 - 35	Quarterly WQ & SWL
P1_CL_06	Pit 1	274177	8596230	75	63 - 75	Quarterly WQ & SWL
P1_CL_07	Pit 1	273751	8595738	7	4 - 7	Quarterly WQ & SWL
P1_CL_08	Pit 1	273752	8595738	18	15 - 18	Quarterly WQ & SWL
P1_CL_09	Pit 1	273753	8595738	35	29 - 35	Quarterly WQ & SWL
MS4	Pit 3	274311	8598255	9.25	6 to 9.25	Biannual WQ & SWL
MS4-A	Pit 3	274311	8598255	5.25	1.45 to 5.25	Biannual WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Monitoring
P3-4B	Pit 3	273822	8598301	100	60 to 99.5	Biannual WQ & SWL
P3-8	Pit 3	274292	8598235	81	42 to 69	Biannual WQ & SWL
P3-11	Pit 3	274362	8598122	25.6	11 to 25.6	Biannual WQ & SWL
P3-12	Pit 3	273893	8598467	75.6	56 to 71	Biannual WQ & SWL
P3-13	Pit 3	274477	8597921	39	24.6 to 39	Biannual WQ & SWL
P3-15A	Pit 3	274651	8598250	57	39 to 54	Biannual WQ & SWL
P3-15B	Pit 3	274677	8598252	30	22 to 30	Biannual WQ & SWL
P3-16	Pit 3	274117	8598323	57.7	34.7 to 57.7	Biannual WQ & SWL
P3_CL_01	Pit 3	274283	8598187	10	4 - 10	Quarterly WQ & SWL
P3_CL_02	Pit 3	274287	8598183	25	19 - 25	Quarterly WQ & SWL
P3_CL_03	Pit 3	274290	8598181	60	48 - 60	Quarterly WQ & SWL
P3_CL_04	Pit 3	273608	8598337	70	46 – 70	Quarterly WQ & SWL
P3_CL_05	Pit 3	273820	8598300	20	8 - 20	Quarterly WQ & SWL
P3_CL_06	Pit 3	273823	8598299	45	33 - 45	Quarterly WQ & SWL
R3D49S	R3D	274800	8597799	294	263 – 284	Biannual WQ & SWL
R3D52D	R3D	274446	8598214	367	352 - 367	Biannual WQ & SWL
R3D52S	R3D	274446	8598214	284	263 - 284	Biannual WQ & SWL
R3D54	R3D	274562	8597836	397	351 – 393	Biannual WQ & SWL
R3D56A	R3D	274557	8598065	449	0 - 349	Biannual WQ & SWL

* Additional monitoring undertaken to support operational requirements

Figure 10-6: Location of Pit 3 monitoring bores

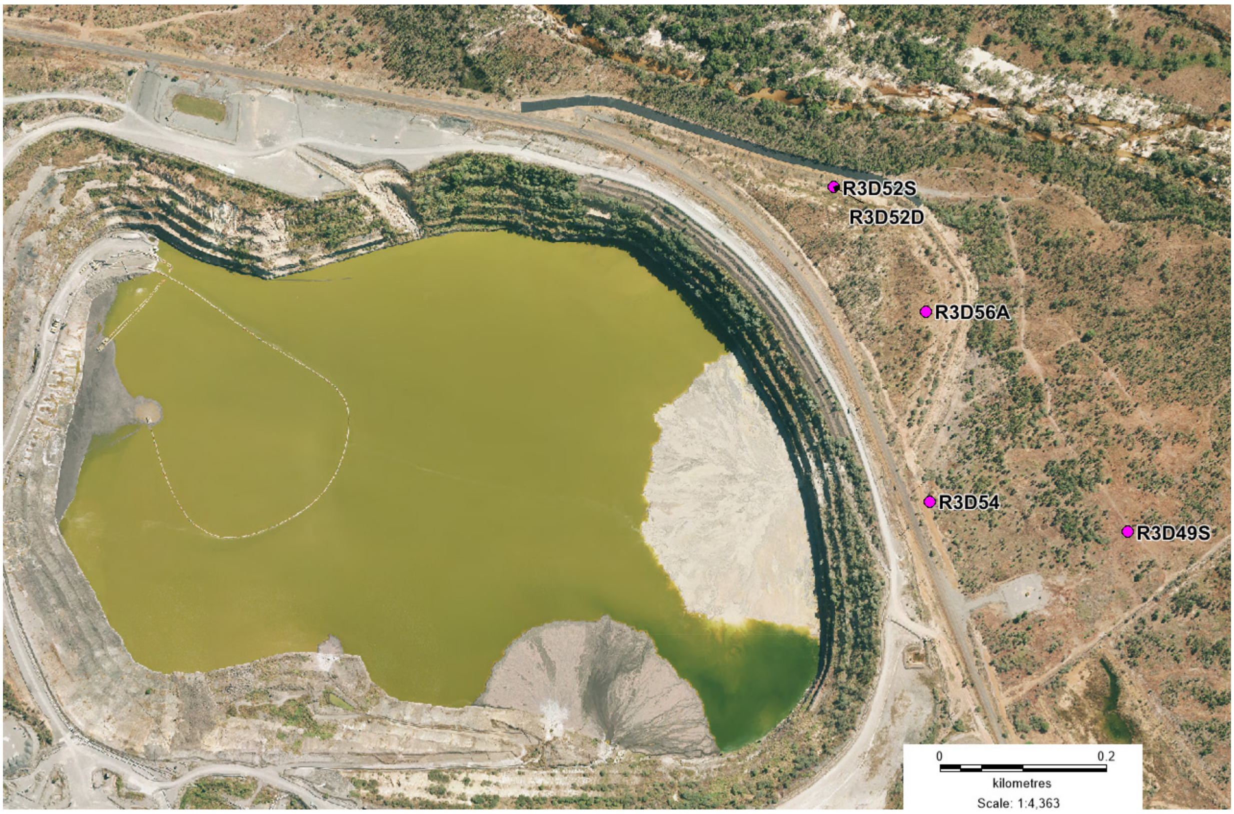

Figure 10-7: Location of R3D closure monitoring bores

A similar monitoring regime will be implemented across the other sub-catchments. This may be in the form of monitoring bores within hydrolithologic units, or in the form of primary, secondary and tertiary bores staged at various distances down-gradient of each potential contaminant source. These bores will provide background water quality data and enable expeditious verification of model predictions and detection of longer range effects of solute migration.

Monitoring of existing bores, as per Table 10-6, is underway. Results are presented in the annually in the Annual Ranger Groundwater Report. Assessment of this monitoring program will undergo continuous review to ensure it remains suitable for supporting closure studies and validating modelling results. Updates of the groundwater monitoring plan to support ongoing closure studies will be detailed in the annual RWMP and subsequent MCPs.

The proposed closure and post-closure monitoring will comprise monthly measurements of standing water level and quarterly or biannual sampling and chemical analysis (Table 10-8). The objective of the post-closure groundwater monitoring program, as with the closure groundwater management program, is to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and that the receiving environment will remain protected from defined COPCs. A representative sample of bores will remain for the groundwater monitoring program post-closure. The monitoring frequency is expected to decrease as the post-closure groundwater environment stabilises providing no further risks are identified.

COPCs are constituents considered to be a potential concern to the environment, and can be a concern for humans, biota and/or fauna. The Ranger Authorisation stipulates environmental monitoring of groundwater for the solutes magnesium (Mg), sulfate (SO_4), manganese (Mn), uranium (U) and radium-226 (^{226}Ra). Organic contaminates such as total petroleum hydrocarbon (TPH) are potential COPCs for the historical processing plant area.

COPC trigger levels for all parameters must be determined from suitable background collection sites, and these will inform the criteria for ongoing management. These figures will be updated in the post-closure monitoring report as received. Weaver *et al.* (2010) provided a general review of background groundwater chemistry of the TSF. This review is intended as a guide below in Table 10-7. The proposed monitoring will comprise measurements of standing water level plus sampling and chemical analysis at defined frequencies of, for example, pH, EC, Ca, Cl, HCO_3^-, K, Mg, Mn, Na, SO_4^{2-}, ^{226}Ra and U. Updates of the groundwater monitoring plan to support closure will be detailed in the annual RWMP.

The final groundwater monitoring plan for post-closure will be developed with continued stakeholder engagement and advice from INTERA upon completion of the post-closure solute transport modelling. Development of the post-closure groundwater monitoring plan will be detailed in subsequent mine closure plans. The post-2026 groundwater monitoring plan will also incorporate refined background chemistry data as presented in Section 5. Groundwater monitoring currently proposed and executed for closure and monitoring and maintenance period is presented in Table 10-8.

