8 Post-mining land use, closure objectives and closure criteria

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Cover photograph: Wasp nest (*Polistes* sp.) on Scarlet Gum (*Eucalyptus phoenicea*) on Trial Landform

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Below are key terms that are used in this section.

Key term	Definition
Benchmark dose rate	Also referred to as environmental reference level, a chronic radiation dose rate received by the most highly exposed individuals of non-human biota that would be unlikely to have significant effects on terrestrial or aquatic populations.
Bininj	Bininj means many things depending on context: 1. Bininj means 'Aboriginal person' as opposed to a non-Aboriginal person. 2. Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent (as opposed to say, a Yolngu person from north eastern Arnhem Land or 'Mungguy' which is the Jawoyn language equivalent). 3. Bininj means a man as opposed to a daluk (a woman). 4. Bininj means a human being as opposed to a non-human animal. In the context of the mine closure Bininj means a speaker of Bininj Kunwok languages and a person of local Aboriginal descent.
Closure criteria	Performance criteria that will be used to measure the achievement of the rehabilitation closure objectives.
Constituents of potential concern	Chemical elements identified through scientific studies as being of potential concern to the receiving environment.
Environmental Requirements	The Ranger Environmental Requirements are attached to the s.41 Authority and set out Primary and Secondary Environmental Objectives, which establish the principles by which the Ranger operation is to be conducted, closed and rehabilitated and the standards that are to be achieved.
Ranger Project Area	Abbreviated to RPA. The Ranger Project Area means the land described in Schedule 2 to the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976.*

ABBREVIATIONS AND ACRONYMS

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

Abbreviation/ Acronym	Description
ALARA	As Low As Reasonably Achievable
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
BPT	Best Practicable Technology
CCWG	Closure Criteria Working Group
COPC/COPCs	Constituent of Potential Concern / Constituents of Potential Concern
DEM	Digital Elevation Model
ER	Environmental Requirement(s)
ERA	Energy Resources of Australia
ERISS	Environmental Research Institute of the Supervising Scientist
GAC	Gundjeihmi Aboriginal Corporation
GV	Guideline Values
IAEA	International Atomic Energy Agency
ICRP	International Commission of Radiological Protection
KKN	Key Knowledge Needs
LAA	Land Application Area
LEM	Landform Evolution Model
MCP	Mine Closure Plan
MTC	Minesite Technical Committee
NEPM	National Environment Protection Measure
NLC	Northern Land Council
NOHSC	National Occupational Health and Safety Commission
NP	National Park
RDP	Radon Decay Product(s)
RP1	Retention Pond 1 – also denotes other retention ponds used on site – e.g. RP2, RP3, RP6
RPA	Ranger Project Area
SSB	Supervising Scientist Branch
TBC	To be confirmed
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
W/SQO	Water or Sediment Quality Objectives

Abbreviation/ Acronym	Description
WoNS	Weeds of National Significance
WQMF	Water Quality Management Framework

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

8.1 Post-mining land use

An understanding of the post-mining land use allows for the development of specific closure objectives, which are used in the development and formalisation of closure criteria. In accordance with industry guidance (DMIRS 2020), the proposed post-mining land use for the Ranger Mine is to be:

- relevant to the wider regional environment;
- achievable in the context of post-mining land capability;
- acceptable to Energy Resources of Australia (ERA) stakeholders; and
- ecologically sustainable in the context of the local and regional environment.

The Environmental Requirements (ERs) (*Section 3 Closure Obligations and Commitments*) specify that the Ranger Project Area (RPA) must be rehabilitated:

> *…to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.*

It is noted that any decision on the actual incorporation of the RPA into Kakadu National Park (Kakadu NP) will be made by the relevant authority and may not eventuate until sometime after closure, if at all.

Thus, the predetermined post-mining land use of the rehabilitated RPA is the ‘potential incorporation into the Kakadu NP’. To meet this land use, the closure of the Ranger Mine is required to meet a number of closure objectives, which are discussed below (Section 8.2).

Whether the RPA is incorporated into Kakadu NP or not, the rehabilitated site will most likely be utilised for both recreational and cultural use by the local Aboriginal people. ERA has a long history of engagement with the Mirarr people through consultation with the Northern Land Council (NLC) and Gundjeihmi Aboriginal Corporation (GAC). In 2014, ERA formalised the engagement regarding post-mining land use and closure criteria through extensive consultation with Traditional Owners via the consulting linguist and anthropologist Murray Garde (Garde, 2015). This report was summarised by Paulka (2016) and refined for habitation, use of traditional plants and animals, and the assumed post closure bush food diet.

