10 Closure monitoring and maintenance

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Cover photograph: Surface water monitoring station in Magela Creek

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GLOSSARY

Below are key terms that are used in this section.

Key term	Definition
Airborne radiometric survey	Estimation of the concentration of radioactive elements in the surface of the landform via the detection of gamma radiation using low flying aircraft.
Closure criteria	Direct, measurable and quantifiable target values or tiered assessment processes, developed to demonstrate achievement of the closure objectives.
Contaminated Land Risk Register	Register of all sites where activities have occurred that have the potential to contaminate land on the RPA.
Constituents of potential concern	Chemical elements identified by the Supervising Scientist Branch as being of potential concern to the receiving environment.
Diameter at breast height	Measurement of tree diameter taken at 1.3 m above ground level (an adult's approximate breast height).
Digital Elevation Model	Digital representation of the land topography.
ERICA Assessment	Exposure/dose/effect assessment for radiological risk to terrestrial, freshwater and marine biota.
Groundwater conceptual model	Calibrated numerical groundwater flow model encompassing all hydrogeologic elements governing groundwater flow and transport at the Ranger Mine to provide the foundation for simulating groundwater flow and transport from all mine sources to potential receptors under post-closure conditions.
Groundwater solute transport modelling	Prediction of the temporal and spatial mobilisation of constituents of potential concern from the RPA to the surrounding environment through groundwater using the groundwater conceptual model.
Hydrolithologic unit	A grouping of soil or rock units or zones based on common hydraulic properties.
LiDAR	Remote sensing technique using pulsed laser to measure distances.
Long Lived Alpha Activity	Abbreviated to LLAA. The presence, generally in airborne dust, of any of the alpha emitting radionuclides in uranium ore, except for the short lived alpha emitting radon decay products.
Mirarr	Mirarr is primarily a patrilineal moiety system. Within the Mirarr People, there are descent groups often called 'clans' in English and kunmokurrkurr in Kundjeyhmi language. There are several Mirarr clans with each one distinguished by the language they historically spoke (e.g. Mirarr Kundjeyhmi, Mirarr Urningangk, Mirarr Erre). The Mirarr are the Traditional Owners of the land encompassing the RPA.
Monitoring and maintenance phase	Period after rehabilitation works have been completed (currently estimated to be 25 years). Completion criteria monitoring (and maintenance rehabilitation works if required). Site access pending.

Key term	Definition
Pit 1	The mined out pit of the Ranger #1 orebody, which is used as a tailings repository. Mining in Pit 1 commenced in May 1980 and was completed in December 1994, after recovering 19.78 million tonnes of ore at an average grade of 0.321 %.
Pit 1 Progressive Rehabilitation Monitoring Framework	Overarching framework of environmental monitoring for the rehabilitation of Pit 1.
Pit 3	The mined out pit of the Ranger #3 orebody, which is currently being backfilled with tailings. Open cut mining in Pit 3 commenced in July 1997 and ceased in November 2012.
Potential Alpha Energy Concentration	The concentration of the total alpha energy emitted in air during the decay of radon-222 progeny. Usually measured in μJ m^{-3}.
Radon exhalation	Activity of radon gas leaving the surface of the landform
Trigger, Action, Response Plan	Abbreviated to TARP. Plan of tasks to be undertaken should monitoring detect a change in parameters of a level that requires preventative or remedial action. Designed to be adaptive in nature.

ABBREVIATIONS & ACRONYMS

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

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
COPC	Constituents of Potential Concern
DEM	Digital Elevation Model
DITT	Department of Industry, Tourism and Trade
DWPZ	Deeps Water Producing Zone
EC	Electrical Conductivity
ERICA	Environmental Risk from Ionising Contaminants: Assessment and management
GAC	Gundjeihmi Aboriginal Corporation
GCC	Gulungul Creek Control
GCLB	Gulungal Creek water monitoring site
HLU	Hydrolithologic unit
LEM	Landscape Evolution Model
LLAA	Long Lived Alpha Activity
LiDAR	Light Detection and Ranging
MCP	Mine Closure Plan
MCUS	Magela Creek Upstream water monitoring site
NLC	Northern Land Council
NP	National Park
PAEC	Potential Alpha Energy Concentration
RPA	Ranger Project Area
RWD	Ranger Water Dam
RWMP	Ranger Mine Water Management Plan
RWMS	Ranger Water Management Strategy
SERP	Species Establishment Research Program
SSB	Supervising Scientist Branch
S&TM	State and Transition Model
TARP	Trigger, Action, Response Plan
TPH	Total Petroleum Hydrocarbon
TSF	Ranger Water Dam formerly the Tailings Storage Facility
WASWG	Water and Sediment Working Group
WoNS	Weeds of National Significance

10 CLOSURE MONITORING

This section describes the monitoring programs that will be implemented by ERA to demonstrate successful rehabilitation of the Ranger Mine, and to comply with clause 13.3 of the Environmental Requirements: *"… the company must carry out a monitoring program approved by the Supervising Authority or the Minister with the advice of the Supervising Scientist following cessation of operations until such time as a relevant close-out certificate is issued"*.

For the purpose of the MCP, mine closure and monitoring programs are discussed in two separate phases:

1. Closure Phase: the period between 8 January 2021 (when on-site processing was completed), throughout the period of decommissioning and bulk material movements to achieve the final landform, and up until the completion of initial rehabilitation works; and
2. Monitoring and Maintenance Phase: the period after the Closure Phase and continuing until results of the monitoring demonstrate that the site has met the required closure objectives and relinquishment of the RPA is achieved (currently estimated to be 25 years).

An adaptive management approach will be critical during this monitoring and maintenance phase because the landform may settle over time, there is the potential for subsidence and/or erosion to occur, and revegetation will be young and developing. Adaptive management will help promote continued progress towards a stable landscape and self-sustaining ecosystem. Adaptive management planning is a fundamental component of State and Transition Models (S&TM; the ecosystem model development is discussed in Section 5) and include three key elements:

- routine monitoring to track that the rehabilitation is on the desired trajectory, and to identify potential risks that might threaten the desired outcome;
- maintenance activities to proactively ensure that the rehabilitation remains on the desired development trajectory; and
- management actions to implement when a risk has been identified to avoid the rehabilitation transitioning into a deviated state, or to revert a deviated state back into a desired state if a transition has already occurred.

Adaptive management, whereby monitoring results are analysed to identify issues and inform maintenance activities, will occur during both phases mentioned above. However, and purely because of time, adaptive management is likely to be applied more often during the longer monitoring and maintenance phase.

The monitoring programs discussed below align with the following closure themes:

- Landform;
- Radiation;
- Water and sediment;

- Ecosystem (flora & fauna); and
- Cultural.

An overview of the monitoring programs for each of the closure themes is provided the following sections.

ERA have summarised much of the monitoring and maintenance activities into a series of Trigger, Action, Response Plans (TARPs). TARPs provide a practical guide to identify early warning signals that a rehabilitated area is moving away from the desired state. The triggers within each TARP represent the primary drivers to be monitored. Each trigger will eventually have a threshold so that monitoring results can clearly identify the risk of transition and the need for action. TARPs are discussed further in Section 10.6.

10.1 Landform theme

10.1.1 Closure research, monitoring, maintenance and adaptive management

A number of studies (Section 5) have been undertaken to address key closure issues and risks associated with landform: including removal of site infrastructure and backfilling of pits, containment of tailings, and erosion of the final landform. These studies, including those completed by both ERA and the SSB on the trial landform, have informed the overall design and predicted performance of the final landform.

10.1.1.1 Trail landform and final landform monitoring

The trial landform was constructed in 2009, and studies on the trial landform have been used to validate design attributes such as landform stability, erosion, topography and visual amenity; and inform the current landform model predictions. The outcomes of these studies have resulted in a final landform topography that incorporates low elevation and slopes to enhance landform stability and visual aesthetics to blend with the surrounding landscape.

Landform monitoring will continue throughout the closure phase, and monitoring and maintenance phase, to assess the condition of the landform, stability and suitability for revegetation. The primary objective of monitoring during the closure phase is to assess adherence to the planned landform design, including material transfer and placement. In the monitoring and maintenance phase, parameters such as settlement and subsidence performance, surface topography, erosion and sediment controls, bedload and sediment control, and suspended sediment will be monitored.

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

Changes in geotechnical conditions will be monitored to identify the presence, and measure the extent of, subsidence, slumping, deformation and/or settlement. This will provide a mechanism to track progress towards the closure objectives. Maintenance will be undertaken, where necessary.

10.1.1.2 Pit 1 tailings consolidation monitoring

The tailings consolidation model comprises two stages (deposition and consolidation). The deposition phase includes tailings distribution, rate of rise and hence the level, while the consolidation phase involves pore water dissipation (expression) with resultant settlement. The monitoring of Pit 1 tailings consolidation now focusses on the consolidation stage, which can be informed by the settlement. Pipes attached to 28 settlement plates were installed over the tailings in Pit 1 prior to placement of the backfill material in 2017, at locations shown in Figure 10-1. The top of the pipes was surveyed every month during and after completion of the final landform to estimate the tailings level and hence settlement. The measured settlements were compared to the predicted settlements (Figure 10-2) and the results closely agreed, demonstrating the accuracy of the model.

The last survey was conducted in July 2021 and the results showed plateauing of the settlement curve, an indication of a minimal rate of change of settlement. It was also determined that the degree of consolidation is about 98 %, and therefore greater than the targeted value of 95 %. The monthly settlement monitoring has been discontinued and most of the pipes have been cut (reduced) and capped to about 500 mm below the final landform level, which allowed for the installation of a pivot sprinkler to water the trees planted on the landform. The reduced pipes coordinates, including the elevation, were recorded before backfilling.

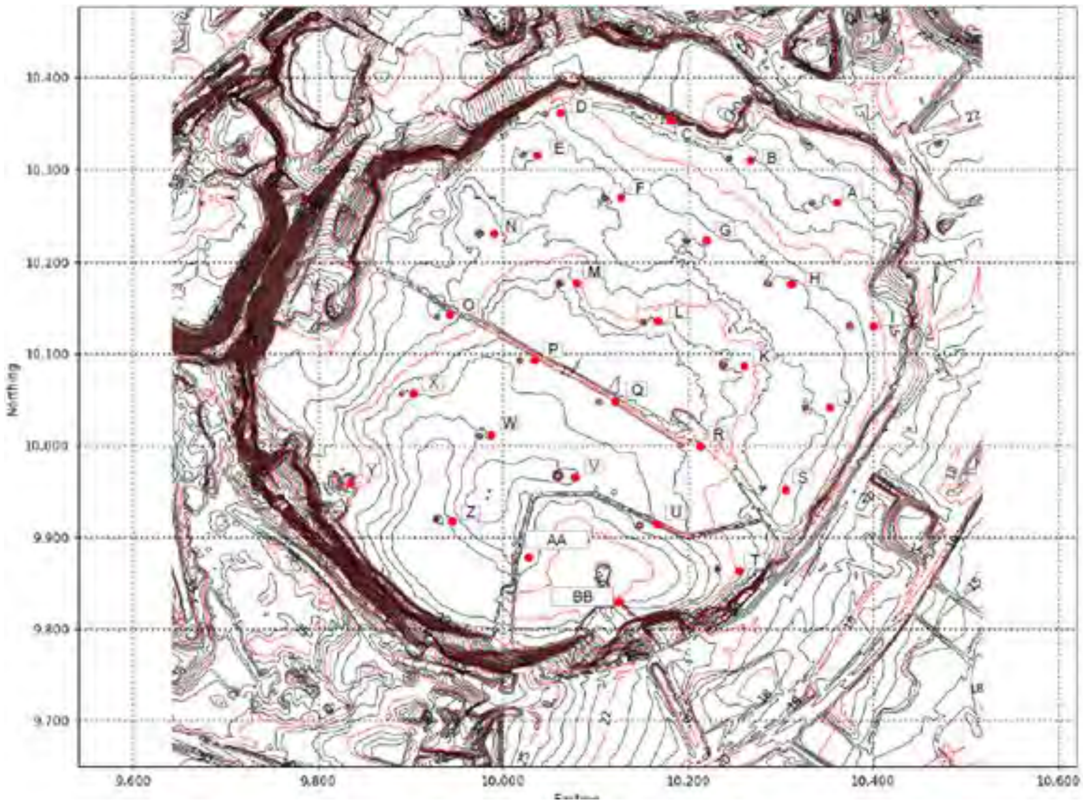

Figure 10-1: Settlement plates locations (locations indicated by red dots)

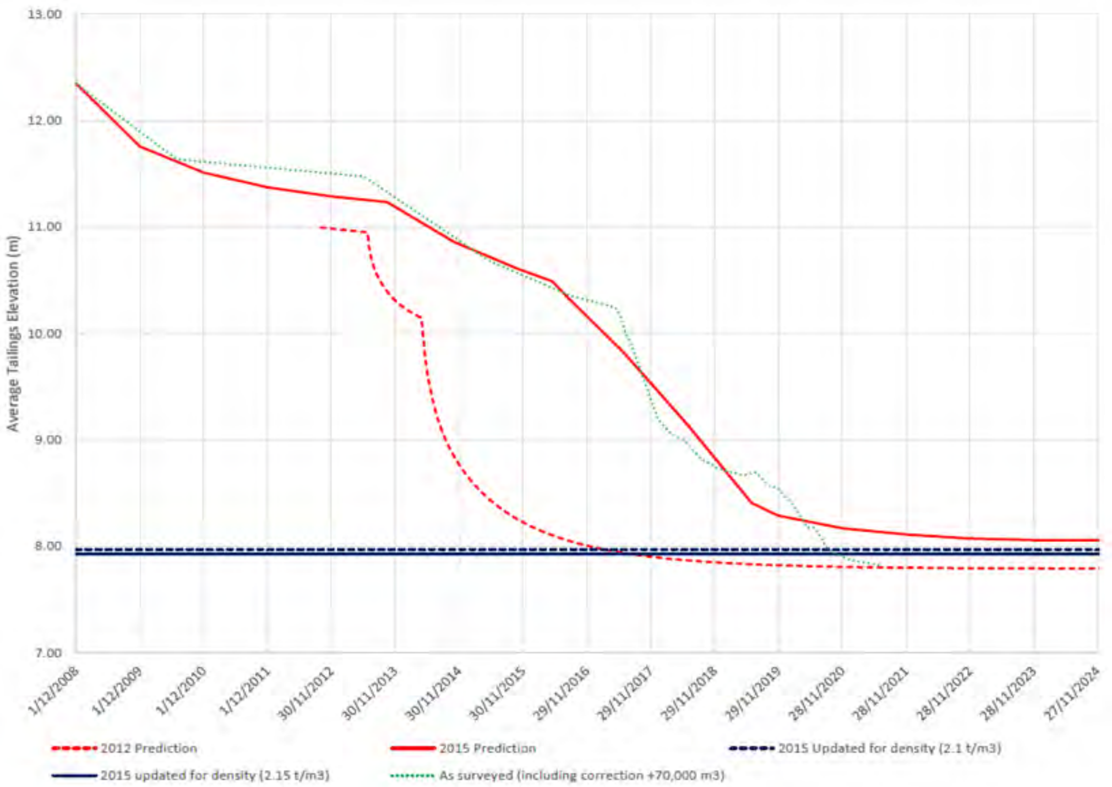

Figure 10-2: Measured versus predicted tailings settlement

10.1.1.3 Pit 3 tailings consolidation monitoring

The deposition phase for Pit 3 tailings consolidation has been monitored since 2017. This has been done by two methods: conducting monthly bathymetric and topographic surveys to determine the tailings level and compare the results to the model prediction (Figure 10-3); and yearly geophysical (bathymetric and seismic) surveys to monitor (confirm) the tailings distribution including fine/coarse ratio, fine/coarse interface and the tailings level. Additionally, some geotechnical investigations have been conducted to monitor (confirm) the fine/coarse tailings interface, tailings level, and pore pressure profiles. Further information on the geotechnical investigations is provided in Section 9 of this MCP.