Table 10-7: General background groundwater chemistry for the RPA

Parameter	Alluvial HLUs	Shallow Weathered HLUs	Deep Bedrock HLUs
EC	<500 µS/cm		
Sulfate	< 5 mg/L Higher concentrations in the dry may result from evapotranspiration. Fluctuating concentrations may relate to input from surface water or runoff.	<5 mg/L Steadily rising concentrations through time are likely to indicate seepage from the TSF or stockpiles.	<5 mg/L Steadily rising concentrations through time are likely to indicate seepage from the TSF or stockpiles.
Magnesium	< 30 mg/L with no indications or steadily rising concentrations.		
Calcium	< 40 mg/L with no indications or steadily rising concentrations.		
Manganese	< 5 to approximately 2000 µg/L, fluctuating concentrations	< 10 to approximately 2000 µg/L with no indication of steadily rising concentrations	
Radium-226	Variable, < 5 to approximately 100 mBq/L	Variable activities < 5 to approximately 300 mBq/L	
Uranium	< 10 µg/L		

Table 10-8: Groundwater closure and post-closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Compliance Reference
Standing water level	Manual standing water level measurements	Compare to adopted background levels to confirm groundwater level is behaving according to modelled predictions, within the documented uncertainties. To determine hydraulic gradients and potential movement of COPCs.	Groundwater monitoring locations listed in Table 10-6	Monthly (during closure and year 1 post-closure) Quarterly (years 2-4 post-closure) if no changes) Annually during wet season (ongoing if no changes)	Until criteria have been achieved	Ranger Authorisation Annexes D & E, Ranger Water Management Plan 2019/20
Chemical analysis	*In situ* parameters (pH, EC) Major ions and cations (Mg, Na, K, Ca, Cl, SO_4, HCO_3, CO_3) Filterable metals (U, Mn, Fe) Total nitrogen (NOx-N (NO_2-N+NO_3-N), NH_3-N) Ra-226	Compare to adopted background levels to confirm groundwater chemistry is not being adversely impacted by COPCs from former RPA activities. Where COPC impacts are already present, to ensure these are not migrating into additional impact areas.	Groundwater monitoring locations listed in Table 10-6	Quarterly (during closure and years 1-3 post-closure if no exceedances) Annually during wet season (ongoing if no exceedances)	Until criteria have been achieved	Ranger Authorisation Annexes D & E

Aspect	Methodology	Analysis	Location	Frequency	Duration	Compliance Reference
	Additional trace metals (Cd, Cr, Cu, Hg, Pb, Zn, Fe, Al) Total Petroleum Hydrocarbons (TPH)		Sites (to be determined) in Process Plant Area			

10.5 Radiation monitoring

10.5.1 Closure monitoring period

The current operational radiation monitoring program will continue throughout the closure phase in accordance with the requirements of the Authorisation. The purpose of this monitoring is to confirm that radiation exposure to workers on the Ranger Mine site and members of the community is kept as low as reasonably achievable (known as ALARA) and below the relevant dose limits. Variations to the monitoring program will be necessary as rehabilitation progresses beyond the cessation of uranium processing.

Radiation monitoring, undertaken for the purposes of assessment of closure criteria, will be limited during the closure phase. Detail will be provided in future MCPs following the outcomes of the Monitoring Evaluation and Research Review Group.

10.5.2 Pit 1 radiological monitoring

ERA is currently finalising the scope of works to undertake radiological monitoring on the completed Pit 1 landform. The following monitoring will be undertaken:

- Surface gamma survey
- Radon 222 exhalation flux density
- Radium 226 substrate sampling
- Passive Radon 222 sampling

Further details on the scope of works is described in Section 5 and will be refined for review by stakeholders before execution.

10.5.3 Monitoring & maintenance period

The proposed post-closure monitoring for radiological performance has been structured around the exposure pathways for radiation due to the potential access to, and final land use of the area. These pathways are:

- inhalation of Long Lived Alpha Activity (LLAA e.g. radioactive dust)
- inhalation of radon progeny (Potential Alpha Energy Concentration; PAEC)
- ingestion of radioactive material in (or with) food or water, and
- external irradiation from gamma rays (and beta particles).

Given the possible post-closure use of the landform, the critical group will be Aboriginal people using the site for traditional activities including transient camping and the gathering of traditional bush foods for consumption.

LLAA and PAEC will be measured towards the end of the dry season for the initial five-year period following construction of the final landform, the details of the monitoring program are outlined in Table 10-9. Lower soil moisture during the dry season results in increased Rn exhalation rates and higher dust concentrations in air. Monitoring will be undertaken over a minimum one-week period each dry season using either:

- High volume air samplers (LLAA) or continuous radon decay product monitors (PAEC) targeting areas with increased activity present in the sediments, or
- Passive techniques that integrate over a longer time period, such as track etch detectors (PAEC) or passive dust samplers (LLAA) over a three- to six-month period.

Potentially contaminated waters will be monitored in conjunction with the water and sediment monitoring program with grab samples taken upstream and downstream of Ranger Mine in Magela Creek and Gulungal Creek and at key receptor locations. Samples will initially be taken monthly during creek flow, this will reduce to annually once low levels have been confirmed. Results of this monitoring program will be used to determine ingestion dose from drinking water and eating bush foods.

At the completion of decommissioning activities, an airborne radiometric survey with targeted ground surveys for external gamma dose rate and ^{226}Ra in soils will be undertaken to determine the gamma dose from the final landform.

Radiation monitoring for closure and monitoring and maintenance period is presented in Table 10-9.

Table 10-9: Radiation closure and post-closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Long Lived Alpha Activity (LLAA) – Radionuclides in dust	High volume samplers or deposited dust samplers to monitor	Confirm radiation doses to members of the public are below limits (as defined in closure criteria)	RPA and key receptor locations off site	Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3-6 months (for years 1-5)	Five years following 8 January 2026	R1, R2
Radon Decay Products (RDP)	Continuous radon decay product monitors or more passive techniques such as radon track etch detectors	Confirm radiation doses to members of the public are below limits (as defined in closure criteria)	RPA and key receptor locations off site	Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3-6 months (for years 1-5)	Five years following 8 January 2026	R1, R2
External gamma radiation	Airborne radiometric survey with ground gamma survey and soil sampling	Confirm radiation doses to members of the public are below limits (as defined in closure criteria)	final landform	Once at the completion of rehabilitation activities	NA	R1, R2
Radionuclides in bushfood	Alpha spectrometry analysis of samples for Ra-226, Po-210 and Pb-210. ICP-MS for U.	Confirm radiation doses to members of the public are below limits (as defined in closure criteria)	RPA	To be refined based on fruit and seed production seasons	Until demonstrated progression towards closure criteria, i.e. low levels have been confirmed	R1, R2

Aspect	Methodology	Analysis	Location	Frequency	Duration	Closure Criteria
Bushfood – water	Analysis of samples for Ra-226, U, Po210 and Pb210 *Analysis method to be determined*	Confirm radiation doses to members of the public are below limits (as defined in closure criteria). Confirm radionuclide concentrations used in concentration ratios for ERICA assessment	MG009 and GCLB	Monthly during wet season flow decreasing to annually over time	Until demonstrated progression towards closure criteria, i.e. low levels have been confirmed Duration or timeline for ERICA assessment (5 years post-closure)	R1, R2,
Soil radionuclide analysis	Gamma spectometry analysis of samples for Ra-226, U-238	Confirm radionuclide concentrations used in concentration ratios for tier 2 ERICA assessment	RPA other than final landform waste rock areas	Once	Immediately post-closure	R1, R2

10.6 Soils monitoring

The *Contaminated Land Risk Register* has been developed and maintained by the site environment team at the Ranger Mine, in accordance with the operational *Hazardous material and contamination control plan* (ERA 2018). The *Contaminated Land Risk Register* identifies all sites where activities have occurred that have the potential to contaminate land. This register has been developed in conjunction with a number of targeted assessments undertaken at known contaminated sites on the RPA (Sections 5.5.2.5).

The key environmental receptors of the Ranger Mine are the surface water bodies adjacent to the mine site. These receptors are far away from contaminated sites. Groundwater velocities in the underlying formations are low, and the weathered rock underlying the site tends to retard most contaminants. Nevertheless, further characterisation of contaminants at some contaminated sites on the RPA may be required to determine vertical extent, lateral extent and/or mass of contamination.

It is intended that the degree of remediation required for each contaminated site will be remediated to a level where the environmental impact is ALARA to ensure the protection of the environment. Soil assessments, and additional investigations, will be used to undertake BPT assessments which will determine whether remediation action plans are required.

10.7 Ecosystem monitoring

Monitoring is an integral part of the ecosystem restoration process. It is used to determine the initial success of revegetation efforts in establishing the desired species density and composition and evaluate the progress of older revegetation in terms of growth rates, structural development, ecological function and tracking along a trajectory towards longer-term sustainability. Monitoring provides feedback to identify problems and inform adaptive management or intervention and is also needed to demonstrate acceptable performance against criteria and standards, ultimately leading into stakeholder acceptance of the ecosystem restoration (Reddell & Meek 2004).

Ecosystem (revegetation and fauna) monitoring undertaken during the operation of Ranger Mine is presented in Section 5.

The current proposed program allows for potential improvements following a number of investigations proposed for the Pit 1 revegetation works, such as optimised species-specific establishment methods, the influence of substrate characteristics (and soil water availability) on plant success. Thus, the monitoring of Pit 1 will comprise a combination of research structured monitoring along with routine revegetation monitoring methods. The MERRG are currently developing the ecosystem rehabilitation monitoring plan for Pit 1 as part of the *Pit 1 Progressive Rehabilitation Monitoring Framework*. This plan will be completed in late 2020.

The ecosystem monitoring program presented in Table 10-10 represents the routine tasks anticipated for the overall revegetation program, regardless of additional research activities, which will be developed separately. Completion criteria relevant to ecosystem are in Table 8-10 and Table 10-10.