8.1.1 Future occupancy intentions

Consultation with Bininj, Aboriginal people of the West Arnhem region, including the Mirrar, has established there is an enthusiastic intention to continue visitation post-rehabilitation on the condition that Bininj are satisfied that the area is safe to enter and occupy (Garde, 2015). Over the past 35 years there have been restrictions on visitation to this significant area of the Mirarr clan's estate and people are keen to reconnect with the country and the places of cultural significance to them. Intended visitation can be grouped into the following purposes:

- hunting, fishing, bush food gathering;
- recreation;
- land management activities; and
- cultural site visitation, ritual responsibilities.

The following sections outline the intentions to occupy or visit the rehabilitated RPA in terms of average number of days per person per year. These are estimates based on consultations with Bininj combined with knowledge about current occupation patterns for each of the four visitation purposes. It is highly likely that these four categories will not be discrete or mutually exclusive. For example, hunting may occur during visits originally associated with a different purpose (e.g. a monitoring or management visit).

Based on this information ERA has estimated occupancies at various locations to enable the calculation of radiation doses post closure and the development of appropriate closure criteria. A summary of the estimated occupancy times for the various activities are provided in Table 8-1 with an estimate of the typical locations expected to be occupied shown in Figure 8-1.

The table of estimated occupancies contains the original Garde (2015) estimated days per activity and a breakdown over various locations. The table also provides an estimate of percentage of time for each location and an estimate of hours per year.

As can be seen in both the figure and table, the majority of area estimated to be occupied will be in the Magela riparian zones. With the exception of land management and monitoring, Garde (2015) details that occupancies will be centred on the Magela creek and site billabongs (Georgetown and Coonjimba). It is expected that hunting and gathering (and to a lesser extent other activities) will also extend into the previously disturbed water management areas, including the old Retention Pond 1 (RP1) area, Land Application Areas (LAAs) and Corridor Creek. As the landform evolves into a self-sustaining ecosystem, vegetated drainage lines will reform and fauna will reinhabit the landform. It is estimated that occupancy at these locations, mainly in the form of hunting and food gathering, will occur (Figure 8-1). It is likely that infrequent hunting will occur on the remainder of the landform, however this has been estimated to be minimal. The fauna detailed by Garde (2015) are either aquatic based or likely to gather in the riparian areas around water and food sources.

Table 8-1: Estimates of occupancy periods at various locations on the rehabilitated RPA

Purpose of visit	Estimated time[1]	Location	%	Estimated hours per year
Hunting and food gathering (day trips)	30 days per person per year[2]	Magela riparian zones (undisturbed)	70	126
		LAA, RP1, water management areas and site billabongs	20	36
		Landform waste rock	10	18
Seasonal camping (extended camping)	20 days per person per year[3]	Magela riparian zones (undisturbed	75	360
		Site billabongs	20	96
		LAA, RP1 and water management areas	3	14
		Landform waste rock	2	10
Recreation	10 days per person per year[3]	Magela riparian zones (undisturbed)	90	216
		Site billabongs	7	17
		LAA, RP1 and water management areas	2	5
		Landform waste rock	1	2
Land management and monitoring	10 days per person per year[4]	Site billabongs	25	20
		LAA, RP1 and water management areas	25	20
		Landform waste rock	50	40
Ritual	5 days per year[5]	Magela riparian zones (undisturbed)	90	54
		Site billabongs	5	3
		LAA, RP1 and water management areas	5	3

1 – Estimated time from Garde 2015

2 – A 6 hour day has been assumed (Garde estimated both half and full day trips)

3 – Full 24 hour day assumed (conservatively assume camping overnight for bush walks)

4 – Land management assumed to be conducted on an 8 hour day

5 – Rituals assumed to last for 12 hours on average (some may be overnight, some very short)