The consolidation phase monitoring will commence once tailings deposition has been completed and capping has commenced. The Pit 3 capping design includes consolidation monitoring during capping, and the monitoring approach will be similar to that used in Pit 1 in that it will determine the *in-situ* tailings settlement and compare it with the modelled prediction and targeted value.

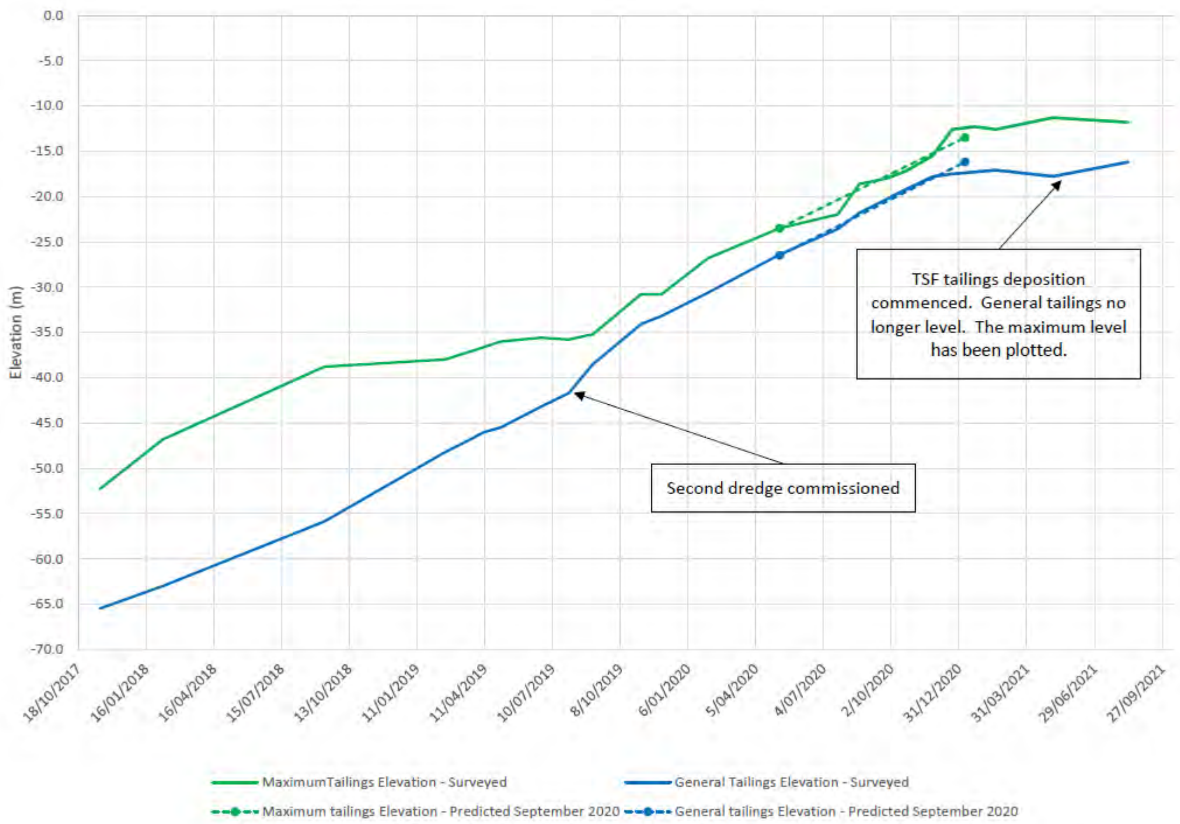

Figure 10-3: Predicted versus measured Pit 3 tailings levels

The tailings settlement will continue to be monitored during the secondary capping and bulk backfill layers construction utilizing settlement monitoring and decant towers installed at locations shown in Figure 10-5.

This is a similar concept as for that used in Pit 1. A set of twenty settlement towers will be installed across the Pit 3, with the base of the tower located as close as practical to the top of tailings surface. Survey of the location of the top of the tower, less the known height of the tower, will provide a measurement of the location of the tailings surface underneath the tower. This will be conducted monthly as per Pit 1.

Towers in Pit 1 were constructed by placing a horizontal settlement plate near the top of tailings, connected to a riser constructed from segments of known length of 100 mm diameter steel pipe, with the height of the tower progressively raised with segments as backfill progressed. A variation of this approach will be used for Pit 3, with the settlement towers constructed from sections of nominally metre diameter concrete or HDPE pipe. Use of larger diameter pipe provides more resistance to buckling as the waste rock moves during tailings consolidation, and also permits the settlement towers to be used as backup decant towers, or for water level and conductivity profile monitoring.

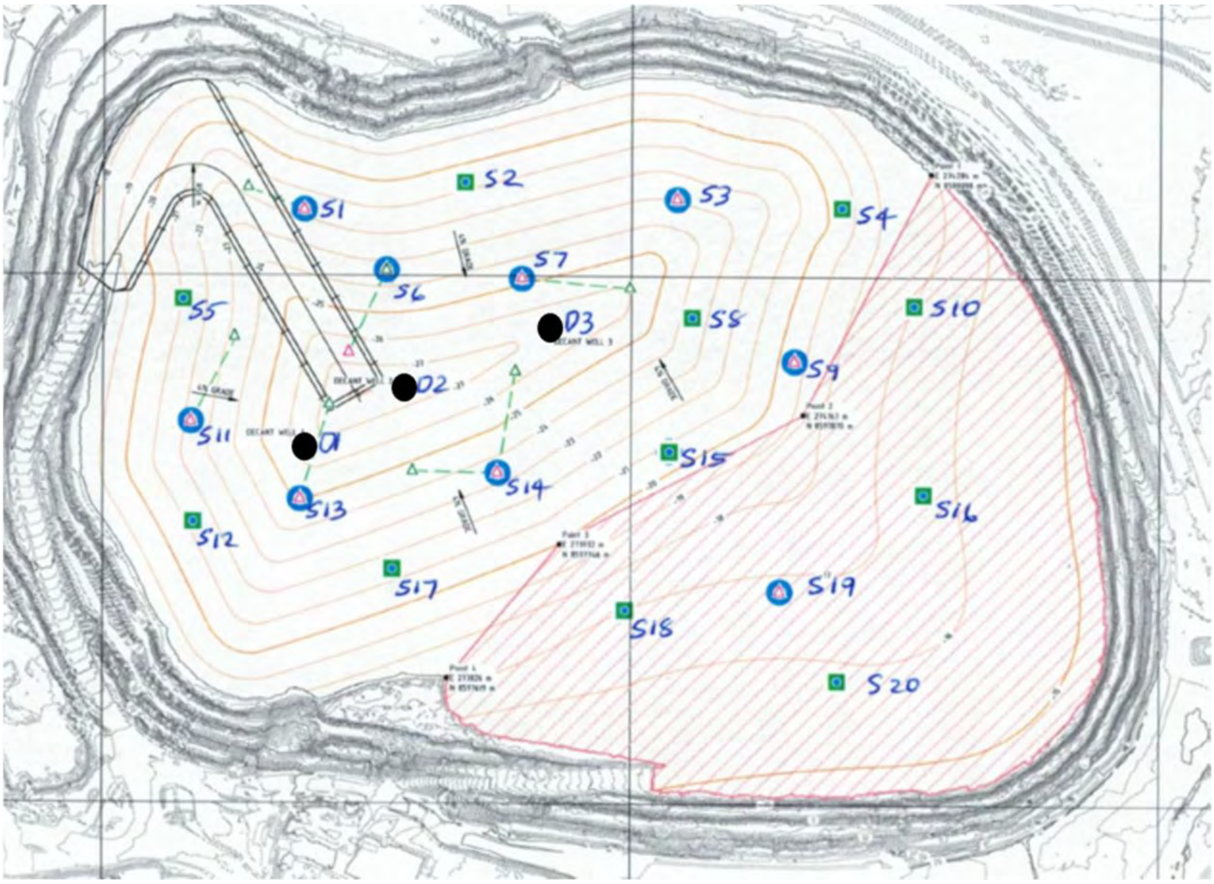

Figure 10-4: Pit 3 Locations of settlement towers

NB: Green squares: water quality configuration;
Blue circles: water extraction configuration; and
Black circles: decant towers.

Monitoring to measure progress towards landform closure criteria will also include final landform topography after completion. It is expected that either airborne and/or terrestrial LiDAR (or equivalent) technology will be used to survey and capture the final landform topography. Specific details on which LiDAR techniques will be utilised have yet to be determined, and new information will be incorporated into future iterations of the MCP. Landform monitoring for closure and the monitoring and maintenance period is presented in Table 10.1 and Table 10.2, respectively (noting that some monitoring presented in Table 10.1 will also carry through into the monitoring and rehabilitation phase – i.e. Table 10.2).

10.1.1.4 Pit 1 landform monitoring (includes Stage 13)

Following the tailings consolidation in Pit 1, the monitoring focus will shift to the surface landform profile, which reveals the final landform behaviours. As discussed in Section 9, Pit 1 is currently undergoing revegetation. *Pit 1 Progressive Rehabilitation Monitoring Framework* (Appendix 10-1) was developed to provide guidance for landform, sediment, and revegetation monitoring on the Pit 1 final landform. Key landform monitoring activities on Pit 1 and Stage 13 include:

- annual survey on the landform and DEM production;
- monthly aerial imagery (UAV orthomosaic) during wet season; and
- visual assessment on landform surface erosion and hydrology.

Updated survey and DEM will provide direct data on waste rock landform settlement and continue to inform Landform Evolution Modelling (LEM) studies. Monthly drone photographs are compared in time sequence to enable a visual assessment of erosion across the entire Pit 1 and Stage 13 surfaces (Figure 10-5). This is complemented by field observations (as required) and weekly ‘photo-point’ monitoring (photos taken at the same location with the same target angle) to characterise micro-topographic changes, local sediment movement and hydrological behaviour within the water management infrastructure.

The monthly stitched-orthomosaic proved to be a helpful monitoring tool to identify the leading indicators for landscape changes, which will inform the preparation works required for the next year’s wet season.

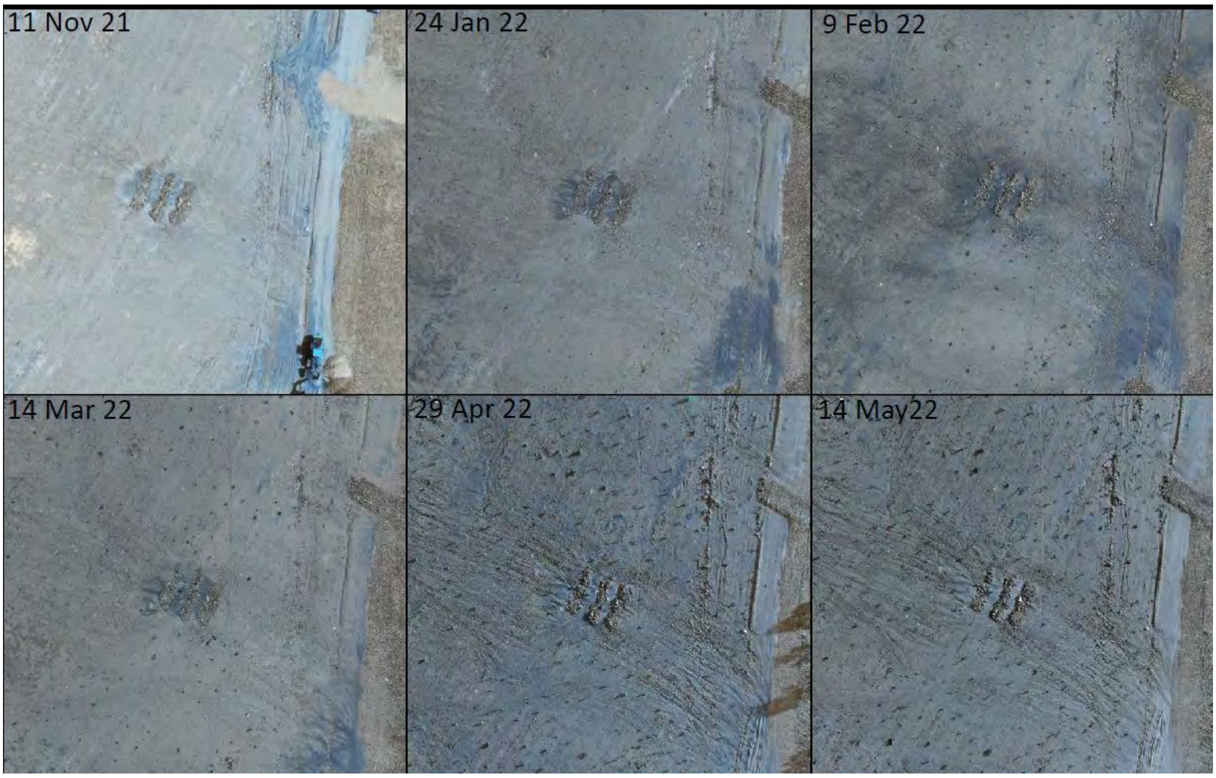

Figure 10-5: Time sequence of first order drainage channel forming on Pit 1 (2rog, 2022)

At the end of each wet season, a review is undertaken of the monitoring activities undertaken to assess appropriateness of each monitor activity and where efficiencies may lie. To date, this has included:

- Monthly aerial imagery (UAV orthomosaic) during wet season was found to be adequate, with observable changes more effective by comparing the last orthomosaic (end of wet season) to the first orthomosaic (start of wet season). There is little additional benefit to the quality and frequency of image capture if also flown after a significant rainfall event (>50 mm), in addition to monthly captures.
- A review of the photo-point monitoring was undertaken to better place weekly photo-point captures, to target the final landform. Previous locations were found to be focused on the Pit 1 perimeter drain rather than the final landform. These have been optimised in advance of the 2022/2023 wet season.

ERA will continue to review the monitoring activities and optimise where possible for better monitoring outcomes.

10.1.2 Completion criteria monitoring

Sediments from erosion of the landform will be measured through both coarse sediment (bedload) and finer sediment (sedimentation). For coarse sediment, bedload is not to be transported from the constructed landform. This parameter will be monitored through post wet season observations after the active post closure management has been completed and the sediment controls structures have been removed. Work completed by the SSB has demonstrated that turbidity can be used as an indicator for suspended sediment. The method developed involves the comparison of annual difference in turbidity between upstream and downstream sites.