10.7.1 Ecosystem (revegetation) monitoring

The scope and frequency of monitoring is largely dependent upon the stage of development of the revegetation. An initial assessment soon after planting (one to three months) will capture any mortality caused by planting stress or other revegetation execution problems. The highest mortality is anticipated to occur in the first six to twelve months post-planting, due to drought conditions of the dry season. Thus, the determination of the requirement for infill planting will typically be made six to eight months after planting. Ongoing annual monitoring of establishment success will continue until all initial establishment and subsequent infill plantings have developed sufficiently and attrition rates have dropped to a recoverable level. This initial monitoring will focus on survival rates for tubestock and germination rates for direct seeding, species composition, density, height, health and other opportunistic observations such as weeds, fauna, pests and erosion. Subsets of individual plants will be identified and recorded each year to allow assessment of individual species development.

Initial annual monitoring may involve recording every planted stem, though this will depend on the size of the area revegetated. Alternatively, belt transects, point centred quarter or other techniques may be used to sample a subset of the stems. Some permanent plots will be established and repeatedly measured to gather information on rates of change of various attributes over time. Fixed photo points will be used to provide a visual representation of revegetation progress. For the initial monitoring attributes, consistent methods will be used each year, to enable comparisons over time and between sites, and into the long-term monitoring program.

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

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

As secondary introductions of additional plant species and plants occur, additional 'initial' monitoring of these plants will need to occur in addition to the routine vegetation monitoring of the already established vegetation.

Long-term ecosystem monitoring will need to continue on an annual basis, until the developmental trajectory can be seen to be steadying and the risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention is sufficiently reduced. As development stabilises, the frequency, intensity and potentially the scope of the monitoring program can be adjusted to allow more effective use of resources.

Areas that receive remediation treatment will require a targeted monitoring program, independent of the surrounding areas, to assess the effectiveness of the remedial action and progress back towards the desired trajectory.

Revegetation monitoring and maintenance will begin following initial planting. The majority of the infill planting and understorey planting activities will occur during this phase. Information provided by the monitoring of established reference sites and revegetation plots will be used to address ecosystem revegetation closure criteria.

The proposed survey frequency of revegetation across the final landform is: three, six and twelve months (year one); annually (years two to five, inclusive); one-off surveys every five years (e.g. at years 10, 15, etc). Some routine surveys, such as weed, will be annual, and every five years a more comprehensive monitoring will be required to demonstrate the trajectory. The details are presented in Table 10-10.

10.7.2 Weed monitoring

ERA has undertaken fine scale annual weed surveys and mapping across the RPA since 2003 (Section 5.3.3.2). This mapping provides data to assess the effectiveness of weed control measures and to inform the ongoing weed monitoring and subsequent corrective actions required to meet closure criteria, particularly within the first five years, whilst the revegetation is establishing.

Weeds may out-compete and/or smother tubestock, or may increase the risk of fire, and thus potentially increase tubestock mortality. ERA will monitor and maintain a weed control buffer zone around the rehabilitated site. Targeted weed monitoring, and routine revegetation monitoring will record if any weed infestations occur on the final landform.

Weed control methods will be situation and species-specific, with the most effective controls determined from ERA experience and input from specialists. Weeds are likely to be controlled by a combination of chemical and physical methods, including application of residual and or short acting chemicals, seed head cutting and burning, or fuel-load reduction by fire.

10.7.3 Exotic fauna monitoring

ERA currently undertakes exotic animal monitoring and culling to manage densities of particular species on the RPA, such as pigs. This practice will continue during the initial maintenance period after commencement of post-closure monitoring (e.g. years one to five). Exotic animals will be culled if densities become too high and other remedial actions will be taken if feral animals are adversely affecting physical works (e.g. damaging wetlands or revegetation on the final landform) or significantly compromising recolonisation by native fauna. As the landform develops, exotic animal monitoring and management will revert to that which is followed within Kakadu National Park (NP).

10.7.4 Native fauna recolonisation

Fauna recolonisation closure criteria have been included in the 2020 MCP (Section 8). The fauna criteria is in draft and will require further studies and stakeholder consultation. Once closure criteria is finalised, appropriate monitoring plans will be developed.

Monitoring of fauna recolonisation may be more suitable on a campaign (e.g. five-year) basis in the mature revegetation (along with similar surveys of the reference sites). Some details are presented in Table 10-10.

Figure 10-8: Water quality sampling

Table 10-10: Flora and fauna closure & maintenance period monitoring

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
Initial Establishment Monitoring.	Species composition, total species richness, density and species relative abundance	Use standard NT vegetation survey methods such as plots and transects.	In specific plots to provide representative samples within the RPA. Also to be used following infill planting and remediation that involves the introduction of new plants.	3, 6 and 12 months after planting, and then annually each post-wet / early dry season.	To transition to 'long-term' vegetation monitoring program once rates of attrition reduce and structural and functional attributes begin to develop, e.g. 3-5 years.	E1-4, C10-12
	Survival rates (incl. height and health) for tubestock and germination rates for direct seeding	Rapid assessment of broadscale plant survival using tubestock planting data (location / species). Permanent plots, individual plants assessed over repeat monitoring events. % of planted (or sown) plants.				N/A
	Opportunistic observations such as weeds, fauna, pests and erosion	Opportunistic observations as part of flora monitoring program. Aerial / LiDAR assessment of erosion and/or weeds.				N/A
Long-term Revegetation Monitoring.	Species composition and relative abundance, Stems per hectare	Use standard NT vegetation survey methods such as plots and transects. Bray-Curtis similarity index.	In specific plots to provide representative samples within the RPA.	Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any	Until closure criteria achieved	E1-E7, C10, C12

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
				requirement for active management intervention.		
	Canopy architecture	Presence of multi-strata. Presence of understorey shrubs and grasses developed appropriate to the substrate.		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria achieved	E8-E11, C9-C10
	Canopy cover index, ground cover index	Use standard NT vegetation survey methods. Comparable to appropriate reference sites.		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria achieved	E8-E10, C9-C10
	Tree distribution	Trees are planted in a manner to appear 'natural'. Traditional owners inspection and assessment		Annually each post-wet / early dry season. Frequency, scope, intensity to be reduced, based on assessment of risk of deviation (due to mortality, weeds or fire) and any requirement for active management intervention.	Until closure criteria E11 achieved	E11C4

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
	Reproduction (flowering and seeding)	Evidence of flowering and fruiting		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E12, C10
	Recruitment & regeneration	Presence of seedlings and/or suckers		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E13, C9, C11
	Nutrient cycling	Chemical and biological indicators, e.g., Soil nutrient analysis, Accumulation of litter and organic matter. Evidence of decomposition of litter. Presence of soil, animals and saprophytic fungi.		One-off surveys every five years (e.g. 5, 10, 15 years)	Until closure criteria achieved	E14
	Fire resilience	Vegetation plots/transects Following a recent fire (within the previous five years), all other closure criteria must be shown to have been met, demonstrating recovery.	RPA where required according to fire events	Event-based	Until closure criteria achieved	E15
	Wind & drought resilience	Woodland ecosystem demonstrates survival under natural condition,	In specific plots to provide representative	Event-based	Until closure criteria E16 achieved	E16

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
		similar to appropriate reference sites.	samples within the RPA.			
	Weed composition and abundance	Spatial mapping and density scoring Survey for Class A weeds and Class B weeds and other introduced species.	Spatial mapping: priority species Density scoring: across the RPA	Annual	Until closure criteria E17-19 achieved	E17-E19, C11
Fauna Monitoring	Fauna habitat connectivity: lack of physical barriers (e.g. fences)	Visual assessment	RPA	Annual	Until closure criteria E21 achieved	Draft criteria E21 C3
	Native fauna species richness and diversity: Number of vertebrate Evenness of bird species across sites	Survey plots and transects Pielou's evenness	RPA	Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites). One-off surveys every 5 years (ongoing).	Until closure criteria achieved	Draft criteria E22-E23
	Functional diversity of native fauna: Species richness for each of four Key Functional Groups of ants	Survey plots and transects		Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites).	Until closure criteria achieved	Draft criteria E22-E23

Type	Aspect	Methodology /Analysis	Location	Frequency	Duration	Closure Criteria
	Species richness of nectivorous and frugivorous species			One-off surveys every 5 years (ongoing).		
	Target native fauna species: culturally significant fauna Activity, diversity, and functional diversity of subterranean active termites Number of threatened species	Survey plots and transects		Opportunistic observations included as part of initial vegetation monitoring method. One-off comprehensive surveys every 5 years (including reference sites). One-off surveys every 5 years (ongoing).	Until closure criteria achieved	Draft criteria E22-E23
	Exotic fauna Density of buffalo, horses and pigs	Survey plots/transects Density of buffalo, horses and pigs	RPA		Until closure criteria achieved	E20, C12

10.8 Cultural monitoring

Alongside the development of the cultural closure criteria (Section 8.3.6), linguist Murray Garde (Garde 2015) proposed a number of indicators that could be used to reflect the Traditional Owner attitudes towards rehabilitation progress and by extension the satisfication of the cultural closure criteria during the closure and post-closure phases (Table 10-11). A number of these indicators are largely based on visual and aesthetic values, as viewed through the lens of Mirarr culture. These indicators represent the overall cultural health of the ecosystem, which needs to be assessed by Mirarr Traditional Owners.