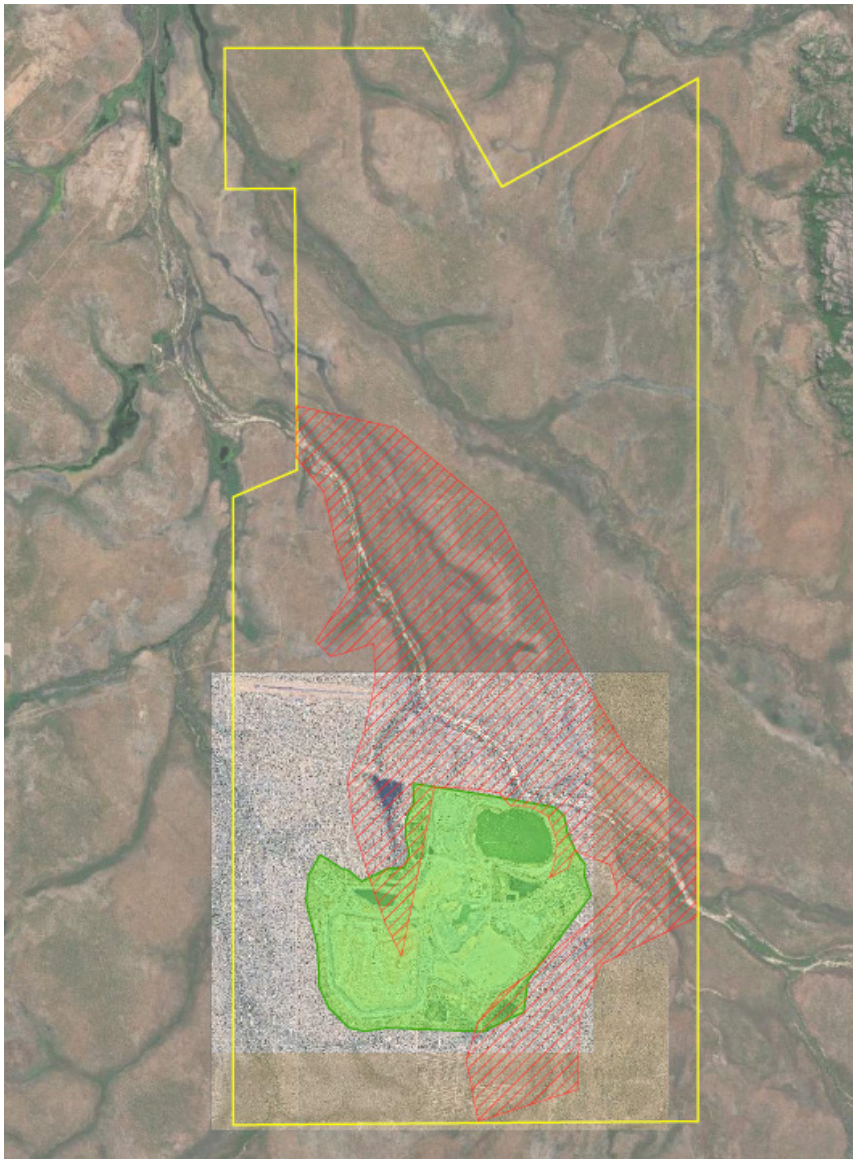

Figure 8-1: Estimated location for occupancy post closure

8.1.1.1 Hunting and gathering

Customary harvesting by local people of terrestrial bush foods from former mine impacted areas is likely to become more prevalent as the rehabilitation of the RPA progresses.

Garde (2015) notes that the most popular of excursions usually involve fishing in Magela Creek, but also that Bininj regularly hunt macropods, pigs, buffalo, waterfowl (mostly magpie geese) and emus, mostly with guns. The estimates of potential visitation periods for hunting, fishing and food collection purposes are based on the following observations:

- hunting visitation is likely to be more frequent on weekends as people combine hunting/food collection with recreational purposes;
- hunting and gathering visits are frequently day trips (that extend for either a half-day or the full duration of the day);

- hunting and gathering trips usually depend on the availability of transport (4WD vehicle), a firearm, seasonal access conditions (i.e. road not inundated) and the seasonal availability of the intended resource; and
- Seasonal camping or extended occupation for seasonal resource exploitation is also highly likely.

Extended seasonal camps are common in the region and are linked with the concentration of food resources at various times, including the late dry/early wet season for waterfowl such as magpie geese, ducks and other bird life. These resources will mostly attract Bininj from Jabiru to places such as Georgetown Billabong, Coonjimba billabong, the rehabilitated RP1, and Magela Creek mainly from MAG009 and upstream as far as the Magela Falls region.

Estimate of time spent on hunting and gathering, day trips:

Average of three times a month (less with lack of access in wet season) = 30 days per year.

Estimate of time spent on hunting and gathering, extended seasonal camping:

= 20 days.

Notional estimate of number of people accessing the rehabilitated RPA:

50 people— mostly from local resident areas.

8.1.1.2 Recreation

When consulted about intended recreational activities, the Bininj listed the following possibilities:

- intergenerational knowledge transfer visits;
- residential college and school trips;
- camping trips along Magela Creek;
- bushwalking trips along traditional walking routes; and
- weekend swimming, ‘get out of town picnics’.