Both the monitoring programs and closure criteria are subject to review as the outcomes of studies and/or new information becomes available, and stakeholder feedback is incorporated. As such, some aspects of closure monitoring for landform require further development prior to finalising. Many landform monitoring parameters being measured now are capturing the erosion characteristics of newly constructed final landforms. This data will also be used to determine whether the eroded sediments are in the trajectory towards the background denudation rate. These include water and sediment monitoring within mine area and visual observation undertaken on Pit 1 and Stage 13. If appropriate and feasible, monitoring data on sediment yield in newly constructed landforms can further inform and refine the landform evolution modelling (LEM). Parameters developed to measure the other landform closure criterion under ER 2.2 I, including bedload and turbidity, will be measured where feasible to further inform the trajectory of meeting landform closure criteria.

In addition, high resolution digital elevation model (DEM) and LEM prediction of gully erosion are two parameters developed to measure against the landform closure criterion – 'tailings will remain isolated under 10,000 years'. The LEM configuration update, based on ongoing monitoring to measure erosion characteristics, tailing consolidation (i.e., tailing storage level post consolidation) and landform settlement, will feed into the ongoing use of a multi-year CAESAR-Lisflood landform evolution model (LEM), which can predict the future landform state and demonstrate that tailings will remain isolated for at least 10,000 years denudation rate.

The description of how other landform monitoring results (e.g., landform material properties) are being used to improve LEM configuration change (i.e. parameter optimisation) are described in Section 5.

Table 10.1: Landform monitoring for ‘closure’ phase

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

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

Aspect	Methodology	Analysis	Location	Frequency	Duration
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	Turbidity can be used as an indicator of fine suspended sediment. On an annualised basis, the difference between up and downstream can be used as an indicator of site-scale erosion characteristics.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks).	Continuous turbidity monitoring during wet season.	Until suspended sediment loads are approaching background values (note: 5 years in the closure criteria).

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

Table 10.2: Landform monitoring for ‘monitoring and maintenance’ phase

Aspect	Methodology	Analysis	Location	Frequency	Duration
Erosion (local scale post-wet season)	Field inspection of erosion and sedimentation, notes, photographs	Identify significant erosion – rill erosion > 40 cm depth, sheet erosion or prevention of revegetation (>0.1 ha). Identify erosion around drainage channels.	Erosion of drainage channels. Sedimentation of sensitive receptors.	Annually after wet season.	Until final landform is on a stable trajectory to meet final criteria.
Erosion (general)	Field inspection* of erosion, notes, photographs	General inspection for localised scouring and damage.	All disturbed areas.	Biannually.	First 5 years of phase.
				Annually.	Until final landform is stable and has met final criteria.
Bedload (Access Roads and Creeks)	Field inspection* of erosion, notes, photographs	Identify any erosion on roads that may be source of bedload moving offsite.	Access roads Magela and Gulungul creeks.	Biannually and after each significant rain event.	Until final landform is stable and has met final criteria.
Bedload (Sediment Basins)	Field inspection* of sediment control basins, notes, photographs	Sediment volumes in sediment control basins. Structural integrity of sediment control basins.	All sediment control basins.	Quarterly.	First 3 years of phase.
				Biannually.	Until final landform is stable and has met final criteria.
Suspended Sediment	Assessment of turbidity (fine suspended sediment)	Difference in net annual turbidity between sites located upstream of the mine-site and downstream at the boundary of the Ranger Project Area.	Monitoring points upstream and downstream of site (Magela and Gulungul creeks).	Continuous turbidity monitoring during wet season.	Until suspended sediment loads are approaching background values (note: 5 years in the closure criteria).

*Assuming access to the landform is permitted after 2026

10.2 Water and Sediment theme

10.2.1 Surface water and sediments - Closure research, monitoring, maintenance and adaptive management

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

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

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

Once the mine enters the monitoring and maintenance phase, discharges of water from the rehabilitated site will be passive, so the three-tiered approach with discharge management responses will not be the most appropriate regime to implement. Monitoring will instead be interpreted against closure criteria at the locations agreed to for each criterion (Section 8).

Monitoring in the monitoring and maintenance phase (currently estimated to be 25 years after the closure phase) will assess rehabilitation success, any unexpected events or concentrations of COPCs (compared to model predicted results), and the protection of ecosystems, human health and environmental values, by comparison of water quality against closure criteria.

Groundwater solute transport modelling with uncertainty analysis has predicted the period of time post closure at which peak solute loads will exfiltrate in the four major RPA surface water catchments (Magela, Gulungul, Coonjimba and Corridor). The periods at which peak loads exfiltrated in the surface water catchments vary as a result of the location of the source, the type of source, and transport pathway/s associated with the source.

Timeframes for the peak loads from the major mine sources (INTERA 2021) are:

- TSF contaminant plume ~6 years;
- Pit 1 tailings flux ~13 years; and
- Pit 3 tailings flux ~22 years.

The Ranger surface water model (Section 5) predicts the concentrations of COPCs that the creeks and billabongs will be exposed to as a result of these loads.

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

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

Thus, the aims of the long-term surface water monitoring program can be described as:

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

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

The locations and monitoring frequencies for current surface water monitoring (Figure 10-6, Figure 10-7 and Figure 10-8) forms the basis of the proposed monitoring strategy. Sub-catchment monitoring exit points will be included as part of surface water monitoring during Pit 1 rehabilitation. Consideration of onsite and sub-catchment exit points will be discussed in future planning meetings with the SSB, with new information included in updates to the MCP. The rationale for monitoring at these locations are:

- Current compliance points MG009 and GCLB, just inside the boundary of the RPA. Comparison of water quality at the current compliance points in Magela and Gulungul creeks against agreed water quality objectives will continue to provide the basis of

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

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

assessing protection of the aquatic environment, human health and recreational values in creeks and billabongs downstream of the RPA.

- Upstream and downstream on Magela and Gulungul creeks. Continuous turbidity during the wet season will enable the comparison of suspended sediment with natural distribution (suspended sediment landform criteria and aesthetic values of clarity).
- Onsite billabongs. Comparison of water quality and sedimentation in Coonjimba and Georgetown billabongs with criteria accepted as representing impacts that are as low as reasonably achievable (ALARA) will demonstrate acceptable levels of protection for ecosystems and land use on the RPA.
- Comparison of results against model predictions for all of the above sites will be undertaken for validation purposes.

Table 10.3 provides the proposed monitoring program for the monitoring and maintenance phase, which is also applicable for the closure phase. Monitoring during the closure phase may identify the potential opportunity to decrease the monitoring scope during monitoring and maintenance phase.

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

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

Reporting of the surface water monitoring program during the monitoring and maintenance phase, including frequency, format, and degree of results interpretation, will be discussed by the WASWG. It may be that the results, and any triggered investigations and actions, will be provided to stakeholders with an interpretive report at the end of each wet season. Targeted investigation reports may be provided as completed, rather than at the end of the wet season.

Figure 10-6: GC2 monitoring station in the dry season

Figure 10-7: GC2 monitoring station in the wet season

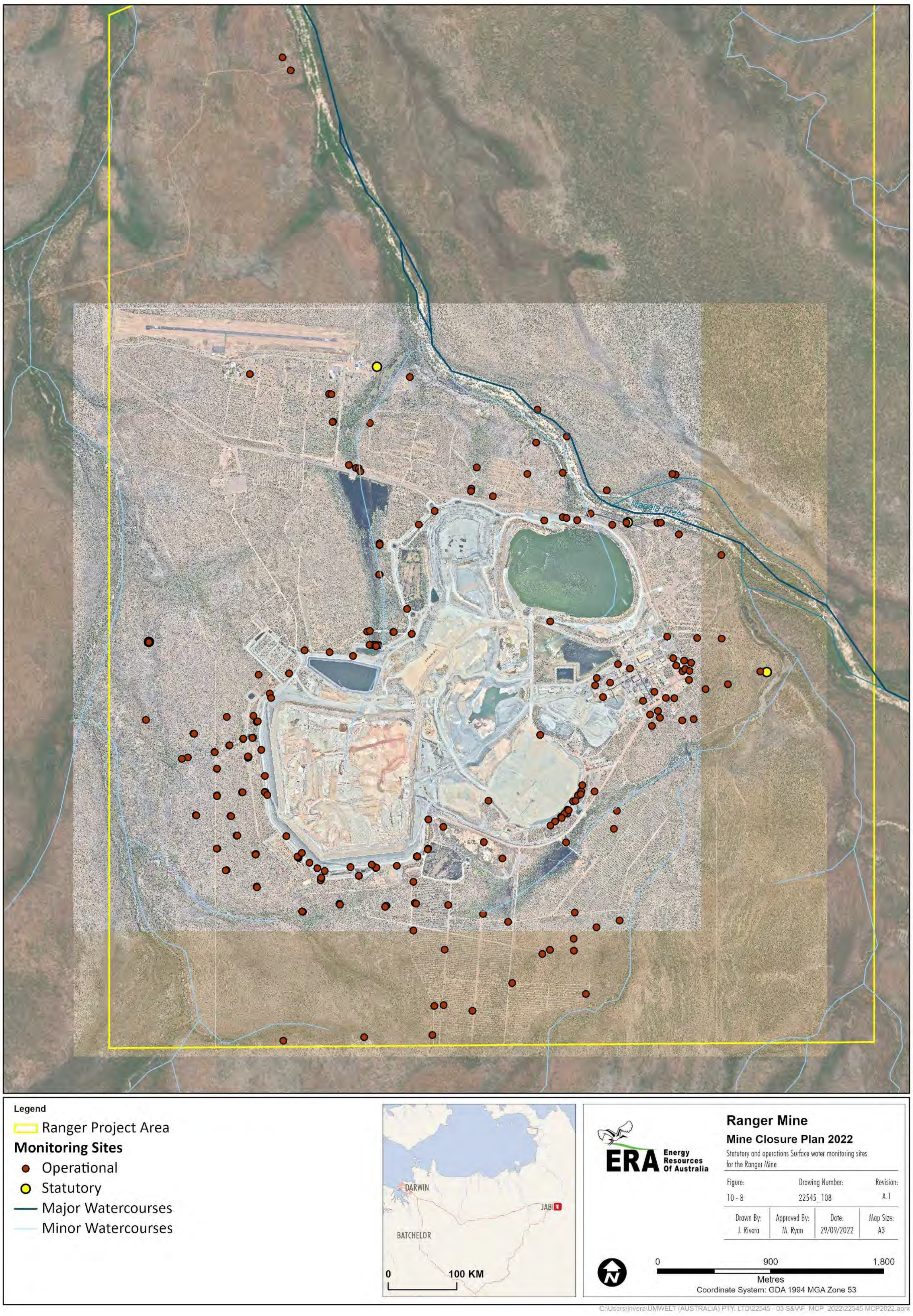

Figure 10-8: Statutory and operations surface water monitoring sites at the Ranger Mine

Table 10.3: Parameters and locations for post-closure surface water monitoring to assess compliance with closure criteria

Location	Parameter	Frequency
MG009, GCLB, MCUS, GCC *The parameter list for MCUS and GCC upstream sites may be reduced in future where criteria does not include comparison against natural distributions*.	Turbidity	Continuous
	EC (proxy for Mg)	
	Mn, U, SO_4	Event-based auto-sampling based on continuous EC during the wet season with frequency reduced over time based on performance and risk review.
	Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N	
	NO_3, NO_2	
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.
Georgetown, Coonjimba and Gulungul Billabongs	Turbidity	Continuous.
	EC	
	U, Mn, Cu, Zn, Mg, Ca, Mg:Ca, NH_3-N, SO_4	Event-based auto-sampling based on continuous EC during the wet season with frequency reduced over time based on performance and risk review.
	NO_3, NO_2	Monthly (if recreational and drinking water identified as community value for these sites).
	Visual clarity and surface films	Observations at each grab sampling collection. Also undertaken as part of cultural criteria monitoring.
	Sediment concentrations and U	Accumulation in sediments limited by U in water criteria. Sediment sampling to demonstrate current compliance via scheduled projects in closure phase.
	Sedimentation	Event-based triggered by results of landform monitoring. TBC in consultation with Landform criteria and Water quality stakeholder groups.

10.2.2 Groundwater – Closure research, monitoring, maintenance and adaptive management

The groundwater monitoring program has been designed to identify changes in groundwater head and solute concentrations for comparison against expected changes in the groundwater system (i.e. changes in groundwater heads and flow direction and changes in concentrations of selected solutes). This monitoring regime will be undertaken at an appropriate temporal and spatial scale to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and achieve the relevant closure criteria.

10.2.2.1 Broader groundwater monitoring program

The primary objective of the groundwater monitoring program is to confirm that measured time series changes to water quality are consistent with the hydrogeological model predictions and the regional groundwater environment remains protected. The groundwater monitoring program has been modified to provide a greater focus on source terms, site activities, pathways and receptors relevant to the particular monitoring programs and/or site areas.

The groundwater monitoring network on the RPA is described through discrete hydrolithologic units (HLU), divided into seven areas to better identify and report on source-pathway-receptor linkages. These HLUs are delineated based on similar geological and groundwater flow and transport characteristics. The HLUs monitored as part of the Annual Ranger Groundwater Report (ARGWR) are described in detail in *Section 5 KKN Supporting Studies* of this MCP.

The results of solute transport modelling (INTERA 2014a, 2014b, 2018, 2021) indicate that solutes at depth in the backfilled pits will enter low-permeability Hydrolithologic units (non-aquifers) and migrate away from solute sources at very low rates. The modelled flux rates from these units to shallow and deep aquifers and surface water bodies are very low. Ongoing monitoring of groundwater will provide data to validate these solute transport model predictions and assumptions.

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

The location of piezometers, constructed to specifically monitor standing water level (SWL) at various points around the RPA, are shown in Figure 10-9. Frequency of SWL checks are presented in the annually released Ranger Water Management Strategy**.**

Figure 10-9: Area 8 – Piezometers

10.2.2.2 Groundwater monitoring across the site

A number of locations have been selected to inform closure studies, collect baseline data to support post closure monitoring, and assess the performance against closure objectives. Timeframes for installing bores are dependent on multiple external factors and therefore cannot have date-specific commitments in this plan.

Groundwater monitoring programs for closure for Pit 3 (Djalkmarra catchment), Pit 1 (Corridor Creek), and R3D are included as components of the annual RWMP and annual RWMS. The programs have been designed to target pathways for transport of solutes into the environment and the various HLUs defined in the groundwater conceptual model. Various new bores have been drilled and developed across the RPA since 2019, in the vicinity of Pit 1, Pit 3 and the processing plant.

Pit 1

The closure specific groundwater monitoring in the Pit 1 area is intended to demonstrate that solute transport velocities and concentrations within each hydrolithologic unit are consistent with modelling predictions, and provide baseline data to support post closure monitoring and the achievement of closure criteria in the receiving environment.

The program monitors changes in groundwater head and solute concentrations, within each hydrogeological unit, for comparison against expected changes in the groundwater system between Pit 1 and Corridor Creek.

Nineteen groundwater bores will be monitored, consisting of thirteen bores drilled specifically for the purpose of closure monitoring, and six existing groundwater monitoring bores (Figure 10-10; ERA, 2022). Monitoring will consist of a water quality laboratory analysis and groundwater level monitoring (Table 10.104; ERA, 2021). The bores monitored for closure purposes are listed in Table 10.10.

Data collected from the Pit 1 groundwater monitoring bores will be reported to stakeholders as part of the existing reporting requirements for the Ranger mine in the ARGWR, together with all other groundwater data collected across the site. Studies undertaken using the data will be shared with stakeholders through the Ranger Closure Consultative Forum (RCCF), ARRTC and the MCP where appropriate.