Table 10-11: Suggested indicators of cultural health of rehabilitated site (Garde 2015)

Landscape surface	Vegetation	Riparian zone	Biodiversity
Size of rocks	Growth rate	Presence or absence of artificial water bodies	Natural species numbers and diversity
Presence/absence of erosion	Botanical diversity	Visual impressions of water quality, sedimentation, silting of rehabilitated water courses	Impressions of hunting potential
Accessibility	Correct species for ecological zone	Condition of water course margins, creek banks	Impressions of vegetable food availability
General aesthetic (does it look 'natural')	Presence/absence of weeds		

Garde (2015) states that there are very few established models or methodologies to inform programs that assess cultural health. One notable example comes from New Zealand: *Cultural Health Index for Streams and Waterways: Indicators for Recognising and Expressing Maori Values* (Tipa & Teirney, 2003, 2006). The index attempts to apply indicators that Maori land owners use to assess the health of waterways.

In the absence of an established best practice methodology in an Australian context, Garde (2015) described a proposed process by which to monitor the success of rehabilitation using a set of cultural health indices. The process described a scalar score generally out of ten that allowed impressionistic responses to be quantified. A key aspect of the indices is the bilingual format, including information in both Kundjeyhmi and English (an example is in Table 10-12).

It was suggested that the cultural monitoring assessments could be carried out at specific locations that collectively provide a cross section of rehabilitation and include a number of significant cultural areas. An assessment of cultural health and rehabilitation progress will be conducted at each location on an annual basis. The proposed locations include:

1. TSF rehabilitated landform
2. Pit 3 rehabilitated landform

3. Retention Pond 2 (RP2) rehabilitated landform
4. Pit 1 rehabilitated landform
5. Retention Pond 1 (RP1)
6. Kundjinba Billabong (Coonjimba Billabong)
7. Georgetown Billabong (Madjawulu)
8. Brockman irrigation area (i.e. Corridor Creek LAA)
9. Karnbowh Djang (Tree Snake Dreaming), and
10. Ranger Mine 34 archaeological site (quartz outcrop with grinding holes).

Table 10-12: An example of a bilingual, scalar cultural index score for cultural criteria monitoring

ga-djalbolkwarre yerre	**ga-bolkwarre yiga ga-bolkmakmen gun-yahwurd**	**kareh ga-bolkmakmen gare lark**	**ga-bolkmakmen wurd**	**bon, ba-bolkmakminj wanjh**
no improvement yet noticed	some minor improvements	some areas improved, some areas not	noticeable return to healthy state in most areas	satisfactory return to natural state
1 | 2	3 | 4	5 | 6	7 | 8	9 | 10

The Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC) have provided feedback that the MCP is to include a compliance and monitoring process for meeting the cultural closure criteria and that they would propose a process for ERA consideration that included direct involvement of Traditional Owners with technical support. The GAC and the NLC have been working with Traditional Owners and Murray Garde to build on previous work completed. Once GAC and NLC have finalised the proposed process, it will be reviewed by ERA and incorporated into future revisions of the MCP.

10.9 Trigger, action, response plan (TARP)

The monitoring program described in Sections 10.3 to 10.8 have been summarised into a preliminary TARP, which will also be updated in future iterations of the MCP based on agreement of closure criteria and the outcomes of ongoing studies. The TARP is presented in Table 10-13.

Table 10-13: Trigger, action, response plan

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Landform					
Final landform surface (topography, erosion and settlement)	Sites: RPA Parameters: Landform terrain Analysis: LiDAR or drone survey Frequency: Annual	To inform landform settling rate and erosion rates	Change from previous Comparison to modelled	Site-based plan and action as required	Site Environmental Officer (or delegate)
Erosion (local scale)	Sites: Sensitive receptor areas and drainage channels Parameters: Field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels	Significant erosion – rill erosion > 40 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha) Erosion around drainage channels	Site-based plan and action as required Repairs to area identified	Site Environmental Officer (or delegate)
Subsidence, slumping, deformation, and/or settlement	Sites: Identified geotechnical sites Parameters: Geotechnical monitoring of pits, landfill walls, TSF Analysis: Identify any changes (subsidence or deformation) of landform Frequency: Quarterly	Identify any subsidence or deformation of landform areas	Subsidence, deformation, or settlement of final landform are noted	Site-based plan and action as required. May require additional works including modifying the sediment control basis	Site Environmental Officer (or delegate)
Bedload	Sites: Water courses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Biannually before and after the wet season	Identify bedload being transferred off site	Bedload identified moving offsite	Site-based plan and action as required. May require additional works including modifying the sediment control basis	Site Environmental Officer (or delegate)
Bedload (sediment basins)	Sites: 18 temporary sediment basins Parameters: Sediment volume and structural stability Analysis: Design requirements Frequency: Annual	To maintain basins in operational condition	Outside operational design criteria	Site-based plan and action as required	Site Environmental Officer (or delegate)
Suspended Sediment	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS)) Analysis: BACIP analysis (Moliere & Evans, 2010) Frequency: Ongoing monitoring, analysis after wet season	Assess site denudation rates	Turbidity trajectory not transitioning to control environment levels after 5 years	Site-based plan and action as required May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin	Site Environmental Officer (or delegate)
Water and sediment					
Surface water and sediment – turbidity and aesthetic	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Turbidity at both sites and other aesthetic parameters (e.g. surface films, odour) Analysis: Physical and observational analysis of samples Frequency: Continuous monitoring for turbidity	Identify erosion issues and conformance with ecosystem and recreational quality of surface water	Results exceed specific agreed closure criteria	Monitor trends and develop site specific action plan as required	Site Environmental Officer (or delegate)
Surface water and sediment – other parameters	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Various parameters (e.g. EC, major ions, nutrients and metals)	Assess compliance with closure criteria Validate surface water model predictions. Identify surface water and sediment quality issues	Samples exceed specific screening criteria defined in closure criteria	Monitor trends, identify cause and develop site specific action plan as required	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
	Analysis: Chemical analysis of samples and continuous EC Frequency: Ongoing monitoring for EC (Mg), scheduled grab sampling			Review model assumptions and outputs	
Surface water and sediment – U in sediment	Sites: Gulungul, Coonjimba and Georgetown Billabongs: Parameters: U in sediment Analysis: Chemical analysis of samples Frequency: Sample prior to and at end of decommissioning	Characterise contaminants in sediments on and off the RPA. Inform decommissioning of onsite billabongs and confirm success of decommissioning activity (if conducted)	Samples exceed specific screening criteria defined in closure criteria	Identify causes (chemical analyses to identify source) and develop site specific action plan if the mine is the source a	Site Environmental Officer (or delegate)
Groundwater	Sites: Monitoring bores Parameters: Standing water level and *in situ* parameters (pH, EC) Major ions and cations, filterable metals and total nitrogen Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly progressing to quarterly in years 2-4 post closure then annually in no changes, chemical analysis quarterly until year 3 post closure progressing to annually during wet season until criteria have been achieved	To confirm groundwater level and chemistry is behaving according to modelled predictions, within the documented uncertainties	Analysis indicates that groundwater is not tracking according to model predictions	Site-based plan and action as required	Site Environmental Officer (or delegate)
Radiation					
LLAA and PAEC inhalation	Sites: RPA Parameters: LLAA and PAEC (mSv per year) Analysis: High volume samplers and continuous radon decay product monitors or more passive techniques such as radon track etch detectors and passive dust samplers Frequency: Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3-6 months (for years 1-5)orm.	To confirm radiation doses to members of the public are below limits	Exceedance of the baseline radiation dose as defined in the closure criteria	Action plan to mitigate identified pathway to ALARA Apply additional restrictions on the use of the land in consultation with Traditional Owners	Radiation Safety Officer (or delegate)
Food and water contamination	Water Sites: Magela Creek at MG009 and GCLB, , also upstream sites Parameters: Ra-226, U-238, Po-210 and Pb-210 (other isotopes if risk identified). Bushfoods to be collected from the RPA. Analysis: Gamma spec analysis Frequency: initially monthly during the wet season, decreasing to annually over time Bushfood collection on and off RPA as per current Kakadu National Park approvals Parameters: Ra-226, U-238, Po-210 and Pb-210 Analysis: Aplha spec analysis and ICP-MS Frequency: Field campaigns with traditional owners and park rangers	As above	As above	As above	Radiation Safety Officer (or delegate)
External gamma radiation	Sites: RPA Parameters: Radiation dose rate (µGy/h) Analysis: Airborne radiometric survey with ground gamma survey and soil sampling for Ra-226 for ground-truthing Frequency: At the completion of rehabilitation activities	As above	As above	As above	Radiation Safety Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
Ecosystem					
Flora species composition	Sites: Vegetation plots and transects across the RPA Parameters: Species composition and total species richness (all overstorey, midstorey and understorey species), density of overstorey and midstorey framework species, vegetation structure (e.g. height, DBH), canopy and ground cover indices and overstorey and midstorey species distribution. Analysis: vegetation survey analysis Frequency: three, six and 12 months (year 1); annually (years 2 – 5, inclusive); one-off surveys every five years (e.g. at years 10, 15)	To determine whether species composition and community structure is similar to adjacent areas of Kakadu NP	Exceedance of final criteria defined in closure criteria	Site-based plan and action as required	Site Environmental Officer (or delegate)
Ecosystem maintenance	Sites: vegetation plots and transects across the RPA Parameters: Reproduction (flowering and seeding), recruitment / regeneration, nutrient cycling, fire resilience, resilience to wind and drought, and weed density and composition, species richness of native fauna, density of exotic animals Analysis: vegetation and fauna survey analysis. Frequency: One-off surveys every five years (e.g. at years 5, 10, 15). for all parameters except fire, wind and drought for which it will be event-based. Exotic animal: annual	To determine whether the long term, viable ecosystem requiring maintenance is similar to adjacent areas of Kakadu NP	As above	As above	Site Environmental Officer (or delegate)
Fauna surveying	Sites: Fauna survey plots/transects across the RPA Parameters: Species richness and diversity. Analysis: Fauna survey analysis Frequency: One-off surveys every five years (e.g. at years 5, 10, 15)	To determine the presence of major functional species groups in comparison to surrounding Kakadu NP	As above	As above	Site Environmental Officer (or delegate)
Weed surveying and mapping	Sites: RPA Parameters: Weed density and priority Analysis: Spatial mapping and density scoring Frequency: Annual	To determine the spread of weeds and invasive flora within the revegetation areas	As above	As above No Class A[5] weeds. Class B[2] weeds similar to surrounding Kakadu NP (defined by monitoring). Presence of other introduced species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	Site Environmental Officer (or delegate)
Cultural					
Cultural values	To be determined (see Section 10.8)	To determine whether Traditional Owners are satisfied that the rehabilitated environment supports cultural land uses	Conditions identified in closure criteria not met	Site-based plan and action as required	Site Environmental Officer (or delegate)