Some Bininj said they would like young people (Bininj) to become familiar with certain cultural sites on the RPA post-rehabilitation. Estimates of such activities are about 2 days per person per year. These may be either sponsored by one of the Bininj organisations or they could be private trips (e.g. a family outing).

Other Bininj said that if they could be assured that it was safe to do so, they would consider camping at traditional or well-known camping places. Examples would include various billabongs along the Magela and associated tributaries. There is also an historical precedent for some long term residence at sites along the Magela, for example 009 camp, where Bininj have spent some years in residence. The area at 009 on the Magela remains a popular recreational site where weekend visits are still popular. In recent years however, the increase in the crocodile population has meant that people are only swimming there in isolated waterholes that appear in the late dry season.

The advent of local rangers is likely to see a program of bush walking and other site visits as the young rangers become familiar with places that have been closed or difficult to access due to mining over the past 35 years. There are plans to include these bushwalks as annual or biannual events, which will form part of a land management program on the Mirarr estate. These will follow the traditional Aboriginal walking routes. Further documentation of these routes took place in 2013 with assistance of the Indigenous Heritage Program and the results have been archived on an online content management database. Robert Layton (1981) documented traditional walking routes on the RPA and Magela Creek area. Whilst they have a recreational aspect to them, bushwalking programs by indigenous ranger groups are also considered as important activities discussed in Section 8.1.1.3 'Land management and monitoring'.

Estimate of time spent on or transit through rehabilitated RPA for recreation:

10 days, on average, per person per year.

Locations:

Gulungul Creek road crossing, Georgetown Billabong, Coonjimba Billabong, the rehabilitated RP1 area, and Magela Creek mainly from Mudginberri to MG009 and then upstream in the area just north of Georgetown Billabong.

8.1.1.3 Land management and monitoring

An ongoing program of monitoring and management in relation to cultural criteria for closure will be required following the rehabilitation of the RPA. In the early days of rehabilitation, it is envisaged that indigenous rangers will make periodic visits to undertake assessment of the cultural criteria associated with closure of the Ranger mine. It is difficult to fix the frequency of these visits at this early stage. Notionally, annual visits would be undertaken.

Fire and weed management will result in regular visits to the site once vegetation has matured. The time needed to conduct site monitoring and management is estimated to be 10 days per person each year. Specific locations requiring the majority of effort are currently difficult to determine.

8.1.1.4 Rituals

Many traditional ceremonies are no longer performed in Kakadu National Park as it is a national park full of tourists and inquisitive non-indigenous people. Garde (2015) outlines some of the historic major and public ceremonies that still occur in Arnhem land.

Bininj in Jabiru and Kakadu are required to undertake certain rituals associated with the recent death of a family member. An example is the painting of ochre on trees, buildings and vehicles with which the recently deceased person has been associated. This ritual also involves visits by the family to sites in the country of the deceased so that the ochre can be placed on trees at important camping places. Bininj may need to access the rehabilitated area for this purpose. The time needed to conduct such activity is estimated to be one day per person each year. Locations would include established seasonal camps and other sites of frequent visitation (e.g. favourite fishing places or goose hunting places near billabongs).

Bininj also have the responsibility in this region to perform increase rituals at certain key sites, especially sacred sites that are totemic centres for particular natural species. These kinds of rituals are performed throughout Australia and are well documented in anthropological literature. The rituals are performed within a matter of minutes and in some cases (depending on the site) they can take longer. A half day or day trip to the relevant area would be typical to 'throw the dreaming totem'. The sacred sites on the RPA may be locations where such rituals might be carried out in the future as Bininj attempt to reconnect with the rehabilitated land. It is estimated that one day per person per year could be dedicated for this purpose.

Locations:

The recorded sacred sites, but possibly also at any of the archaeological scatters.

Bininj in the Kakadu and West Arnhem Land region also visit sites to introduce new visitors or young people (Bininj) to such places. They may also wish to communicate with the spirits of deceased kin at certain sites. It is difficult to determine how frequently site visits for this purpose may be undertaken. Two or three days per year is assumed.

Locations:

Mostly along the Magela Creek, but possibly also at the gravesite and the other recorded sacred sites.

8.1.2 Bush food diet

Establishing how much bush food is consumed by Bininj in the northern region of Kakadu NP informs the post rehabilitation radiological dose assessment. Sources for bush meat are generally defined by three categories:

- hunted by Bininj in Kakadu;
- delivered as a community service by other agencies or non-indigenous individuals; or
- shared by more distant kin (e.g. relatives visiting from Gunbalanya or Western Arnhem Land outstations).