Data collected from the Pit 1 groundwater monitoring bores during the closure phase will inform development of post-closure monitoring plans, including thresholds and adaptive management outcomes.

Table 10.4: Groundwater monitoring bores for Pit 1 closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
GC2A	Pit 1	274455	8596171	12	7 to 11.7	S-WC	Biannual WQ & SWL
GC2B	Pit 1	274448	8596171	4	0.5 to 3.5	S-WC	Biannual WQ & SWL
MB-A	Pit 1	274092	8596243	50	44 to 50	UMS	Quarterly WQ & SWL
MB-G	Pit 1	273681	8595812	50	44 to 50	UMS	Quarterly WQ & SWL
MB-L	Pit 1	273933	8595935	50	14 to 16	MBL	Quarterly WQ & SWL*
R1C3-1	Pit 1	273977	8595978	22.25	16.25 to 22.25	Pending	Quarterly WQ & SWL
P1_CL_01	Pit 1	273624	8595993	18	10 - 18	WR	Quarterly SWL
P1_CL_02	Pit 1	273965	8595950	8	2 - 8	S-WC	Quarterly WQ & SWL
P1_CL_03	Pit 1	274174	8596230	9	3 - 9	S-WC	Quarterly WQ & SWL
P1_CL_04	Pit 1	274175	8596230	18	12 - 18	D-WC	Quarterly WQ & SWL
P1_CL_05	Pit 1	274176	8596230	35	29 - 35	HWS	Quarterly WQ & SWL
P1_CL_06	Pit 1	274177	8596230	75	63 - 75	MBL	Quarterly WQ & SWL
P1_CL_07	Pit 1	273751	8595738	7	4 - 7	S-WC	Quarterly WQ & SWL
P1_CL_08	Pit 1	273752	8595738	18	15 - 18	D-WC	Quarterly WQ & SWL
P1_CL_09	Pit 1	273753	8595738	35	29 - 35	MBL	Quarterly WQ & SWL
P1_CL_01A	Pit 1	273628	8595996	18	3-18	WR	Quarterly WQ & SWL
P1_CL_10	Pit 1	273521	8596265	18	3-18	WR	Quarterly WQ & SWL
P1_CL_11	Pit 1	274014	8596263	18	3-18	WR	Quarterly WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P1_CL_12	Pit 1	273915	8596019	18	3-18	WR	Quarterly WQ & SWL

Figure 10-10: Pit 1 groundwater monitoring bores

Historic tailings deposition

Several bores surrounding Pit 1 are monitored as part of historic approvals for tailings deposition, which have associated trigger values to ensure protection of the environment during these previous activities. These trigger values are provided in Table 10.5. Proposed control actions to limit the historic migration of seepage is described below.

Table 10.5: Historic trigger values for Pit 1 tailings deposition

Analyte	Stage 1 Trigger Value	Stage 2 Trigger Value
EC (µS/cm)	459	918
Mg (mg/L)	64	128
SO_4 (mg/L)	22	44

Stage 1

If the values of the parameters EC (459 µS/cm), Mg (64 mg/L) and SO_4 (22 mg/L) are exceeded, quarterly monitoring will be increased to monthly monitoring for the SMP, PMP series bores, MB-H, MB-L and OB30.

Stage 2

If the trigger values of the parameters listed in **Table 10.6** for Stage 2 are exceeded, one or a number of actions will be taken. These actions are outlined in the original deposition of tailings application. These actions have already been completed, or are ongoing operational actions, that are already in place irrespective of concentrations of the parameters. These actions include:

- remnant process water is being removed from the historic Pit 1 void via decant abstraction;
- pumping of MB-L bore has ceased, increasing groundwater levels behind the pit wall; and
- the construction of the seepage limiting barrier has been completed.

Pit 3

The closure specific groundwater monitoring for Pit 3 is to monitor groundwater head levels and solute concentrations, within each HLU for comparison against expected changes in the groundwater system between Pit 3 and Magela Creek.

Closure monitoring is via 28 bores detailed in the RWMS. Monitoring of bores proximal to Pit 3 are to address closure related monitoring objectives, including monitoring for any solute transport from Pit 3 associated with the deposition of tailings, to develop a background dataset to support post-closure monitoring, and to inform ongoing closure related studies. The bores monitored for closure purposes are listed in Table 10.6 and shown in Figure 10-11.

Table 10.6: Parameters for groundwater monitoring bores for Pit 3 closure

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
MS4	Pit 3	274311	8598255	9.25	6 to 9.25	DS	Biannual WQ & SWL
MS4-A	Pit 3	274311	8598255	5.25	1.45 to 5.25	DS	Biannual WQ & SWL
P3-4B	Pit 3	273822	8598301	100	60 to 99.5	D-UMS	Biannual WQ & SWL
P3-8	Pit 3	274292	8598235	81	42 to 69	D-UMS	Biannual WQ & SWL
P3-11	Pit 3	274362	8598122	25.6	11 to 25.6	D-WC	Biannual WQ & SWL

Bore ID	Locatio n	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P3-12	Pit 3	273893	8598467	75.6	56 to 71	D-UMS	Biannual WQ & SWL
P3-13	Pit 3	274477	8597921	39	24.6 to 39	S-BC	Biannual WQ & SWL
P3-15A	Pit 3	274651	8598250	57	39 to 54	S-BC	Biannual WQ & SWL
P3-15B	Pit 3	274677	8598252	30	22 to 30	S-BC	Biannual WQ & SWL
P3-16	Pit 3	274117	8598323	57.7	34.7 to 57.7	D-UMS	Biannual WQ & SWL
P3_CL_01	Pit 3	274283	8598187	10	4 - 10	DS	Quarterly WQ & SWL
P3_CL_02	Pit 3	274287	8598183	25	19 - 25	D-WC	Quarterly WQ & SWL
P3_CL_03	Pit 3	274290	8598181	60	48 - 60	D-UMS	Quarterly WQ & SWL
P3_CL_04	Pit 3	273608	8598337	70	46 – 70	S-WC	Quarterly WQ & SWL
P3_CL_05	Pit 3	273820	8598300	20	8 - 20	S-WC	Quarterly WQ & SWL
P3_CL_06	Pit 3	273823	8598299	45	33 - 45	D-WC	Quarterly WQ & SWL
23562	Pit 3	274404	8598253		4.43 to 5.43	DS	Quarterly WQ & SWL
F11	Pit 3	273663	2598557		0.5 to 6	S-WC	Biannual WQ & SWL
F12	Pit 3	273768	8598629		0.5 to 6	S-WC	Biannual WQ & SWL
MC11	Pit 3	274909	8597892		1.5 to 2.5	S-WC	Quarterly WQ & SWL
MC12	Pit 3	274821	8598170		0.3 to 3	S-WC	Quarterly WQ & SWL
MC21	Pit 3	275015	8598001		3 to 4	S-WC	Quarterly WQ & SWL
NWOB003	Pit 3	274012	8598271		3 to 9	DS	Quarterly WQ & SWL
P3-3A	Pit 3	273686	8598892		40 to 52	S-BC	Biannual WQ & SWL

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
P3-3C	Pit 3	273687	8598898		10.5 to 16.5	D-WC	Biannual WQ & SWL
P3-7	Pit 3	273968	8598296		91.5 to 97.5	D-UMS	Biannual WQ & SWL
P3-9	Pit 3	274240	8598515		18.5 to 36.5	D-UMS	Biannual WQ & SWL

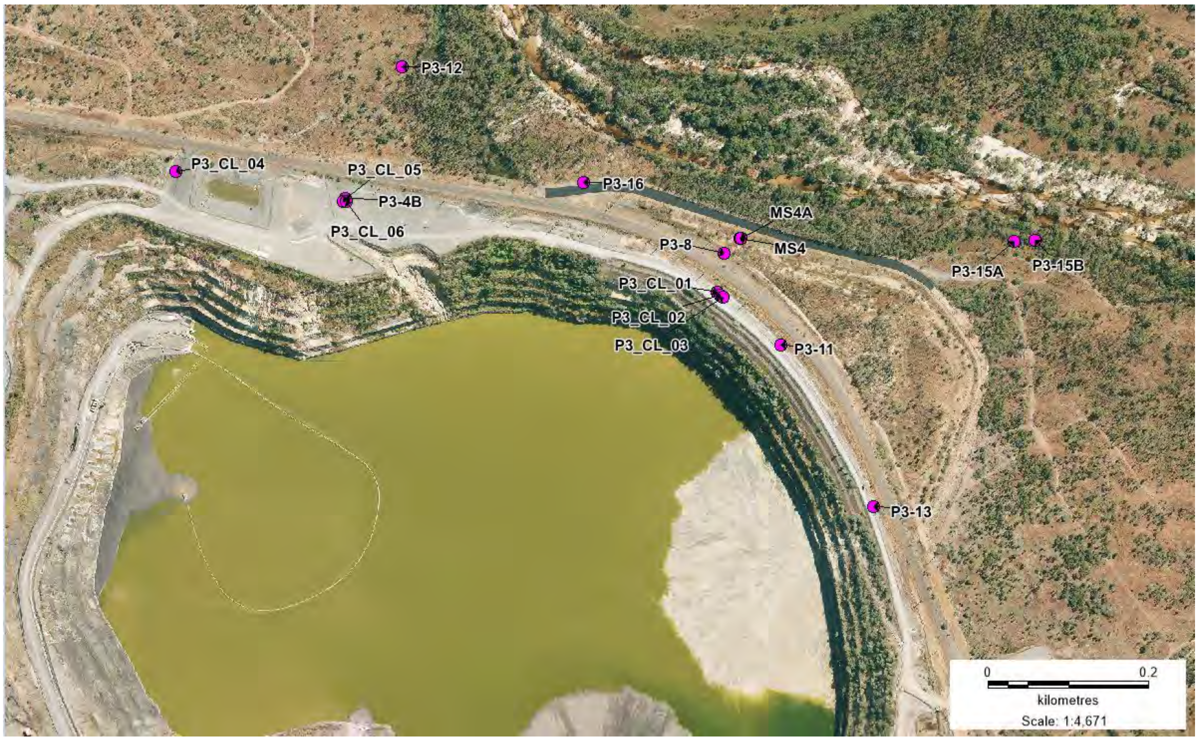

Figure 10-11: Location of Pit 3 monitoring bores

Ranger 3 Deeps

Ranger 3 Deeps (R3D) exploration decline and ventilation shaft rise was backfilled with waste rock in in 2021, however the following section is presented for historical context. This section will be removed from future iterations of the RWMS, and upon the recommendation to remove the associated groundwater monitoring infrastructure once reviewed in the ARGWR.

The overall objective of the groundwater monitoring in this area was to monitor changes in groundwater head and solute concentrations within hydrolithological units adjacent the R3D underground workings.

Adjacent the R3D working, existing bores had been designated for monitoring to capture pre and post-wet season groundwater quality. However, the depth and age of these bores make conventional groundwater sampling impossible, as detailed in the RWMS.

Figure 10-12 shows the location of the groundwater bores used to monitor groundwater levels in the area of the R3D. As per the RWMS (ERA, 2022), all but one bore (R3D56A) has been removed from sampling because of the limited amount of relevant data collected from the bores due to their depth (Table 10.7).

Table 10.7: Groundwater monitoring for Ranger 3 Deeps

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
R3D56A	R3D	274557	8598065	449	0 - 349	DWP-Z	Biannual WQ & SWL

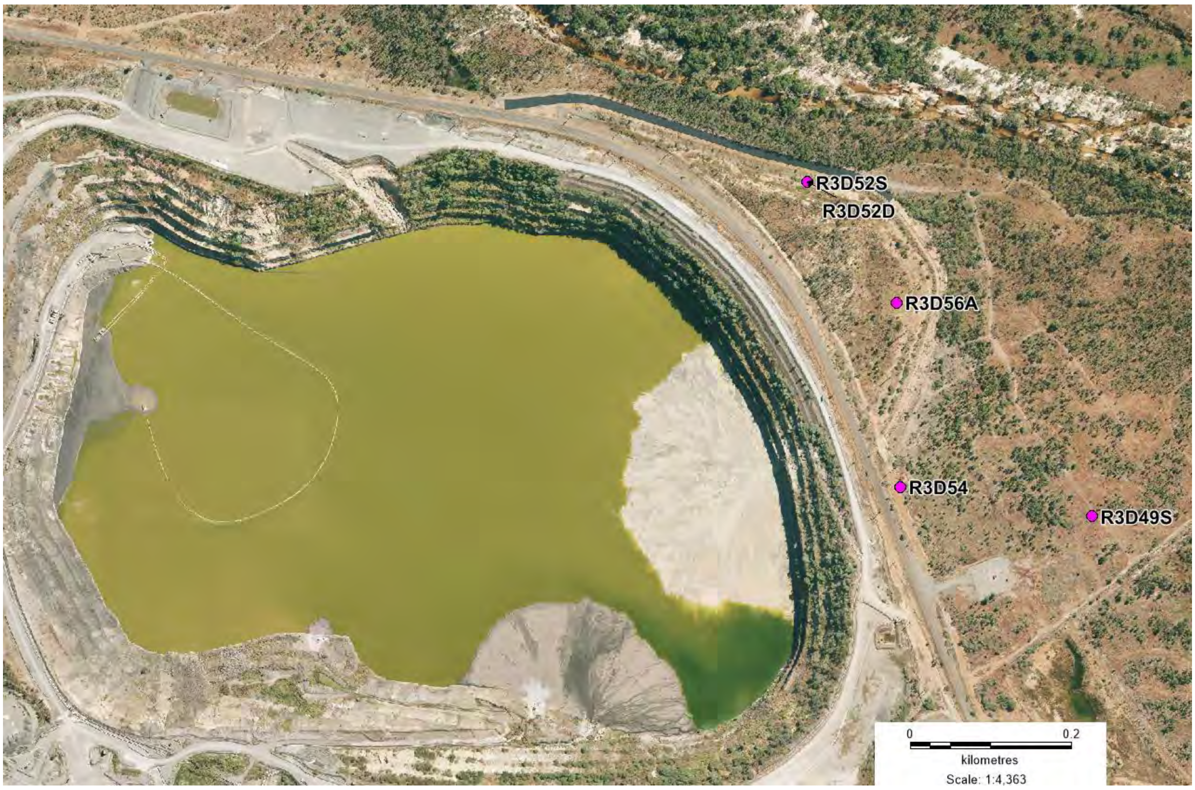

Figure 10-12: Location of R3D closure monitoring bores

Ranger Water Dam

The closure specific groundwater monitoring in this area is to monitor groundwater head levels to support the groundwater to surface water interaction study. The bore monitored for closure purposes is listed in **Table 10.8** and monitored as per the RWMS.

Table 10.8: Groundwater monitoring for the Ranger Water Dam

Bore ID	Location	Easting (MGA94)	Northing (MGA94)	Depth (m)	Screen Interval (mbgl)	Target HLU	Monitoring
78_5	RWD	270305	8596283	45	5 to 45	D-WC	Biannual WQ & SWL

Stockpile seepage monitoring

This short-term monitoring program aims to collect and characterise stockpile seepage water for source-term use. The monitoring locations, objectives and sampling methodology are outlined the RWMS. The study to quantify the post closure source term for the waste rock has been completed (INTERA, 2020). As a result, water quality monitoring frequency is reducing from monthly to quarterly while the sampling frequency for filterable Radium and Polonium will reduce to annual samples.