[5] Class A Weeds are to be eradicated. Class B weeds growth and spread to be controlled

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Soils					
Contamination	Sites: Sites in the Ranger Mine contaminated site register Parameters: Various contaminants Analysis: Contaminated soil assessment based on local background concentrations or published investigation levels Frequency: Prior to decommissioning and as identified by assessment.	To ensure impacted soils are remediated to as low as reasonably achievable to protect the environment	Impacts not ALARA	If concentrations of contaminants are not ALARA then a detailed site investigation and/or remediation plan will be developed, requiring further monitoring	Site Environmental Officer (or delegate)
Nutritional Assessment	Sites: Stratified sampling sites across the rehabilitated landform. Parameters: Macro and micro-nutrients, pH, EC, OC% etc. Analysis: Soil chemical (and physical) parameters compared with known reference sites and vegetation requirements Frequency: Five-yearly surveys (at years 0, 5, 10, 15, etc).	To assess the development of the soil profile and inform follow-up fertiliser application type, quantity and timing	Conditions required for development of rehabilitation not met	Develop soil amelioration plan, such as fertiliser application	Site Environmental Officer (or delegate)

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APPENDIX 10.1: PIT 1 PROGRESSIVE REHABILITATION MONITORING FRAMEWORK

ERA Energy Resources of Australia Ltd

2rog

Pit 1 Progressive Rehabilitation Monitoring Framework

April 2019

Author(s): Dr Paul Frazier (2rog)

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V1b	4/02/19	Final	PF	EF	PF
V2	9/04/19	Following SSB review	PF	EF	PF

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FIGURES

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Abbreviations

Abbreviation	Description
AARTC	Alligators Rivers Region Technical Committee
BACIP	Before After Control Impact Paired
DEM	Digital Elevation Model
ERA	Energy Resources of Australia
LEM	Landscape Evolution Model
SSB	Supervising Scientist Branch

1 INTRODUCTION

The Ranger Progressive Rehabilitation Monitoring Workshop was held on 4 September 2018 to ‘agree on high-level monitoring, to avoid missing information that is needed to inform the progressive rehabilitation process’ (SSB 2018).

This workshop defined the progressive rehabilitation period as being from present to 2026 and identified key monitoring themes that included:

- Landform
- Water (groundwater and surface water)
- Radiation
- Ecosystem restoration.

The workshop also identified that rehabilitation of Pit 1 is planned to proceed in late 2019 and presents an opportunity to develop and refine the Progressive Rehabilitation Monitoring Framework.

Following the initial workshop, a subsequent workshop was held with Energy Resources of Australia (ERA) staff on 27 November 2018, to develop a monitoring and research framework specifically focussing on the Pit 1 area. This team reviewed and incorporated knowledge and advice from the Ranger Progressive Rehabilitation Monitoring Workshop meeting notes, subsequent stakeholder meetings, best practice monitoring procedures and the wealth of knowledge and research available for the site.

Supervising Scientist Branch (SSB) held a Pit 1 monitoring objectives workshop on 23 November 2018. The outcomes of this workshop were shared with ERA on 26 November 2018 (Leggett, Amie. 26 November 2018) and discussed at the internal ERA workshop held on 27 November 2018.

Parallel to these workshops, the 41st Alligator Rivers Region Technical Committee (ARRTC) meeting was held in Darwin on 13-14 November 2018. ARRTC members were actioned to provide input recommendations to the Pit 1 monitoring requirements.

- ***ACTION 41.2****: ARRTC to consider what parameters should be monitored on the Ranger Trial Landform to inform relevant KKNs. While this would include parameters informing plant available water modelling (WAVES), they should also be broadened if necessary to consider parameters informing the design of future research and monitoring for Pit 1 rehabilitation*
- ***ACTION 41-4****: ARRTC to provide input into planning and implementing an adaptive management approach to Pit 1 rehabilitation, including reviewing the detailed plans of ERA/SSB for any additional studies and monitoring that are required to inform the Key Knowledge Needs and the broader rehabilitation project.*

Subsequent communication and feedback via email and meetings was also incorporated into the design of this framework (Dixson, Kingsley. 11 December 2018, Leggett, Amie. 18 December 2018, Leggett, Amie. 20 December 2018, Leggett, Amie. 21 December 2018, Rumpff, Libby. 13 December 2018, Zichy-Woinarski, John. 11 December 2018).

This framework focusses on monitoring and research activities that may be conducted to ensure successful rehabilitation of the Pit 1 area (Figures 2-3) and inform ongoing progressive rehabilitation across the Ranger site.

To ensure clarity throughout this document the terms monitoring and research have been defined as:

> Monitoring – repeated measurement of target indicator parameters that are linked to trigger/threshold values that may invoke a management action.
>
> Research – a defined study with a clear hypothesis and defined objective/s that is designed to inform a specific knowledge gap.

Monitoring data may be incorporated into a research program with properly constructed hypotheses. Likewise, research activities may be incorporated into a monitoring program with suitable action triggers established.

The Pit 1 Rehabilitation Monitoring Framework consists of two distinct monitoring phases: construction; and ecosystem establishment. A separate section on defined research studies associated with Pit 1 is also included.

It is intended that the Pit 1 monitoring framework provides the basis for the progressive rehabilitation monitoring plan for the Ranger site. Lessons learned from the monitoring and research outcomes from Pit 1 will be incorporated into the site monitoring plan as required under an adaptive management framework.

The location and set out of the Ranger Mine and Pit 1 is shown in Figures 1-3.

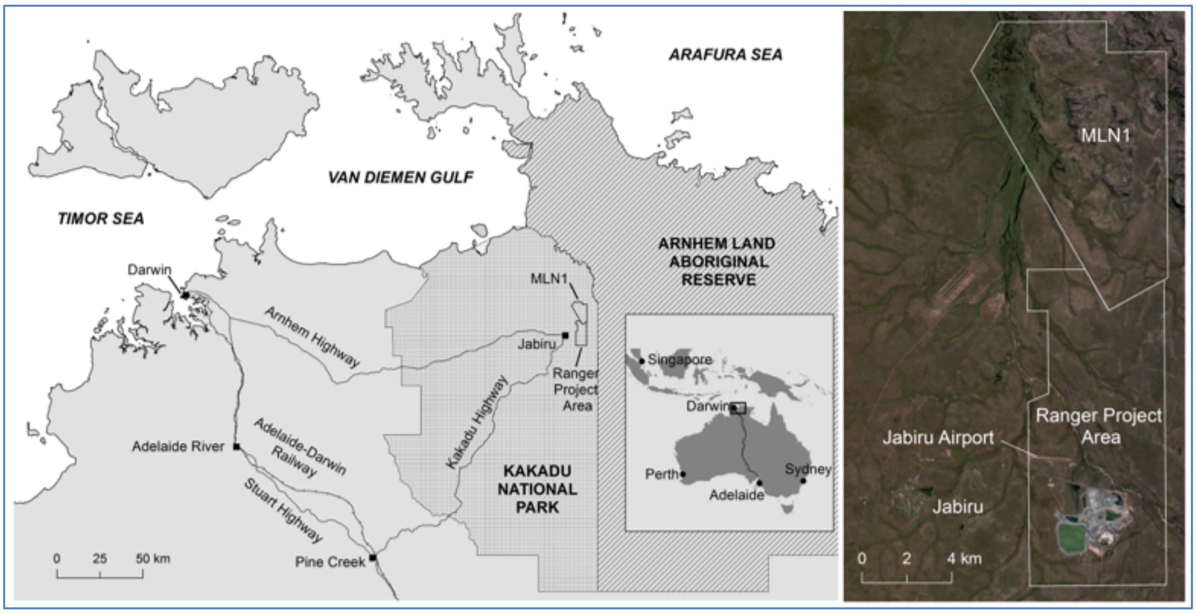

Figure 1 Ranger uranium mine location

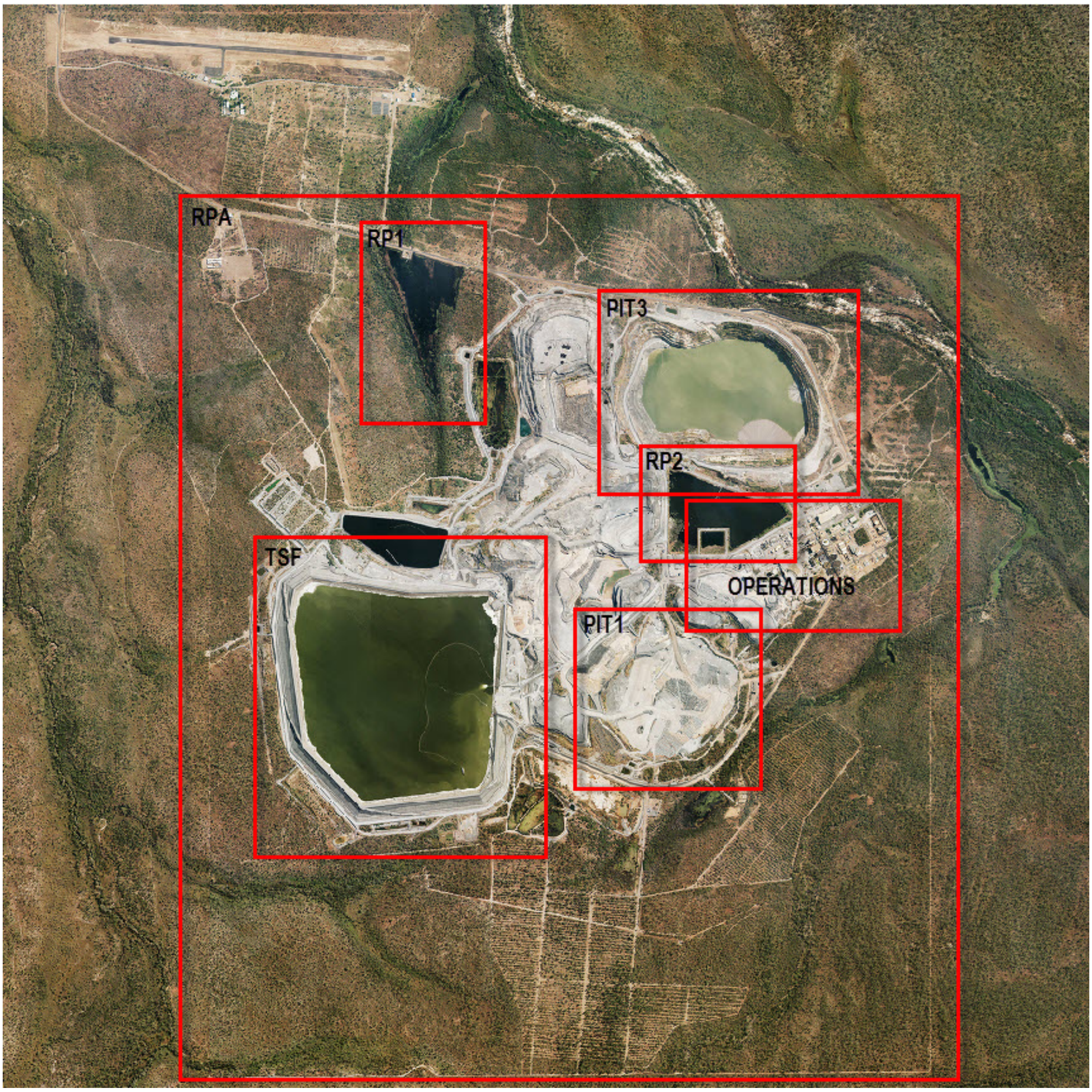

Figure 2 Aerial imagery of Ranger Mine layout with Pit 1 identified (Photo capture June 2018)

Figure 3 High-resolution image of Pit 1 area (Photo capture June 2018)

2 PIT 1 REHABILITATION SCHEDULE

The Pit 1 rehabilitation schedule comprises two main phases: construction; and ecosystem establishment (Table 1). The construction phase consists of:

- Backfill with detailed tracking of fill material in regard to material grade (3112-01)
- Construction of the final landform topography (3112-03/04)
- Survey and sign-off of final landform topography (3112-05).

Once the final landform has been created and meets required specifications the ecosystem establishment phase will be undertaken, although some activities such as tube-stock growth and weed spraying will be undertaken between the two phases as required.

At this time the construction phase extends from 01-May-19 through to 25-Aug-20 and the ecosystem establishment phase extends from 15-May-20 to 04-Nov-22 (Table 1).

The Pit 1 rehabilitation monitoring framework will extend from May 2019 to 2026 to provide for a continuous monitoring framework from rehabilitation to closure.

Table 1 Pit 1 rehabilitation schedule (indicative pending appropriate approvals) provides information as provided from Closure Execution schedule.

Project code	Activity	Identifier code	Scheduled Start date	Scheduled End date
Pit 1, backfill and capping and final landform (3110, 3111, 3112)				
3112-01	1s to Pit 1 Backfill	275	01-May-19	01-Feb-20
3112-03	1s to Final Landform Pit 1	120	05-May-20	07-Jul-20
3112-04	Final Landform Details by Dozer Pit 1	34	14-Jul-20	15-Aug-20
3112-05	As-Built Surveying Pit 1	10	15-Aug-20	25-Aug-20
Revegetation – Pit 1 (3113)				
3113-01	Handover of site – Pit 1 Area	0		15-Aug-20
3113-02	Seed Planting and Growing – Pit 1 Area	92	15-May-20	15-Aug-20
3113-03	Initial Weed Spraying – Pit 1 Area	24	15-Aug-20	08-Sep-20
3113-04	Cultivation Period – Pit 1 Area	48	08-Sep-20	24-Oct-20
3113-05	Irrigation Installation – Pit 1 Area	90	24-Oct-20	04-Feb-21
3113-06	Initial Planting – Pit 1 Area	375	04-Feb-21	06-May-22
3113-07	Irrigation Starts (First 3 Months) – Pit 1 Area	90	06-May-22	04-Aug-22
3113-08	Irrigation for 3-6 Months – Pit 1 Area	90	04-Aug-22	04-Nov-22
3113-08	Inspection/Monitoring for Mortality – Pit 1 Area	1	04-Nov-22	04-Nov-22

3 CONSTRUCTION PHASE MONITORING

The construction phase will result in a final landform that complies with the planned landform design. Key elements include:

- Burial of all tailings materials to designed depths
- Staged back fill with higher grade material (grade 2) buried deeper and lower grade material (grade 1) forming the landform surface layer (Table 2).
- Shaping into the planned landform topography
- Installation of water and sediment traps at landscape outflow locations
- Micro-topography construction that may include ripping and placement of surface materials.

Ranger mine is currently operating under the requirements detailed in the Ranger Authorisation to Operate (current version 0108 issued June 2018). The requirements provide a comprehensive set of monitoring and reporting schedules that help to ensure the protection of the surrounding environment and communities. The Ranger Authorisation requirements will continue throughout the construction phase of Pit 1 rehabilitation and they will be enhanced with the additional monitoring and research described in this Framework. As per the requirements in the Ranger Authorisation to Operate, the following reporting and monitoring will continue as normal during the construction of Pit 1:

- Mining Management Plan
- Annual Radiation and Atmospheric Monitoring Interpretative Report
- Tailings Dam Surveillance Reports
- Water Management Plan
- Annual Groundwater Report
- Whole of Site Groundwater Conceptual Model
- Groundwater Monitoring Plan
- Provision of Monitoring Data, including routine Water Quality Reports
- Surface Water Wet Season Report
- Rehabilitation Progress Report

Further detail on Pit 1 construction is provided in the Ranger Mine Closure Plan (MCP 2018).

Table 2 Indicative ore grades and mineral type

Grade	Grade (% U_3O_8)			Material type
	1980-1997	1998-2009	2010-Current	
1	<0.02	<0.02	<0.02	Un-mineralised rock
2	0.02-0.05	0.02-0.08	Low 2 0.02-0.06	Very low grade ore
			High 2 0.06-0.08	Low grade ore
3	0.05-0.10	0.08-0.12	0.08-0.12	ore
4	0.10-0.20	0.12-0.20	0.12-0.20	ore
5	0.20-0.35	0.20-0.35	0.20-0.35	ore
6	0.35-0.50	0.35-0.50	0.35-0.50	ore
7	>0.50	>0.50	>0.50	ore

The Pit 1 Construction Phase monitoring framework focusses on all aspects relevant to Pit 1 rehabilitation (Table 3), thus key elements relating to the physical construction approach and final landscape shape are the focus of this framework. A Trigger, Action, Response, Plan (TARP) is presented in Table 4 and includes management actions should a threshold be exceeded.