Groundwater to surface water interaction

Data loggers recording the static groundwater level are to be installed in various shallow monitoring bores situated within the Magela floodplain to support assessment of groundwater to surface water interaction. The intent of this short-term monitoring program is to collect additional groundwater level data to refine numerical groundwater flow modelling in this vicinity. The monitoring locations are described in the RWMS. Additional monitoring includes bores 78_5 west of the RWD adjacent to Gulungul Creek, and MC12 adjacent to Magela Creek.

Pit 3 North Ramp

Current observed groundwater levels in monitoring bores in proximity to the Pit 3 North Ramp waste disposal location indicate that there is very low likelihood that groundwater adjacent the disposal location will migrate to Magela Creek, particularly whilst Pit 3 is a groundwater sink. Similarly, an investigative drilling program confirmed that there was no contamination of soils adjacent the liquid waste disposal site, with the exception of low hydrocarbon concentrations at the base of the ramp.

To verify this hydraulic response, groundwater monitoring in the vicinity of the disposal location has been increased to a quarterly frequency. Furthermore, the monitoring objectives for monitoring bore P3_CL_05 and NWOB001 have been expanded to include assessment of contaminant migration from the disposal location. The augmentation of the monitoring program will continue for a 12 month period, in order to collect sufficient data to verify the hydraulic response adjacent Pit 3. Monitoring locations, objectives and sampling methodology are outlined in the RWMS.

Background COPC

Following completion of the background COPC study (ERM, 2020), it was identified that some HLU's did not have sufficient data. To support future assessments, eleven existing monitoring bores in the primary transport pathway HLUs that were identified as having insufficient data (Djalkmarra Sands and Depressurised UMS at Pit 3, and MBL Zone at Pit 1) have been identified with an additional data objective in the RWMS.

Baseline Closure Monitoring

The water quality monitoring suite for all closure monitoring bores has been expanded to ensure that at a minimum all 20 COPCs modelled in post closure solute transport studies are monitored. The updated monitoring suite is outlined for each bore in the RWMS.

Drilling of additional Monitoring Bores

Eleven new monitoring bores were drilled in 2021/2022 in order to replace aging infrastructure, reduce spatial data gaps, and inform additional closure monitoring objectives. These new bores have been incorporated into the RWMS.

10.2.3 Completion criteria monitoring

An indication of background groundwater chemistry obtained from current monitoring data is provided in Table 10.9.

Table 10.9: General background groundwater chemistry on the RPA

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

The proposed closure and post-closure monitoring will comprise monthly measurements of standing water level and quarterly or biannual sampling and chemical analysis (Table 10.10).

The objective of the post-closure groundwater monitoring program is to demonstrate that solute transport velocities and concentrations are consistent with modelling predictions and that the receiving environment will remain protected from defined COPCs.

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

COPC trigger levels for all parameters must be determined from suitable background collection sites, and these will inform the criteria for ongoing management. A representative sample of bores will remain for the groundwater monitoring program post-closure. The monitoring frequency is expected to decrease as the post-closure groundwater environment stabilises, providing no further risks are identified.

The final groundwater monitoring plan and relevant COPCs for post-closure will be developed with continued stakeholder engagement and advice from INTERA upon completion of the post-closure solute transport modelling. The post-closure groundwater monitoring plan will also incorporate refined background chemistry data as established by KKN studies (Section 5).

Table 10.10 Groundwater closure and post closure monitoring

Aspect	Methodology	Analysis	Location	Frequency	Duration	Compliance Reference
Standing water level	Manual standing water level measurements	Compare to adopted background levels to confirm groundwater level is behaving according to modelled predictions, within the documented uncertainties. To determine hydraulic gradients and potential movement of COPCs.	Groundwater monitoring locations listed in **Table 10.5. Error! R eference source not found.**	Monthly (during closure and year 1 post-closure). Quarterly (years 2-4 post-closure) if no changes). Annually during wet season (ongoing if no changes).	Until criteria have been achieved.	Ranger Authorisation Annexes D & E, annual Ranger Water Management Plan and Ranger Water Monitoring Strategy.
Chemical analysis	*In situ* parameters (pH, EC) Major ions and cations (Mg, Na, K, Ca, Cl, SO_4, HCO_3, CO_3) Filterable metals (U, Mn, Fe) Total nitrogen (NO_x-N (NO_2-N+NO_3-N), NH_3-N) Ra-226	Compare to adopted background levels to confirm groundwater chemistry is not being adversely impacted by COPCs from former RPA activities. Where COPC impacts are already present, to ensure these are not migrating into additional impact areas.	Groundwater monitoring locations listed in **Table 10.5**.	Quarterly (during closure and years 1-3 post-closure if no exceedances). Annually during wet season (ongoing if no exceedances).	Until criteria have been achieved.	Ranger Authorisation Annexes D & E.

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

10.3 Radiation theme

10.3.1 Closure research, monitoring, maintenance and adaptive management

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

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

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

LLAA and PAEC will be measured towards the end of the dry season for the initial five-year period following construction of the final landform. The details of the monitoring program are provided in Table 10.11. Lower soil moisture during the dry season results in increased Rn exhalation rates and higher dust concentrations in air. Monitoring will be undertaken over a minimum one-week period each dry season using either:

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

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

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

Radiological research monitoring and studies have been ongoing on the Ranger Trial Landform, the Ranger Land Application Areas and more recently on the Pit 1 landform (ERA, 2020). This includes monitoring to inform human and non-human radiological impact assessments undertaken by both ERA and the Supervising Scientist Branch (Section 5).

10.3.1.1 Surface gamma surveys

ERA is investigating the use of autonomous airborne radiation monitoring equipment for gamma surveying. In the case where autonomous airborne radiation monitoring is not possible, a ground-based gamma survey will be conducted (ERA, 2021).

During 2021, ERA purchased a CZT (Cadmium zinc telluride) based detector unit to undertake drone surveys of the final landform, as different areas become available. A gamma survey will be performed by competent trained personnel using a gamma detector in a regular grid pattern over these areas. Absorbed gamma dose rates are to be measured at a height of 1 m above the ground level and integrated over a 60 second time interval.

In April 2021, SSB undertook a ground-based gamma survey of the Pit 1 landform to verify the grade and U-nat (i.e. U-238 in equilibrium with its decay products) activity concentration of the surface waste rock material (ERA, 2021). This survey was undertaken in a grid pattern and gamma counts over a 60 second time interval was recorded at a height of 1 m above ground level. Measured count rates will be converted into absorbed gamma dose rates and cosmic-ray, Th-232 and K-40 contributions to measured dose rate will be subtracted from the result (ERA, 2021). Dose coefficients for external exposure to radionuclides will then be used to estimate U-nat activity concentrations.

A contour map of U-nat activity concentrations across the entire Pit 1 final landform will be produced to visualize the results.

The distribution (i.e. normal or lognormal) of the U-nat activity concentration data will be determined (ERA, 2021). From the distribution, the percentage (if any) of the Pit 1 final landform with U-nat activity concentration above the cutoff for 1's grade waste rock (i.e. ~2100 Bq/kg) will be estimated (ERA, 2021).

The appropriate mean value (i.e. arithmetic or geometric) for the determined distribution will be calculated and compared with the anticipated average U-nat activity concentration for the entire Ranger final landform of 800 Bq/kg (ERA, 2021).

The results from this survey, and the comparison to historical monitoring data, will be reviewed by ERA and discussed in future iterations of the MCP.

10.3.1.2 Radon 222 exhalation flux density

Radon-222 exhalation measurements on the Ranger trial landform was monitored in 2009, 2014 and 2016 (Bollhöfer & Doering, 2016) to inform the SSB radiation dose assessment for the radon-222 pathway (Doering *et al*., 2018). The SSB radon-222 exhalation measurements on the TLF was re-established in 2019 (Section 5).

ERA aims to undertake radon-222 exhalation monitoring on Pit 1 landform during 2022. Brass canisters containing activated charcoal will be used to collect the exhaled Radon-222 from the surface waste rock and will be estimated using published methodologies with Spehr and Johnston (1983) and Bollhöfer and others (2005) as examples.

To assess seasonal variability, ERA will aim to undertake Radon-222 exhalation flux measurements at the end of dry season in 2022 and end of wet-season in early 2023.

10.3.1.3 Radium 226 substrate sampling

Surface substrate samples of 10cm depth will be collected from directly underneath all the locations where Radon-222 exhalation flux measurements occur. Sufficient volume of substrate to enable analysis is to be collected from each location.

The collected substrate samples are to be homogenised in preparation for radionuclide analysis by gamma spectrometry. Samples will be sent for analysis with an additional storage period of a minimum 24 days after pressing to allow for the ingrowth Radon-222 progeny radionuclides. Radon-222 is used as a proxy measurement of Radium-226 in the sample.

Sampling will be based on a systematic random sampling approach as shown in Figure 10-13 (IAEA, 2019). The systematic random sampling approach will allow radiological monitoring to be deployed without interference with other Pit 1 works (contouring, irrigation, revegetation, etc).

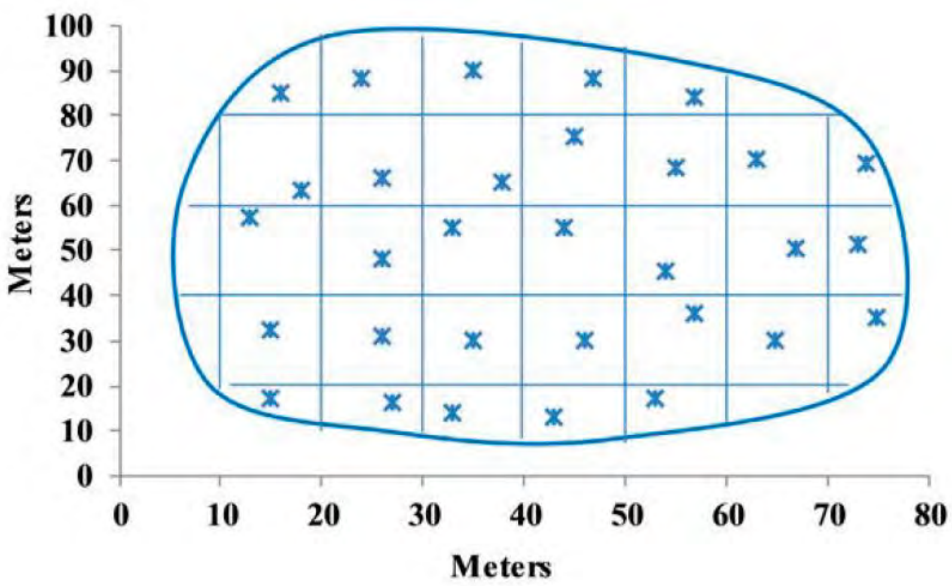

Figure 10-13 Systematic random sampling approach (IAEA 2019)

10.3.1.4 Passive Radon 222 sampling

Passive radon monitors (PRM) will be used for the measurement of radon in air. The monitors will be placed 1 m to 2 m above the ground level for 3 months and then collected to be sent to certified laboratory for Radon-222 analysis. Sampling locations will follow the same grid pattern as Radon-222 exhalation and Radium-226 sampling. The PRM will then be sent to an accredited laboratory for radon gas decay counts.

10.3.2 Completion criteria monitoring

Monitoring and research undertaken will inform the final radiological impact assessment for the Ranger mine closure. The assessment considers potential radiation exposure to members of the public, as well as terrestrial and aquatic biota (Section 5).

Radiation monitoring for the closure phase, and the post-closure phase (i.e. monitoring and maintenance phase), is provided in Table 10.11.

Table 10.11: Radiation closure and post-closure monitoring

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

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

10.4 Ecosystem theme

10.4.1 Closure research, monitoring, maintenance and adaptive management

10.4.1.1 Trail Landform (TLF) and Pit 1 monitoring

The Trail Landform (TLF) and Pit 1 are two of ERA's key ecosystem research programs and are critical components of the Species Establishment Research Program (SERP). Each area has its own respective monitoring plan that cover matters including, soil and moisture relations, nutrient cycling, initial revegetation and ecosystem establishment. A summary of the ERA ecosystem monitoring projects is provided below.

The TLF is a twelve-year-old revegetation trial and is considered to be at an intermediate phase of ecosystem development. It produces valuable information regarding ecosystem trajectories, including:

- waste rock as a growing material, including substrate moisture content, nutrient cycling and soil development;
- species-specific performance over time, including their ability to flower, fruit and self-recruit successfully either from seed and/or vegetative means;
- ecosystem community structure development;
- external colonisation of flora species, both native and exotic;
- visitation and/or colonisation of fauna;
- ecosystem resilience against disturbances such as storms, fire, disease and pests; and
- provides the opportunity to trial maintenance and adaptive management actions to ensure the ecosystem develops on a desirable trajectory.

Pit 1 is a newly formed landform and is at the very early stages of ecosystem development. Research monitoring will primarily focus on:

- waste rock as a growing material, including substrate moisture content, nutrient cycling and soil development; and
- species-specific initial establishment of tubestock, considering the different methods used for propagation and the different revegetation seasons.

Each of the soil moisture stations on Pit 1 consists of an array, or 'vertical nest', of soil moisture content sensors (CS650, Campbell Sci, USA) and thermal conductivity (TC) sensors (CS229 Soil Moisture Matrix Water Potential Sensor, Campbell Sci, USA) (ERA, 2021). The CS650 sensors monitor temperature, EC, and allow for the monitoring of volumetric water content (VWC). The TC sensors allow for the monitoring of matric suction and temperature. TC sensors also allow for the validation of VWC variations through the material. Data collected will allow for continuous monitoring of gradients and changes in the water storage of the growth medium. Whilst the CS650 sensors provide an indication of the actual water content in the soil, matric suction measured by the TC sensors highlights the relationship between rainfall and movement of moisture within the soil profile (ERA, 2021).

The TLF ecosystem monitoring programs are summarised in Table 10.12, and the Pit 1 ecosystem monitoring programs are summarised in Table 10.13 and Table 10.14. Unless otherwise specified, all data collected from monitoring will be used to inform the Ecosystem Establishment Strategy, the ERA State & Transition Model, and ERA's Adaptive Management Plan.

The TLF and Pit 1 plans were created prior to ecosystem closure criteria agreement, therefore they will require review and potential updating to ensure monitoring is providing meaningful data that aligns with criteria. Any revisions and changes will be included in future iterations of the MCP.

Table 10.12: Summary of TLF monitoring programs

Monitoring	Timing and Frequency	Location	Parameters	Purpose
Substrate Moisture	Continuous until 2026, or until system failure	1A	Volumetric water content	To determine the changes in soil volumetric water content over time to better understand how plant water uptake dynamics changes over the long term (e.g., at a decadal scale). Data will be used for WAVES modelling.
Nutrient Sampling	April 2024	1A and 1B Permanent Monitoring Plots	Samples will be analysed for: pH, EC and CEC, Total N, NO_3 and NH_3, Total OC, Water Soluble OC, P-Cowell	To understand the nutrient status of the TLF.
Overstorey Monitoring	Biennially at the end of the wet season until 2026	1A and 3	Species and height for all plants > 1.5 m tall. Diameter at breast height (DBH) for all plants with a DBH > 3 cm at 1.3 m.	To gather species survival and growth data from a mature revegetated waste rock ecosystem.
Understorey Monitoring	Annually at the end of the wet season until 2026	1A	Species abundance and ground cover (%)	To capture the structural and compositional development of the TLF's understorey.
Secondary establishment trials	Annually at the end of the wet season until at least 2022	1A and 1B	Tubestock and direct seeded plots and will be monitored for: Persistence/survival Growth (mm) or cover (%) Health Flowering/fruiting Recruitment	To refine suitable species selection and establishment techniques for introducing understorey species during the secondary phase of revegetation. To better understand understorey establishment, particularly long-term persistence and recruitment.