Table 3 Pit 1 Construction Phase Monitoring Framework (May 2019-Aug 2020)

Aspect	Objective/s	Method	Variable	Frequency
Tailings consolidation	Confirm tailings consolidation	Settlement monitoring plates	Change in level of settlement	Monthly
Material placement	Confirm 2s material placed at basal levels	Implementation of the dynamic mine model created for ERA, (AMC, 2018)	Material load placement log	Daily
		Survey	Regular surface levels	Weekly
	Confirm 1s material placed as surface layer	Implementation of the dynamic mine model created for ERA, (AMC, 2018)	Material load placement log	Daily
		Survey	Regular surface levels	Weekly
Surface topography	Confirm final surface topography for Landscape Evolution Model (LEM). Confirm built to design requirements	High resolution DEM	Surface Elevation	Annual post wet season LEM rerun if required
		Topographic survey	Cross-sections and/or levels	Once; post construction
	Quantify landscape settlement	Year on year DEM change detection	Surface level change	Annual
		Topographic survey	Cross-sections and/or levels	Annual
	Quantify sediment transport	Year on year DEM change detection	DEM change	Annual
Surface micro-topography	Describe surface micro-topography	High resolution DEM and field survey	Surface DEM and surface complexity	After land forming and annually after wet season
		GPS on ripping machinery, field mapping or remote sensing	Ripped areas	Once, after ripping is complete

Aspect	Objective/s	Method	Variable	Frequency
Landscape denudation and erosion	Quantify site denudation rate (suspended load)	BACIP designed turbidity monitoring (Moliere and Evans 2010)	Stream turbidity	Continuous logged in flowing water
	Quantify gully erosion	High resolution DEM	Surface DEM	Annual post wet season
		Field assessment	Field notes	Annually after wet season
	Quantify sub-catchment bedload sediment movement	Measurements from sediment traps	Transported sediment volume	Annually after wet season
Surface water management	Ensure all surface water runoff is captured and managed	Pumping of water from Pit 1 pond water sump to RP2	Continuous monitoring	During and following rainfall periods

Table 4 Pit 1 Construction Phase: Trigger, Action, Response Plan (TARP)

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Materials placement	Site: Whole of landscape via tracking system. Parameters: Material character and volume. Analysis: Dynamic mine model with associated tracking methods. Within landform levels during construction. Frequency: Ongoing, as per Table 3, as landscape is built.	Describe and verify material strata within final Pit 1 landform	Internal strata vary in a manner that increases risk of higher-grade materials exposure	Stop construction. Remove or reshape current level to conform with design plan	Site Environmental Officer (or delegate)
Surface topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEM and survey to planned landform Frequency: Once off. When practical upon completion of final landform	Describe final landform against planned landform. Confirm LEM predictions for tailings encapsulation Potentially provide updated information for LEM	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface settlement	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify topographic settlement rates	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	Purpose	Trigger	Action	Responsibility
Sediment transport	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify site scale denudation rates	Site denudation rate is significantly higher than predicted	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface micro-topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and field survey Frequency: Annual	Describe site scale micro-topography	Microtopography does not conform to planned landscape distribution pattern	Alter microtopography through ripping, grading, placement of material or other works	Site Environmental Officer (or delegate)
Surface ripping	Site: Planned ripped areas Parameters: Area Analysis: mapping via GPS tracking, field survey or remote sensing Frequency: Once after landform creation	Map ripped areas	Ripping does not conform to planned ripped area	Undertake works to amend ripping area	Site Environmental Officer (or delegate)
Landscape erosion (gullying)	Sites: Sensitive receptor areas and drainage channels Parameters: DEM analysis and field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels	Significant erosion – rill erosion > 30 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha) Erosion around drainage channels	Site-based plan and action as required. Repairs to area identified	Site Environmental Officer (or delegate)

Aspect	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Bedload	Sites: Watercourses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Biannually before and after the wet season	Identify bedload being transferred to sediment traps	Bedload transport rates significantly beyond those of trial landform	Site-based plan and action as required. May require additional works including modifying the sediment control basins	Site Environmental Officer (or delegate)
Landscape erosion (turbidity)	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS) Analysis: BACIP analysis (Moliere & Evans, 2010) Frequency: Ongoing monitoring, analysis after wet season	Identify site scale erosion rates	Turbidity trajectory not transitioning to control environment levels after 5 years	Site-based plan and action as required May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin	Site Environmental Officer (or delegate)
Surface water management during construction	Site: Whole of landscape Parameters: EC Analysis: Surface water runoff management Frequency: During and after rainfall periods.	Monitor surface water quality	EC trigger; As per section *5.8 Pit 1 Catchment Management* in RWMP 2018/19	Investigation as per section *5.8 Pit 1 Catchment Management* in RWMP 2018/19	Site Environmental Officer (or delegate)

4 ECOSYSTEM ESTABLISHMENT PHASE

This section describes the Pit 1 monitoring framework for the ecosystem establishment phase (15 May 2020 to closure in 2026), noting that it is a part of the planned whole-of-site monitoring for landform, water (ground and surface), radiation and ecosystem processes.

The Pit 1 Ecosystem Establishment monitoring framework focusses on those aspects relevant to this phase of Pit 1 rehabilitation (Table 5). A Trigger, Action, Response, Plan (TARP) is presented in Table 6 and includes management actions should a threshold be exceeded.

During the ecosystem establishment phase of Pit 1, monitoring of radiation will continue to be undertaken as per the Ranger Authorisation to operate and those plans will be in effect. However, specific radiation assessment research tasks will be undertaken (Table 7).

Table 5 Pit 1 Ecosystem establishment phase monitoring (Aug 2020 – Nov 2022)

Theme: Landform				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Surface topography	Quantify landscape settlement	Year on year DEM change	DEM change	Annual
		Topographic survey	Cross-sections and levels	Annual
Surface micro-topography	Describe surface micro-topography	High resolution DEM and field survey	Surface DEM and field notes	After land forming and annual after wet season
Landscape denudation and erosion	Quantify site denudation rate (suspended load)	BACIP designed turbidity monitoring (Moliere and Evans 2010)	Stream turbidity	Continuous logged in flowing water
	Quantify gully erosion	High resolution DEM	Surface DEM	Annual post wet season
		Field assessment	Field notes	Annually after wet season
	Quantify sub-catchment bedload sediment movement	Measurements from sediment traps	Transported sediment volume	Annually after wet season
Erosion control	Confirm erosion control structure function	Field inspection	Field notes and records	Annually after wet season

Theme: Water				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Surface water quality	Confirm water leaving Pit 1conforms to the approved Water Management Plan	Multiple telemetered probes Designed sub-catchment water and sediment traps Grab samples from sumps etc with lab analysis	Solutes, EC, TSS, COPC, Total P, Total N, NH_4, Turbidity, radionuclides	Continuous and grab samples
	Confirm water quality in adjacent/connected water sources	Multiple telemetered probes Grab samples from sumps etc with lab analysis	Solutes, EC, TSS, COPC, Total N, Total P, NH_4, Turbidity, radionuclides	Continuous and grab samples as per WMP
Surface water quantity	Monitoring discharge leaving landform	Designed sub-catchment water and sediment traps	Discharge	Continuous with flow
	Model surface water runoff	DEM based rainfall/runoff model	Discharge	As required to correlate with discharge measurement and provide input to water balance
Groundwater seepage and contaminant transport	Define groundwater movement and quality dynamics	Monitor bore network develop new bores as required Groundwater modelling (INTERA project)	Groundwater flow and quality	Continuous sampling and dynamic model

Theme: Water				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Groundwater heads	Monitor ground water heads	Monitor bore network develop new bores as required Groundwater modelling (INTERA project)	Bore level	Continuous sampling
GW surface water interaction	Better understand GW-SW interaction if any	Bore logging (INTERA project)	Bore level and water quality Grab samples	Continuous sampling and as sampled
Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Plant species distribution and survival	Confirm species distribution conforms to plan Document plant survival	Planting plan and log of species planting location	Plant species, stems per species	During planting
		Survey quadrats, field transects	Plant species and survival	3 month, 6 months, annually
Plant growth rate	Document plant growth rate	Survey quadrats	Height, DBH	3 month, 6 months, annually
Canopy Cover	Document canopy cover	Survey quadrats	Canopy cover %	3 month, 6 months, annually
Plant recruitment	Document plant recruitment	Survey quadrats	Recruitment occurrence and species (flowering, fruiting, emergence)	3 month, 6 months, annually

Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Weather monitoring	Determine site weather conditions	Weather station and observation	Rainfall, temperature, humidity, ET	Ongoing
Irrigation	Confirm irrigation performance	Inspection	Irrigation function	Daily/weekly
Weed management	Control and/or eliminate all priority weeds	Visual inspection	Weed presence and abundance	Daily/weekly with other checks
Flora pests and diseases	Monitor plant pests and diseases	Visual	Presence of pest or disease	Daily/weekly with other checks
Ground cover	Monitor development of groundcover	Survey quadrats	Species, % cover, litter %	3 month, 6 months, annually
Nutrient cycling	Understand edaphic process	Soil/sediment survey and analysis	Soil nutrients, microbes, soil chemistry	Baseline and 5 years
Fauna colonisation	Document fauna on site	Opportunistic observation during other surveys	Species	Opportunistic
Fauna pests	Monitor and control fauna pests	Visual inspection for animals and animal impacts	Fauna pest species	Ongoing

Theme: Ecosystem				
Aspect	**Objective/s**	**Method**	**Variable**	**Frequency**
Fire exclusion	Confirm fire exclusion	Visual inspection	Presence/absence (location)	As required
Tube-stock quality	Confirm tube-stock quality and viability	Inspection of tube-stock in nursery and upon planting	Root binding, disease	ongoing
Bush foods (aquatic and terrestrial)	Document contaminants levels in bushfoods	Field sampling	Laboratory analysis for contaminants	Baseline and every 2nd year

Table 6 Ecosystem establishment phase TARP

Theme: Landform					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Surface topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and survey Frequency: Annual	Quantify topographic settlement rates	Final landform varies significantly from planned landform and subsequent LEM results show critical erosion over tailings areas	Reshape landform or armour potential erosion areas until LEM results comply with 10,000 year requirement	Site Environmental Officer (or delegate)
Surface micro-topography	Site: Whole of landscape Parameters: Topography Analysis: Comparison of DEMs and field survey Frequency: Annual	Describe site scale micro-topography	Micro-topography does not conform with planned landscape distribution pattern	Alter microtopography through ripping, grading, placement of material or other works	Site Environmental Officer (or delegate)
Bedload	Sites: Water courses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Bi-annually before and after the wet season	Identify bedload being transferred to sediment traps	Bedload transport rates significantly beyond those of trail landform	Site-based plan and action as required. May require additional works including modifying the sediment control basis	Site Environmental Officer (or delegate)