Sustainability Surveys	Monthly or bi-monthly depending on the season, until at least 2023	Along 2 - 4 *ad hoc* transects in all sections	For every species that was introduced (planted or seeded): Level of flowering and fruiting. Self-recruitment type and approximate amount. General health. The approximate amount of externally colonising flora species (native and exotic) is also recorded. Photos of anything anomalous or interesting.	To opportunistically survey patterns and changes on the TLF that may not be captured during other, less-frequent monitoring. To better understand the TLF's ecosystem development and sustainability, specifically: • Are established plants able to flower and fruit? • Are established plants able to recruit? • Do the plants appear healthy (i.e. any pests and/or diseases present, are there signs of recovery after disturbance)? • Are new plant species able to colonise from external sources? • What weed and exotic species are present? • What animals are observed on the TLF?
Resilience Monitoring	After a disturbance event as soon as the TLF can be safely accessed.	All disturbed sections	Parameters will vary depending on the type and severity of the disturbance. For example, after a significant storm event surveys will focus on canopy defoliation, branch and/or trunk damage, and tree/shrub uprooting. The sustainability surveys will capture signs of long-term recovery. If a prescribed burn is performed, pre- and several post-fire surveys will be conducted to capture the full impact of the burn.	To better understand the revegetated ecosystem's sustainability in terms of resilience to disturbance events.

Table 10.13: Summary of Pit 1 substrate and weather monitoring programs

Monitoring	Timing and Frequency	Parameters	Purpose
Substrate Moisture	End of the wet season 2022 until FLF Application submission	Volumetric water content and soil water potential.	To assess growth medium performance, with specific emphasis on water retention and plant available water (PAW). Data will be used for verification of the WAVES model.
Nutrient Sampling (TBC)	Within the first year of final planting and at five year intervals.	Samples will be collected via stratified sampling transect method, and analysed for: Bulk density, pH and EC, Exchangeable Cations (Ca, K, Mg, Na, CEC), Total N, NO_3 and NH_3, Total OC, Water Soluble OC, P, P-Cowell, PBI, S, Cl, and Exchangeable Al.	To determine the changes in nutrient status in the surface layer of Pit 1 over time, as an indication of nutrient availability and cycling.
Soil Formation (TBC)	Within the first year of final planting and at five/ten year intervals.	Samples will be collected via stratified sampling transect method, and analysed for particle size distribution.	To determine the changes in fines proportions in the surface layer of Pit 1 over time, as an indication of surface particle weathering and soil formation.
Weather Conditions	Continuous until 2026	Key weather conditions including solar radiation, wind speed and direction, rainfall, temperature and relative humidity.	The information will support the substrate moisture assessment and will be input to the WAVES and VADOSE/W modelling. The data will also help characterise the local atmospheric conditions that influence revegetation.

Table 10.14: Summary of Pit 1 revegetation monitoring program

Monitoring	Timing	Frequency	Parameters	Purpose
Ongoing nursery monitoring	Propagation period	Regularly throughout nursery propagation, minimum once a week	Seed lot germination rates (quantitative data recorded). Observations on seedling growth, health and general progress (qualitative data / comments recorded). Any nursery actions / treatments to seedlings are also recorded.	To capture species-specific nursery learnings to incorporate into the SERP database and Seed Management Database (SMD). These learnings will then inform: Future nursery practises (seed treatments, over-sow rates, propagation methods, growing times etc). The seed collection plan (readjusted based on germination rates, propagation methods, seed longevity etc). The revegetation plan / schedule.
Pre-planting survey	Within 2 weeks of planting	Once	Final seedling numbers, health (ranked 1 – 4) and height. A photo record is also taken of each species and treatment.	To record the final number of replicates per species per treatment in the nursery. After which, the planting plan for the area can be finalised and randomisation into planting trays can begin. To record a mean starting height for each species and treatment as a baseline for later growth monitoring. To record the health of species prior to transplanting to contextualise later results (eg. if tubestock were stressed prior to planting, it might explain high initial rates of mortality).
Post-planting survey	As soon as possible after planting	Once	DGPS location of each individual seedling, along with species identification and health ranking.	To more easily track individual seedlings over time, and to capture any early signs of transplant shock.

Monitoring	Timing	Frequency	Parameters	Purpose
Rapid assessment monitoring	First six months after planting	Monthly	A thorough walk-through of the planting area. Record observations on general seedling appearance, colonising weeds, flowering / fruiting, recruitment, substrate surface etc.	Adaptive Management (TARP) Allows ERA to identify any significant weed invasion issues or sections of mass seedling mortality, assess irrigation regime etc. which require follow-up action.
Research Trial Monitoring	First two years after planting	At 3, 6, 12, 18 and 24 months	Every individual seedling will be monitored for: Survival, Growth, Health, Flowering/fruiting, Recruitment. Additional comments will be recorded for seedling appearance and obvious environmental factors that may have impacted seedling performance. Photos of anything anomalous or interesting.	To capture species- and treatment-specific performance to incorporate into the SERP database. These learnings, with consideration of previous trial results and different substrate types, will then inform: Revegetation strategy: eg. if a species has considerably better performance with a particular pot type, or a species appears particularly sensitive to waterlogging etc., then the revegetation strategy may be reconsidered or adjusted for that species. Revegetation plan and scheduling: eg. if a species has considerably better performance at a particular age, or a species has very high mortality if propagated/planted during a particular season, then the revegetation plan / schedule will be reconsidered or adjusted for that species. Seed collection plan: may be adjusted based on species field mortality.

10.4.1.2 Revegetation and native flora monitoring

The scope and frequency of ecosystem monitoring is largely dependent upon the stage of development of the revegetation. Regular monitoring will be needed until the developmental trajectory can be seen to be steadying and the risk of deviation (due to mortality, weeds or fire etc.) and requirements for active management intervention is sufficiently reduced. As the final landform stabilises, the frequency, intensity and scope of the monitoring program can be adjusted to allow more effective use of resources.

Monitoring will be the most intensive during the initial revegetation period, as the highest tubestock mortality is expected within twelve months post-planting. Revegetation areas will be regularly inspected in the period immediately following planting to ensure the irrigation regime is appropriate (based on visible ground conditions), that seedlings are generally healthy, and that there is no weed incursion. This will likely be conducted by ground personnel walking through the revegetation areas, and potentially drones where practical. These regular inspections will be performed during the period when irrigation is operational and in the months leading up to the wet season. If considerable mortality is observed, this will trigger a more quantitative survey of species survival and health in the area. Transects or monitoring plots may be used depending on the nature and severity of mortality (i.e. widespread or localised), and the data collected will inform whether infill planting is required (Table 10.15).

Ongoing annual monitoring of tubestock establishment success will continue until all initial and subsequent infill plantings have developed sufficiently and attrition rates have stabilised, which should occur in the first three to five years.

As the ecosystem develops into the intermediate establishment phase (5–25 years), surveys will be performed every few years to monitor ecosystem development. After secondary introduction planting is performed, likely around the ten-year stage when canopy has matured and developed, additional 'initial' monitoring of these plants will need to occur in addition to the routine vegetation monitoring of the already established vegetation.

If the rehabilitation is impacted by a disturbance event (e.g. extreme weather, wildfire) additional monitoring will be performed to assess any damage to revegetation areas. Depending on the level of damage, remediation such as infill planting will be performed. Areas that receive remediation treatment will require a targeted monitoring program, independent of the surrounding areas, to assess the effectiveness of the remedial action and progress back towards the desired trajectory.

Table 10.15: Maintenance work that may be required for revegetation during the closure and/or post-closure phases

Action	Description
Infill planting	Infill planting will be undertaken during wet season where high mortality of 'initial' tubestock is observed in the first 6-24 months. 'Secondary' introductions of additional species will occur once suitable conditions develop. Infill planting may also be required when an unplanned large-scale event such as fire or cyclone causes significant additional mortality.
Application of fertiliser	To improve optimum growing conditions, tubestock will be planted with fertiliser pellets and, approximately 6-12 months later, a second application of fertiliser will be applied. Plant health and development will be the primary indicator of soil and plant nutrition, however five-yearly soil monitoring will assist with interpretation, and amelioration, of any determined nutrient deficiency, if required (e.g. addition of further fertiliser inputs).

ERA have recently begun investigating opportunities for remote sensing to be used for monitoring during closure. In May 2022, Dendra Systems conducted a trial flight over more than 460 ha of the RPA, including all of the LAAs and revegetated areas (Figure 10-14). The priority for the trial was to individually identify flora to a genus or species level where possible. Other components of interest were vegetation community structure, fauna observations, and identification of erosion and man-made features.

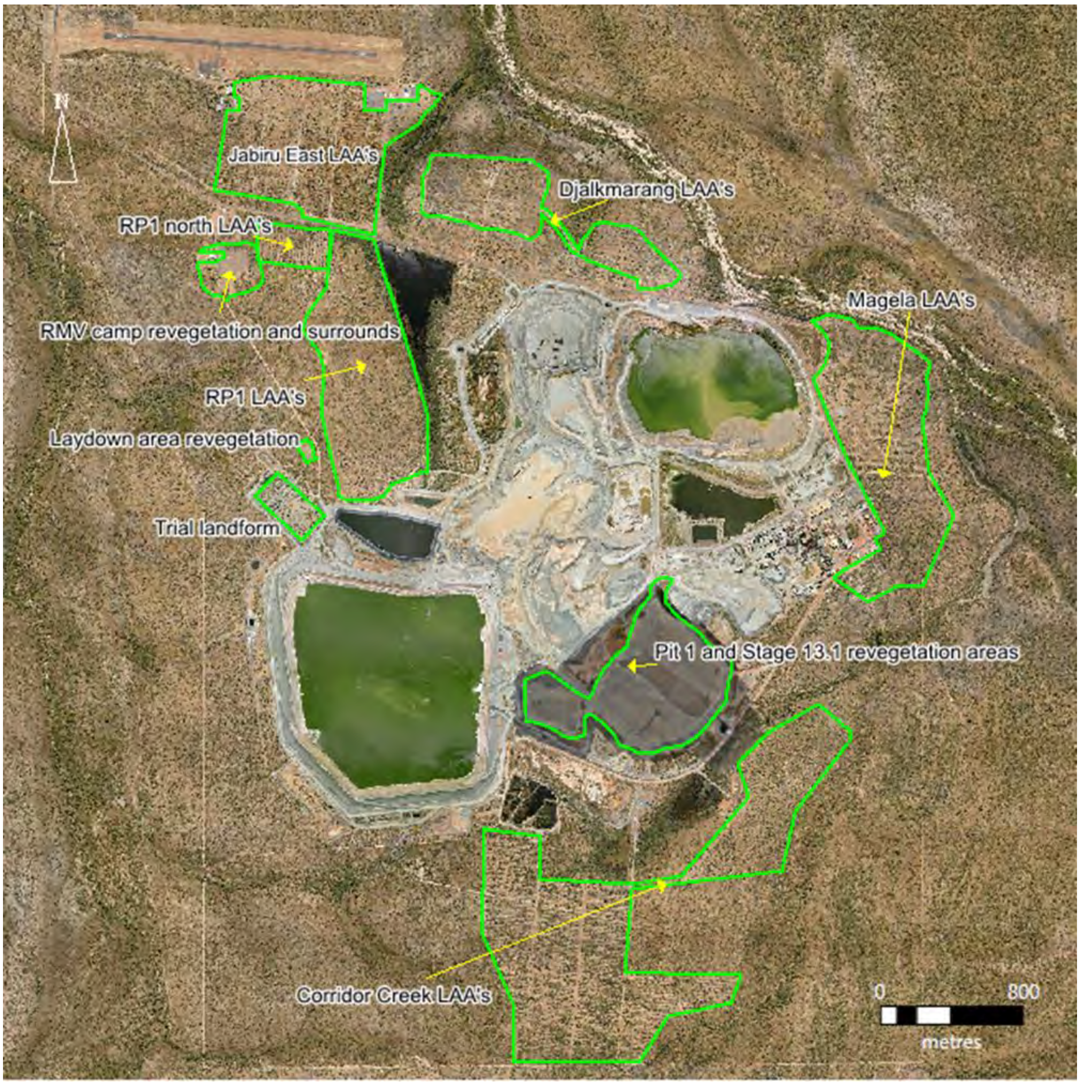

Figure 10-14: Areas surveyed by Dendra in May 2022

Methodology for the Dendra monitoring trials were as follows (pers. comms. Dendra September 2022):

1) Field/ground survey

To support the accurate labelling of features captured by the high-resolution imagery (HR), field ecologists ground-truth features (e.g. plants) in the same areas captured by flight operations. Field ecology operations are carried out at approximately the same time as when the images are captured. Ground-truth data consists of accurate coordinates, captured with a differential GPS unit, photos of features, and other metadata to allow subsequent matching of ground data to HR imagery. Plants are identified in the field when the identity is certain, otherwise specimens are taken, and subsequently identified using relevant literature and resources, and verified against herbarium specimens.

2) My.dendra analysis

Aerial HR and multispectral (MSP) imagery is used for analysis of vegetation cover and height, area classification, digital elevation models (DEMs) and outputs derived from DEMs. DEMs are produced by photogrammetry from the HR imagery. The DEMs that are provided as rasters are digital surface models, that is, they correspond to the ground surface with the shrub and tree layer removed. The vegetation layers are derived from the normalised difference vegetation index (NDVI), which is obtained from the MSP. From the DEM, the slope (gradient) of the terrain is calculated and areas with slopes of specified amounts (e.g. 10-14°) are provided as output. Bare ground analyses are derived from the NDVI and DEM data.

Each area being analysed is further divided into 1x1 m grid cells, with each cell being classified into the following classes: bare ground, grass, shrub, tree or water. These classifications are assigned based on the dominant feature/class within the grid cell. The classifications are produced from the HR using object-based classification. Several classes of features visible in the HR imagery are labelled. That is, separate layers of either points, lines or polygons are associated with the HR imagery. Each of these feature classes fall into seven main groups: man-made objects or structures; native fauna, including their tracks; exotic/pest fauna, including tracks; erosion features; native plants; exotic/weed species; and ecological assessment or habitat structural features, such as fallen logs.

3) Machine learning

HR imagery, along with labelling of features by experienced data ecologists, is used to train a supervised-learning machine learning (ML) system. Provided that sufficient numbers of training examples have been obtained and input into the system, the accuracy and recall of the associations can be assessed. Accuracy of the identifications (often referred to as precision in ML literature) and recall (the ability to recognise a feature in the imagery) are assessed for each feature type and, once these reach minimum thresholds, those features are included into the ML system used to classify new imagery (i.e. imagery not used to train the system).

Preliminary results include:

- identification of almost 80 different flora groups, majority of which at a species level;
- identification of native birds and macropod tracks, as well as ‘cloven hoof’ tracks;
- identification of various erosion features, including splash, rill, gully, sheet and tunnel erosion, dry and wet pooling, as well as sedimentation; and
- identification of over 7,500 man-made features under 19 categories, such as irrigation infrastructure, poles, pipes, fences and gates, rubbish, scrap metal, drums and machinery.

Initial results from the Dendra monitoring trial are encouraging, and more details will be provided in the 2023 MCP once data analysis and reporting from the trial is completed.

10.4.1.3 Exotic flora

ERA has undertaken fine scale annual weed surveys and mapping across the RPA since 2003 (Figure 10-15) and will continue to do so throughout the closure period. This mapping provides data to assess the effectiveness of weed control measures from the previous season and the current weed loads in management areas (Figure 10-16). This informs the ongoing weed monitoring and subsequent corrective actions required. Weed control methods will be situation and species-specific, with the most effective controls determined from ERA experience and input from specialists. Weeds are likely to be controlled by a combination of chemical and physical methods, including application of residual and/or short acting chemicals, seed head cutting and burning, or fuel-load reduction by fire. Further details on weed management are provided in the *ERA Weed Control Management Plan 2021-2022.*

As the mined footprint is rehabilitated to final landform, new zones will be created and incorporated into the weed management plan. Weed management will be critical on the final landform, particularly during the initial stages whilst revegetation is establishing. Weeds may out-compete and/or smother tubestock, or may increase the risk of fire, and thus potentially increase tubestock mortality. Targeted weed monitoring, and routine revegetation monitoring will record if any weed infestations occur on the final landform.

Figure 10-15: Weed Management Zones Map

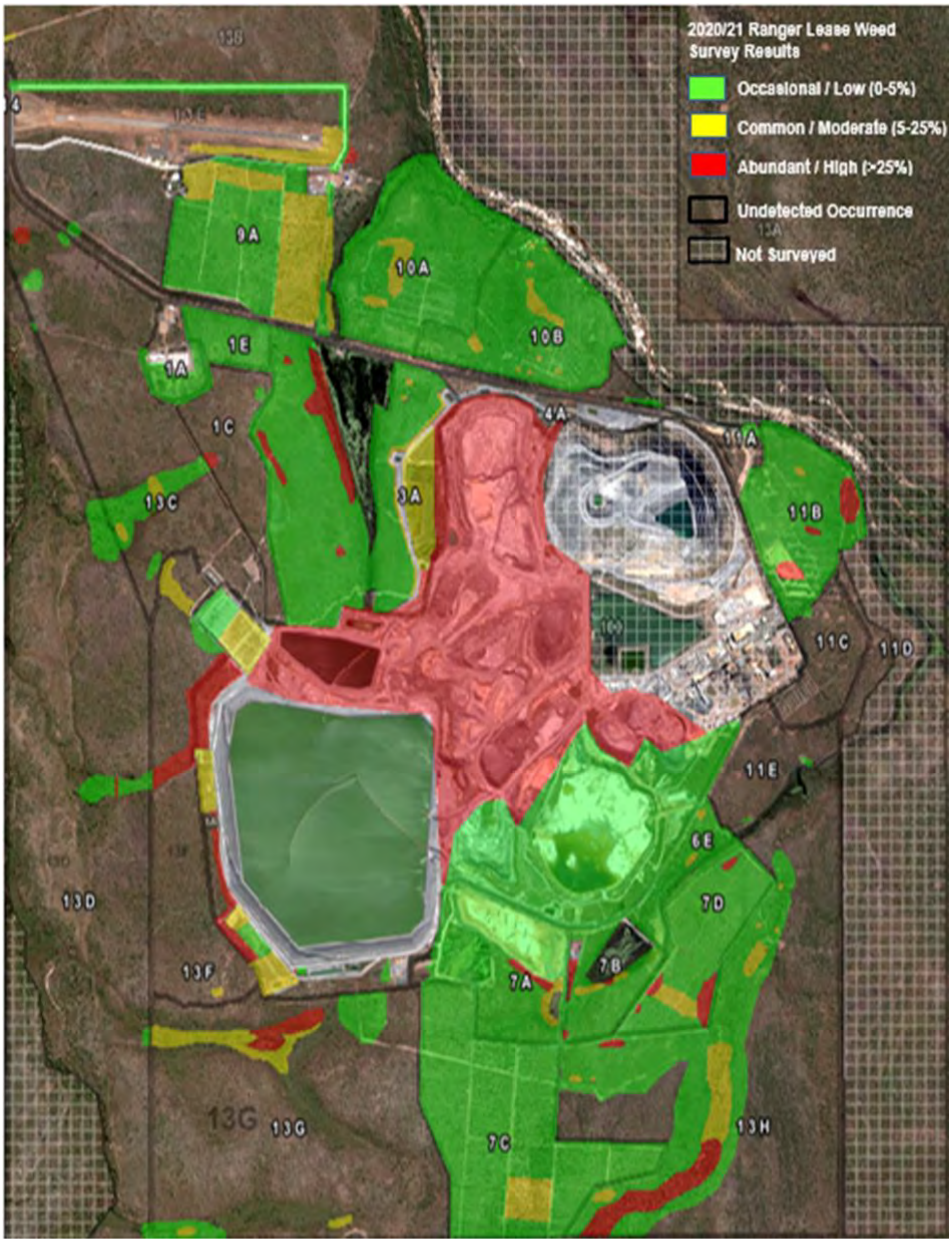

Figure 10-16: Weed loads on the Ranger Project Area 2021

10.4.1.4 Fire management

During operation, ERA's fire management was historically focussed on protecting assets from wildfire by maintaining fire breaks and conducting fuel reduction burns. In the years leading up to closure, the fire strategy shifted to incorporate a greater focus on land management and rehabilitation across the site. With consultation from Kakadu Native Plants Pty Ltd (KNPS), the fire management plan introduced a new aim of conducting wet season burning to deliver a patchwork mosaic of low, medium and high fuel loads across the RPA. These wet season burns not only offered an additional mechanism for the prevention of wildfires, they also improved land accessibility for weed management and helped prepare the landscape for rehabilitation activities. This strategy proved to be very effective and has been continued into closure. Currently, fire teams conduct wet and early dry season burning to manage land and protect the mine footprint and will continue to do so as it is progressively rehabilitated.

Wet season burning (December to March) produces cooler fires that have less impact on the ecosystem; they also allow the fire teams to eliminate fuel loads with minimal risk, as the burn moves more slowly and is less likely to cross containment lines. Carefully timed wet season burning can also be highly effective for reducing highly flammable spear grass loads. Strategically, wet season burns will prevent excessive damage to vegetation, improve groundcover biodiversity by reducing the dominance of annual spear grass, and improve the overall health of the ecosystem. This will also enable natural 'seed and mulch farming' on the RPA, which will assist ERA's seed collection program and ecosystem establishment activities.

Early dry season burning (April to June) is conducted to reduce the intensity of potential fires and ultimately minimise the area burnt by wildfire each year. Weather is closely monitored throughout the burn season to identify favourable burn windows. Burning is not conducted from July to November due to the hotter conditions and more variable wind parameters.

Asset protection, which includes revegetation areas, is still the top priority during closure. However, ERA are also aiming to transition from mostly dry season burning to predominantly wet season burning, with the ultimate goal of reducing the flammability and improving the quality of the surrounding ecosystem. At the time of completion of rehabilitation, the surrounding ecosystem should have transitioned to a state where frequent burning is no longer required; more ecologically-driven, fine-scale fire management can be implemented, with patchy mosaics of small areas burnt at varying intervals, including unburnt areas.

This transition will be achieved through a multi-year fire management campaign during closure, involving comprehensive annual fire plans. Pre-fire season workshops are conducted to review the effectiveness of the previous burn season, share improvement ideas, and strategically plan burns for the following season. The RPA is divided into over forty management areas that are frequently surveyed to inform future fire planning (Figure 10-17). Each area's annual burn plan considers fire history, weed status and accessibility, the type of burn required and the objectives of the burn, and any potential risks. The success of recent fire management plans has been largely due to the collaboration between various ERA site teams, consultation with KNPS, and open communication with stakeholders. Further details on fire management are contained in the *ERA Fire Management Plan 2022.*

Although fire is a part of the current land management of Kakadu NP, it does present a risk to the development of rehabilitation, and therefore needs to be controlled. Fire will be excluded for a minimum of five to eight years until revegetated species have established a certain level of resilience, after which time low intensity 'cool burns' will very gradually be introduced. Any prescribed burns performed will have a specific monitoring plan to help inform future fire implementation and the fire resilience closure criteria.

Figure 10-17: Ranger Fire Management Map

10.4.1.5 Exotic fauna

ERA currently undertakes exotic animal monitoring and culling to manage densities of particular species on the RPA. These management activities have been determined based on risks the species' pose to the environmental, cultural heritage, human health and safety values of the RPA. One invasive invertebrate (Browsing Ant) and the 12 self-sustaining introduced vertebrate species identified in Kakadu National Park (Field *et al*. 2006) have been assigned a broad control management category for the RPA. In order of priority, these categories include (from ERA's *Feral Animal Management Plan 2021*):

- Planned – Feral animal control program planned to be undertaken and/or program established and being undertaken.
- Response to Presence – Feral animal control action may be undertaken where an animal is observed to be present and/or causing actual or potential harm or nuisance.
- Opportunistic – Feral animal control action may be taken if located (for example if animal sighted during the undertaking of animal control program for other target species).
- No known effective control/no planned action – Due to limited knowledge on effective control, ERA will focus investment in the other identified control strategies until effective control measures can be identified.

Management activities for exotic fauna include baiting, trapping and/or ground shooting. These practices will continue during the initial maintenance period after commencement of post-closure monitoring if population densities become too high, if physical works are being adversely impacted (e.g. damaging wetlands or revegetation on the final landform), or if recolonisation by native fauna is significantly compromised. Priority of control for each species may vary over time during closure, subject to population size and risk. As the final landform develops, when appropriate, exotic animal monitoring and management will revert to that which is followed within Kakadu National Park.

Further detail on exotic fauna management is contained in the ERA *Feral Animal Management Plan 2021.*

10.4.2 Completion criteria monitoring

Trajectory monitoring is an integral part of the ecosystem rehabilitation process. It is used to determine the progress of rehabilitation areas and track the development along a trajectory towards longer-term sustainability. Some components of the rehabilitated ecosystem will not be 'similar' to the reference ecosystem(s) within a 25-year timeframe. Consequently, there is a need to undertake monitoring to ensure the values that take longer to develop are on a trajectory to demonstrate acceptable performance against criteria and standards.

The methods for monitoring completion criteria are still under development, with ongoing consultation between ERA, SSB and NLC. There should be significant progress on the development of metrics and monitoring methods for ecosystem closure criteria in 2023. The following sections outline high-level considerations for monitoring site selection, as well as some potential methods for monitoring the flora criteria. Updated monitoring plans, including nutrient cycling and fauna criteria, will be provided in future MCP iterations.

10.4.2.1 Monitoring sites

Ecosystem completion criteria monitoring will largely rely on the establishment of permanent plots, quadrats and/or transects, which will enable more consistent recording of species-specific parameters and ecosystem development. The permanent plots will be established in the early phases of rehabilitation when access and establishment is more easily achievable.

The selection of permanent sampling sites will be based on approximately 5 % coverage of representative areas as per industry standard; where site conditions vary (e.g. seasonally moister sites, areas of greater fines or coarser material, depth of waste rock etc.) additional stratified sampling may be undertaken to cover these local variations.

The monitoring plots could include a variety of sampling areas depending on the lifeform and/or attribute being assessed. For example, plots of 50 m x 50 m for overstorey measurements (which could be split into five 50 m x 10 m strips for ease of recording), would provide the flexibility to cover wider areas and would still allow the data to be collated into four 50 m x 50 m plots to compare with the larger 1 hectare sites in the reference areas. It may be valuable to use a mixed sampling design with both fixed permanent and random plots. All permanent plots will be DGPS'd, pegged and tagged for future reference on the corners of the plots and subplots. Fixed photo points will be used to provide a visual representation of rehabilitation progress.

Reference and rehabilitated monitoring sites for fauna are still to be selected, although Einoder and others (2019) recommend that vertebrate monitoring is conducted at a minimum of 20 rehabilitated sites and 30 reference sites. For some criteria, sites will have specific habitat constraints.

Data will be collected with consistent methodologies and standardised data formats to enable comparisons over time and between sites. To assist in determining trends over time it is critical that permanent reference sites are also assessed in the same season as rehabilitation areas.

10.4.2.2 Species specific flora criteria

Species-specific flora indicators include (full details in Section 8):

- Overstorey and understorey species composition, richness and abundance are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s); and
- Weeds are either absent/eradicated from the RPA (Class A and WoNS), or have a presence and abundance no greater than the reference ecosystem, at a landscape-scale (Class B weeds), or than adjacent areas of Kakadu NP (other introduced flora).

ERA are currently investigating potential options for remote sensing and/or machine learning technology to support the monitoring of species-specific criteria. However, at this stage it is expected that the monitoring will likely rely mostly on ground surveys, at least initially. Even as remote sensing species identification technology develops there will likely be limitations with monitoring ground and mid-strata due to visual blockage from the canopy layer.

round surveys in the plots will likely be performed 2 to 3 years in the initial phases of ecosystem development and then every 5 to 7 year intervals (e.g. 5 to 7, 10 to 12 years, etc.). Overstorey data collected in the plots will include each individual shrub and tree species, which will enable assessment of species composition, richness and abundance. Understorey data will be recorded in quadrats (potentially 5 x 5 m quadrats at set intervals along transects within larger overstorey plots) to ensure coverage of local variations in site conditions and enable easier location of smaller understorey species. Understorey data collected will be on an individual species level which will enable assessment of richness; this can then easily be converted to functional group for composition. Abundance of understorey species may use a ranking system such as Braun-Blanquet (Wikum & Shanholtzer, 1978).

As weed presence across Kakadu NP is highly variable, with disturbed areas such as roadsides having higher weed pressures than pristine and/or remote areas, a landscape-scale monitoring approach for weed closure criteria is appropriate for the RPA.

10.4.2.3 Community structure flora criteria

Community structure flora indicators include (full details in Section 8):

- Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s); and
- Percentage cover of overstorey and understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

ERA are currently investigating potential remote sensing options for monitoring community structure development. Some of these options include ground radar/scanner (e.g. Maptek I-site 8200 scanner), drone-mounted LiDAR and/or multispectral drone imagery. If feasible, remote sensing will be used as the main form of monitoring community structure, with some ground truthing.

Ground truthing surveys for community structure will commence after 5 years and then at 5 to 7 year intervals (e.g. 5 to 7, 10 to 12 years, etc.). The community structural data will be collected in plots/transects and quadrats at the same time as the species-specific monitoring. Overstorey data collected in the plots will include tree/shrub height, potentially just within size class ranges rather than directly measured to within centimetres. Canopy cover will be measured using some form of remote sensing and may not require ground truthing. Percentage cover of understorey vegetation can be determined from the data collected during the species abundance monitoring (e.g. Braun-Blanquet method).

10.4.2.4 Ecosystem resilience criteria

All data collected during the monitoring described in previous sections will take into account disturbance event history of the rehabilitation and reference sites such as fire, drought and cyclones. ERA will also be conducting adaptive management fire trials to inform the Fire Implementation Plan; the data from these trials can also be used for assessment against fire resilience criteria.