Theme: Landform					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Landscape erosion (gullying)	Sites: Sensitive receptor areas and drainage channels Parameters: DEM analysis and Field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels	Significant erosion – rill erosion > 30 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha) Erosion around drainage channels	Site-based plan and action as required Repairs to area identified	Site Environmental Officer (or delegate)
Landscape erosion (Turbidity)	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS) Analysis: BACIP analysis (Moliere & Evans, 2010) Frequency: Ongoing monitoring, analysis after wet season	Identify site scale erosion rates	Turbidity trajectory not transitioning to control environment levels after 5 years	Site-based plan and action as required May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin	Site Environmental Officer (or delegate)
Erosion control structures	Sites: Site structures and works Parameters: Field inspection, notes and photographs Analysis: Identify problem areas Frequency: Annually after the wet season	Confirm function of erosion control structures	Structures not function or compromised	Site-based plan and action as required. Repairs to area identified	Site Environmental Officer (or delegate)

Theme: Water					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Surface water quality (Pit 1)	Sites: sub-catchment designed exit points Parameters: water quality Analysis: Probe and grab sample Frequency: Continuous and grab sample	Monitor surface water quality	Water quality does not meet release water quality standards	Divert away from release water circuit. Evaluate reason for exceedance and implement remediation and amelioration works	Site Environmental Officer (or delegate)
Surface water quality (offsite receiving environments)	Sites: Defined receiving site Parameters: water quality Analysis: Probe and grab sample Frequency: Regular sampling through year	Monitor surface water quality	Samples exceed Magela Creek trigger values (As per Annex C.1 of the Authorisation "Water Quality Objectives for Magela Creek and Gulungul Creek")	As per Turner et al 2015	Site Environmental Officer (or delegate)
Groundwater seepage and contaminant transport	Sites: Bore network Parameters: Water levels and water quality Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly, chemical analysis quarterly	To confirm groundwater level, movement and chemistry is behaving according to modelled predictions, and to increase model performance and power through additional data input	Analysis indicates that groundwater is exceeding model predictions	Site-based plan and action as required	Site Environmental Officer (or delegate)

Theme: Water					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
GW surface water interaction	Sites: Bore network Parameters: Water level and water quality Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly, chemical analysis quarterly	To confirm groundwater interaction, if any, with key surface water sites	Analysis indicates groundwater ingress into surface water sites	Site-based plan and action as required.	Site Environmental Officer (or delegate)

Theme: Ecosystem					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Flora composition performance and distribution	Sites: Vegetation plots across entire site Parameters: Provenance, species composition (tree and shrubs) and species relative abundance, survival, canopy architecture, canopy cover index, ground cover index, tree distribution, flowering fruiting, seeding, juveniles, overall condition. Analysis: vegetation survey analysis Frequency: three, six and 12 months (year 1); annually	To determine whether species composition and community structure is similar to adjacent areas of KNP	Values do not conform with closure criteria	Site-based plan and action as required	Principal Advisor Rehabilitation and Ecology (or delegate)

Theme: Ecosystem

Aspect	Monitoring		Response		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Irrigation	Sites: associated with planting Parameter: Functioning irrigation system Analysis: inspection Frequency: ongoing until irrigation removed	Ensure functional irrigation system	Irrigation failure or poor performance	Mend irrigation system	Principal Advisor Rehabilitation and Ecology (or delegate)
Weed management	Sites: Pit 1 site Parameter: Priority weed presence Analysis: Field survey and inspection Frequency: Prior to planting and ongoing associated with vegetation surveys and other site traverses	Assess weed presence, species and abundance	Priority or other weeds present	Weed management (generally spraying) until weeds are no longer present	Site Environmental Officer (or delegate)
Nutrient cycling	Sites: Pit 1 and TLF Parameter: soil edaphic processes Analysis: Soil pit and analysis Frequency: year 1 and 5	Understand soil formation processes and nutrient cycling	Poor soil formation and nutrient processes affecting plant development	Site-based analysis and ameliorant plan and application	Principal Advisor Rehabilitation and Ecology (or delegate)
Fauna pests	Sites: Pit 1 Parameter: Fauna pest present Analysis: Visual survey Frequency: Ongoing, all staff to report signs of fauna pests	Minimise impact of feral pests on rehabilitation	Presence of pests	Implement appropriate pest management	Site Environmental Officer (or delegate)

Theme: Ecosystem					
Aspect	**Monitoring**		**Response**		
	Method	**Purpose**	**Trigger**	**Action**	**Responsibility**
Bush foods (aquatic and terrestrial)	Sites: Onsite and selected offsite targets Parameter: Food pollutants and toxins Analysis: Field sampling and analysis Frequency: year 1 and 5	Understand potential for contamination of aquatic species	Trigger levels of contaminants found	Remove access to food source and undertake site and source amelioration	Site Environmental Officer (or delegate)

5 PIT 1 RESEARCH PLANNING - PRESENT TO 2026

Ranger mine has developed a list of targeted research projects to inform the creation of a safe and stable final environment. The research tasks listed here are targeted specifically to inform rehabilitation success and are focussed on Pit 1 relevant studies.

Table 7 Pit 1 targeted research tasks

Theme: Landform		
Aspect	**Objective/s**	**Method**
Particle size distribution	Understand Pit 1 surface and top layer particle size distribution	Measures of surface sediment calibre distribution profile appropriate for material type.
Stock pile drilling	To describe the release behaviour and source concentrations of all COPCs over time from each of the waste rock and tailings-derived source materials	INTERA project
Theme: Water		
Aspect	**Objective/s**	**Method**
Water balance	Develop Pit 1 water balance model Identify key parameters that require additional studies (e.g. evaporation and ET, runoff, infiltration, deep drainage and recharge, changes in soil water at key depths related to roots and waste rock dump levels) Undertake targeted studies to complete water balance model	Undertake a specific pit 1 water balance study. Identify key parameters that require additional verification and undertake specific studies to measure these parameters.

Herbicide fate	Understand the fate of glyphosate herbicide in the environment following application and run-off	Develop a trial water quality sampling and analysis program with stakeholders to examine the fate of glyphosate herbicide when it has been applied to an area of weed/grass cover and bare rehabilitation landscape and subjected to watering/rainfall and run off.
Groundwater	Understand Pit 1 groundwater processes	Develop additional bores and undertake site scale monitoring and modelling of groundwater quality, quantify and movement.
Wetland filter process	Understand the water and sediment condition of receiving wetland filter areas	A water and sediment sampling and analysis program to understand the current condition of the Pit 1 wetland filter receiving areas.
Theme: Ecosystem		
Aspect	**Objective/s**	**Method**
Fauna colonisation	Understand fauna colonisation at early stages of rehabilitation	Targeted fauna studies after year 1 and 5 of Pit 1 planting. Surveys developed to specifically early stage fauna such as insects and birds. Field design could follow the pattern established for flora quadrat surveys. Opportunistic records of fauna observations undertaken during regular surveys and inspections.

Fauna translocation	Understand efficacy of translocating critical ecosystem engineer species	In conjunction with fauna studies at other sites develop a study to understand colonisation of critical ecosystem engineering species within rehabilitated areas on site and, if necessary, develop a plan to translocate these species if required. If translocation is required a translocation monitoring study should be developed.
Disturbance	Understand recovery from disturbance	No disturbance is planned during the period covered by this plan. However, should disturbance through fire, disease, wind or other cause occur a disturbance specific assessment and knowledge capture study
Theme: Radiation		
Aspect	**Objective/s**	**Method**
Radon-222 exhalation flux densities	To verify that radon-222 exhalation flux densities	Radon-222 exhalation surveys
Gamma dose rates, waste rock radium-226 activity concentration	To validate predictions on the surface waste rock uranium content	Ground-based gamma dose rate survey

5.1 Whole of site studies

In addition to the studies (research and monitoring) designed specifically considering Pit 1 rehabilitation, several whole of site studies are progressing as parallel programs. These include:

- Nursery establishment and management processes to ensure the quantity and quality of seed and tube-stock
- Trial Landform studies will continue to examine ecosystem establishment processes including:
  - Soil development
  - Plant survival
  - Native species recruitment
  - Fauna establishment and usage
  - Pest and weed treatment
- Trial landform excavation studies
  - Two pits were excavated in March 2019 on the trial landform to collect samples and information to inform further particle size distribution studies and root observation studies.
- ERA is currently undertaking waste rock stockpile oxidation rate studies.

6 REHABILATION FRAMEWORK REVIEW AND STAKEHOLDER COLLABORATION

To ensure the continued refinement of the proposed monitoring framework, the framework will be reviewed by ERA staff in consultation with stakeholders every 12 months and a review outcomes report provided to stakeholders.

A Ranger Rehabilitation – Monitoring Evaluation and Research Review Group will be formed by ERA and include stakeholder group representatives. This review group will be chaired by ERA and will enable collaboration between key stakeholder groups to ensure research programs are developed and refined during the progressive rehabilitation of the Ranger mine. Implementation of additional studies outside of Pit 1 (TLF, nursery etc.) will also be discussed, developed and refined in this review group.

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