10.5 Cultural theme

Alongside the development of the cultural closure criteria (Section 8) linguist Murray Garde (Garde, 2015) proposed a number of indicators that could be used to reflect the Traditional Owner attitudes towards rehabilitation progress and by extension the satisfication of the cultural closure criteria during the closure and post-closure phases (Table 10.16). A number of these indicators are largely based on visual and aesthetic values, as viewed through the lens of Mirarr culture. These indicators represent the overall cultural health of the ecosystem, which needs to be assessed by Mirarr Traditional Owners.

Table 10.16: Suggested indicators of cultural health of rehabilitated site (Garde, 2015)

Aspect	Suggested indicators
Landscape surface	Size of rocks; presence/absence of erosion; accessibility; general aesthetic (does it look 'natural')
Vegetation	Growth rate; botanical diversity; correct species for ecological zone; presence/absence of weeds
Riparian zone	Presence or absence of artificial water bodies; visual impressions of water quality, sedimentation, silting of rehabilitated water courses; condition of water course margins, creek banks
Biodiversity	Natural species numbers and diversity; impressions of hunting potential; impressions of vegetable food availability

As noted in Section 8, in the absence of an established best practice methodology in an Australian context, Garde (2015) described a proposed process by which to monitor the success of rehabilitation using a set of cultural health indices. The process described a scalar score, generally out of ten, that allowed impressionistic responses to be quantified. A key aspect of the indices is the bilingual format, including information in both Kundjeyhmi and English (an example is in Table 10.17).

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

- TSF rehabilitated landform;
- Pit 3 rehabilitated landform;
- Retention Pond 2 (RP2) rehabilitated landform;
- Pit 1 rehabilitated landform;
- Retention Pond 1 (RP1);
- Kundjinba Billabong (Coonjimba Billabong);
- Georgetown Billabong (Madjawulu);

- Brockman irrigation area (i.e. Corridor Creek LAA);
- Karnbowh Djang (Tree Snake Dreaming); and
- Ranger 34 archaeological site (quartz outcrop with grinding holes).

Table 10.17: An example of a bilingual, scalar cultural index score for cultural criteria monitoring

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

The Gundjeihmi Aboriginal Corporation (GAC) and the Northern Land Council (NLC) have provided feedback that the MCP is to include a compliance and monitoring process for meeting the cultural closure criteria and that they would propose a process for ERA consideration that included direct involvement of Traditional Owners with technical support.

ERA have been working closely with the GAC and NLC to ensure that closure execution meets the expectations and needs of the Mirarr Traditional Owners. This is being facilitated through a cultural reconnection committee of Bininj. The committee has been facilitated by the NLC with the objective of promoting the achievement of the Cultural Closure Criteria for the mine by giving Bininj an opportunity for input into closure planning and monitoring (Brady *et al* 2021).

10.6 Trigger, action, response plan (TARP)

The monitoring, maintenance and adaptive management programs described in this section have been summarised into a preliminary TARP, which will also be updated in future iterations of the MCP based on agreement of closure criteria and the outcomes of ongoing studies. The TARP is presented in Table 10.18.

Table 10.18: Trigger, action, response plan

Theme	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Landform					
Final landform surface (topography, erosion and settlement)	Sites: RPA Parameters: Landform terrain Analysis: LiDAR or drone survey Frequency: Annual	To inform landform settling rate and erosion rates.	Change from previous Comparison to modelled.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Erosion (local scale)	Sites: Sensitive receptor areas and drainage channels Parameters: Field inspection, notes and photographs Analysis: Identify erosion problem areas Frequency: Annually after the wet season	Identify erosion problem areas and any maintenance required to drainage channels.	Significant erosion – rill erosion > 40 cm depth, sheet erosion or hostile soil environment prevents revegetation (>0.1 ha). Erosion around drainage channels.	Site-based plan and action as required. Repairs to area identified.	Site Environmental Officer (or delegate)
Subsidence, slumping, deformation, and/or settlement	Sites: Identified geotechnical sites Parameters: Geotechnical monitoring of pits, landfill walls, TSF Analysis: Identify any changes (subsidence or deformation) of landform Frequency: Quarterly	Identify any subsidence or deformation of landform areas.	Subsidence, deformation, or settlement of final landform are noted.	Site-based plan and action as required. May require additional works including modifying the sediment control basis.	Site Environmental Officer (or delegate)
Bedload	Sites: Water courses that direct water off site and associated sediment basins Parameters: Field inspection, notes and photographs Analysis: Identify bedload moving off site Frequency: Biannually before and after the wet season	Identify bedload being transferred off site.	Bedload identified moving offsite.	Site-based plan and action as required. May require additional works including modifying the sediment control basis.	Site Environmental Officer (or delegate)
Bedload (sediment basins)	Sites: Temporary sediment basins Parameters: Sediment volume and structural stability Analysis: Design requirements Frequency: Annual	To maintain basins in operational condition.	Outside operational design criteria.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Suspended Sediment	Sites: Monitoring points upstream and downstream of site Parameters: Turbidity (fine suspended sediment (FSS)) Analysis: TBC Frequency: Ongoing monitoring, analysis after wet season	Assess site denudation rates.	Turbidity trajectory not transitioning to control environment levels after 5 years.	Site-based plan and action as required. May require additional surface stabilisation and/or revegetation or works including modifying the sediment control basin.	Site Environmental Officer (or delegate)
Contamination	Sites: Sites in the Ranger Mine contaminated site register Parameters: Various contaminants Analysis: Contaminated soil assessment based on local background concentrations or published investigation levels Frequency: Prior to decommissioning and as identified by assessment.	To ensure impacted soils are remediated to as low as reasonably achievable to protect the environment.	Impacts not ALARA.	If concentrations of contaminants are not ALARA then a detailed site investigation and/or remediation plan will be developed, requiring further monitoring.	Site Environmental Officer (or delegate)
Nutritional Assessment	Sites: Stratified sampling sites across the rehabilitated landform. Parameters: Macro and micro-nutrients, pH, EC, OC% etc. Analysis: Soil chemical (and physical) parameters compared with known reference sites and vegetation requirements Frequency: Five-yearly surveys (at years 0, 5, 10, 15, etc).	To assess the development of the soil profile and inform follow-up fertiliser application type, quantity and timing.	Conditions required for development of rehabilitation not met.	Develop soil amelioration plan, such as fertiliser application.	Site Environmental Officer (or delegate)

Theme	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
Water and sediment					
Surface water and sediment – turbidity and aesthetic	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Turbidity at both sites and other aesthetic parameters (e.g. surface films, odour) Analysis: Physical and observational analysis of samples Frequency: Continuous monitoring for turbidity	Identify erosion issues and conformance with ecosystem and recreational quality of surface water.	Results exceed specific agreed closure criteria.	Monitor trends and develop site specific action plan as required.	Site Environmental Officer (or delegate)
Surface water and sediment – other parameters	Sites: GCC, GCLB, MCUS, MG009, Gulungul, Coonjimba and Georgetown Billabongs Parameters: Various parameters (e.g. EC, major ions, nutrients and metals) Analysis: Chemical analysis of samples and continuous EC Frequency: Ongoing monitoring for EC (Mg), scheduled grab sampling	Assess compliance with closure criteria. Validate surface water model predictions. Identify surface water and sediment quality issues.	Samples exceed specific screening criteria defined in closure criteria.	Monitor trends, identify cause and develop site specific action plan as required. Review model assumptions and outputs.	Site Environmental Officer (or delegate)
Surface water and sediment – U in sediment	Sites: Gulungul, Coonjimba and Georgetown Billabongs Parameters: U in sediment Analysis: Chemical analysis of samples Frequency: Sample prior to and at end of decommissioning	Characterise contaminants in sediments on and off the RPA. Inform decommissioning of onsite billabongs and confirm success of decommissioning activity (if conducted).	Samples exceed specific screening criteria defined in closure criteria.	Identify causes (chemical analyses to identify source) and develop site specific action plan if the mine is the source.	Site Environmental Officer (or delegate)
Groundwater	Sites: Monitoring bores Parameters: Standing water level and *in situ* parameters (pH, EC) Major ions and cations, filterable metals and total nitrogen Analysis: Physical and chemical analysis of samples Frequency: Standing water level monthly progressing to quarterly in years 2-4 post closure then annually in no changes, chemical analysis quarterly until year 3 post closure progressing to annually during wet season until criteria have been achieved	To confirm groundwater level and chemistry is behaving according to modelled predictions, within the documented uncertainties.	Analysis indicates that groundwater is not tracking according to model predictions.	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Radiation					
LLAA and PAEC inhalation	Sites: RPA Parameters: LLAA and PAEC (mSv per year) Analysis: High volume samplers and continuous radon decay product monitors or more passive techniques such as radon track etch detectors and passive dust samplers Frequency: Initial continuous 3-month period, then continuous one-week period each dry season Deposited dust monitoring every 3-6 months (for years 1-5).	To confirm radiation dose constraint to members of the public are below limits.	Exceedance of the baseline radiation dose as defined in the closure criteria.	Action plan to mitigate identified pathway to ALARA. Apply additional restrictions on the use of the land in consultation with Traditional Owners.	Radiation Safety Officer (or delegate)
Food and water contamination	Water Sites: Magela Creek at MG009 and GCLB, also upstream sites Parameters: Ra-226, U-238, Po-210 and Pb-210 (other isotopes if risk identified) (opportunistic bushfoods to be collected from the RPA). Analysis: Gamma spec analysis	As above.	As above.	As above .	Radiation Safety Officer (or delegate)

Theme	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
	Frequency: initially monthly during the wet season, decreasing to annually over time Bushfood collection on and off RPA as per current Kakadu National Park approvals Parameters: Ra-226, U-238, Po-210 and Pb-210 Analysis: Alpha spec analysis and ICP-MS Frequency: Field campaigns with Traditional Owners and park rangers				
External gamma radiation	Sites: RPA Parameters: Radiation dose rate (μGy/h) Analysis: Airborne radiometric survey with ground gamma survey and soil sampling for Ra-226 for ground-truthing Frequency: At the completion of rehabilitation activities	As above.	As above.	As above.	Radiation Safety Officer (or delegate)
Ecosystem					
Flora species composition	Sites: Vegetation plots and transects across the RPA Parameters: Species composition and total species richness (all overstorey, midstorey and understorey species), density of overstorey and midstorey framework species, vegetation structure (e.g. height, DBH), canopy and ground cover indices and overstorey and midstorey species distribution. Analysis: vegetation survey analysis Frequency: three, six and 12 months (year 1); annually (years 2 – 5, inclusive); one-off surveys every five years (e.g. at years 10, 15)	To determine whether species composition and community structure is similar to adjacent areas of Kakadu NP.	Exceedance of final criteria defined in closure criteria (recognising this will be achieved over time).	Site-based plan and action as required.	Site Environmental Officer (or delegate)
Ecosystem maintenance	Sites: vegetation plots and transects across the RPA Parameters: Reproduction (flowering and seeding), recruitment / regeneration, nutrient cycling, fire resilience, resilience to wind and drought, and weed density and composition, species richness of native fauna, density of exotic animals Analysis: vegetation and fauna survey analysis. Frequency: One-off surveys every five years (e.g. at years 5, 10, 15). for all parameters except fire, wind and drought for which it will be event-based. Exotic animal: annual	To determine whether the long term, viable ecosystem requiring maintenance is similar to adjacent areas of Kakadu NP.	As above.	As above.	Site Environmental Officer (or delegate)
Fauna surveying	Sites: Fauna survey plots/transects across the RPA Parameters: Species richness and diversity. Analysis: Fauna survey analysis Frequency: One-off surveys every five years (e.g. at years 5, 10, 15)	To determine the presence of major functional species groups in comparison to surrounding Kakadu NP.	As above.	As above.	Site Environmental Officer (or delegate)
Weed surveying and mapping	Sites: RPA Parameters: Weed density and priority (eg. WoNS) Analysis: Spatial mapping and density scoring Frequency: Annual	To determine the spread of weeds and invasive flora within the revegetation areas.	As above.	As above. No Class A[4] weeds. Class B[2] weeds similar to surrounding Kakadu NP (defined by monitoring). Presence of other	Site Environmental Officer (or delegate)

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

Theme	Monitoring		Response		
	Methodology	**Purpose**	**Trigger**	**Action**	**Responsibility**
				introduced species would not require a maintenance regime significantly different from that appropriate to adjacent areas of Kakadu NP.	
Cultural					
Cultural values	To be determined (see **Section 10.6**).	To determine whether Traditional Owners are satisfied that the rehabilitated environment supports cultural land uses.	Conditions identified in closure criteria not met.	Site-based plan and action as required.	Site Environmental Officer (or delegate)

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APPENDIX 10.1: PIT 1 PROGRESSIVE REHABILITATION MONITORING FRAMEWORK

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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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.

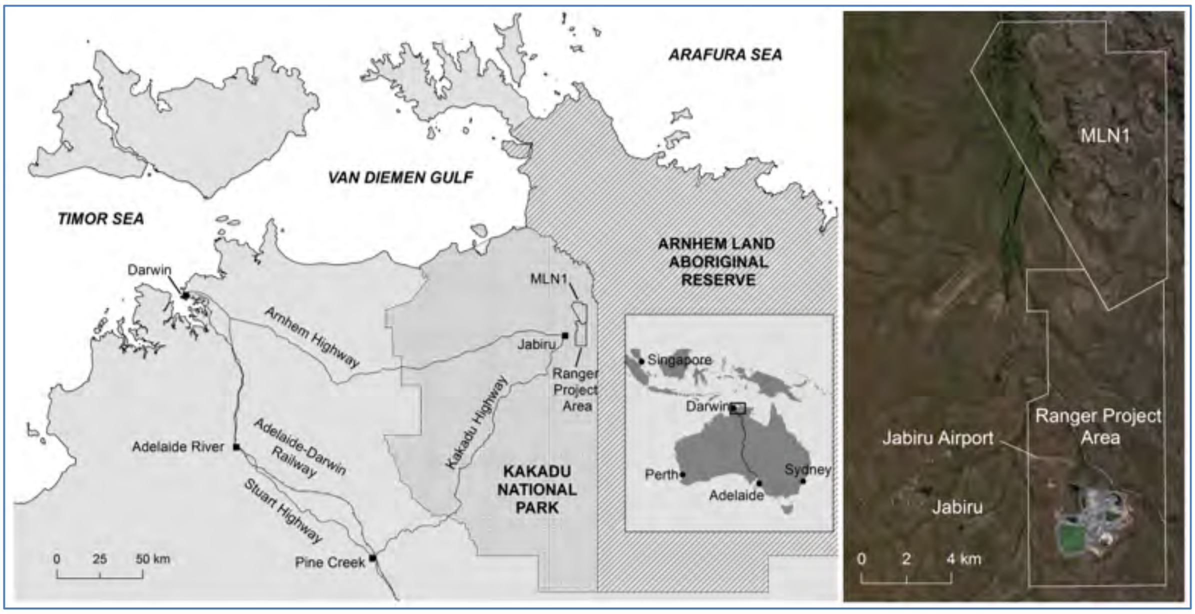

Figure 1 Ranger uranium mine location

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.

7 REFERENCES

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