A more exact study based on detailed quantitative analysis from fieldwork is now deemed impractical, not only for the diverse Aboriginal communities and residences within Kakadu NP, but probably for anywhere in Australia. Measuring the weights of all bush meats and plant foods consumed across the dozen or so communities/outstations/ranger stations in northern Kakadu where bush foods are still a significant element of the diet would require a large number of teams to record all harvested food over an annual cycle.

This would create an unacceptable intrusion into the lives of bush food consumers. This impracticality was confirmed by economic anthropologists during a conference at the Australian National University in September 2014 and based on work by anthropologist Jon Altman.

Altman’s 1987 study is one of two studies in Australia that focused on the quantitative collection of nutritional data for Aboriginal people living remotely on their own estates. The second study

by Betty Meehan's was conducted with coastal Burarra people near the mouth of the Blyth River near Milingimbi (Meehan, 1982).

As part of his late 1970s doctoral research, Altman resided at Mumeka outstation on the Mann River south of Maningrida for about 18 months. Over ten-months during his residency, Altman collected daily data from hunting and gathering (as well as market goods delivered by the store) for the outstation community, employing Bininj assistants to help when more than one production team was absent from the camp on any one day. Altman's data is represented in kilocalories and protein rather than pure weight of food resources collected. In 1980 he calculated for this remote western Arnhem Land community, that forty-six per cent of total kilocalorie per capita, and eighty-one percent of total proteins were provided by bush foods (Altman, 1987).

Comparisons to contemporary northern Kakadu communities some 35 years later was difficult. Bininj in the Kakadu region have higher cash incomes to spend and have greater access to market foods throughout the seasonal cycle. Bush foods still represent a significant economic, nutritional and cultural element of current diets.

An absolute quantitative measurement of bush food consumption is not feasible. Therefore, estimates based on long term and extensive data collection by survey and interview are utilised. This methodology is undertaken by the Supervising Scientist Branch (SSB) (Ryan *et al.*, 2011) as the basis for the proposed post closure diet.

The estimated annual intake of bush food by local Aboriginal people residing in northern Kakadu is provided in Table 8-2. The diet has been adapted from that compiled by Ryan and others (2011). The Gundjeihmi names for these foods have been added with some additions of missing items. Anecdotal evidence based on interviews with residents from Bininj communities in northern Kakadu and long term participatory observation of food collection trips by Murray Garde since 2003, indicate the SSB data is still accurate. Specific differences from historical diets compared to current information includes:

- Emu periodically hunted in the area south of the RPA.
- Flying fox consumed regularly in some communities, occasionally or never in others. Communities that consume flying fox do so between one to two months taking an average of a dozen animals (by shotgun). Sometimes flying fox have been supplied to Bininj by other agencies or individuals including Dave Lindner.
- Various water fowl including plumed whistling ducks, wandering whistling ducks, Radjah shelduck, white ibis and straw-necked ibis, and less frequently brolga and the black-necked stork. Consumption of other birds (i.e. sulphur-crested cockatoos and corellas) is rare.
- Typical crocodile consumption is approximately five or six combined fresh and estuarine species. The observed 2 kg/a per person by ERISS has therefore been increased to 3 kg.
- Goanna consumption excludes frilled neck lizards, now more commonly eaten than goanna. Frilled neck lizard populations appear unimpacted by cane toads compared to goannas. The 2 kg/a per person appears reasonable.

Although there is no quantifiable evidence other than direct comparison to the Australian diet, buffalo consumption used in the SSB diet seems possibly over-estimated at 146 kg/a per person. Agricultural commodity statistics (ABARES, 2013) indicate per capita meat consumption in the Australian population as approximately 100 kg/a per person with beef/veal constituting 32.2 kg.

The Supervising Scientist proposed value was not updated during the Garde review; however, the values presented in Table 8-2 represents bush food consumed over the full year in Northern Kakadu. The buffalo consumed as a bush food in Northern Kakadu often comes from Anbarrawarrgu (the Buffalo Farm), as such this would not be included in the diet consumed on the RPA. Buffalo consumption on the RPA has been reduced to 5 kg/a per person. This has been based on an assumption that Buffalo will be hunted and shot 5 times during the year, that a single person will not consume more than 0.5 kg of Buffalo in a single sitting and that the Buffalo meat will last for two days, being shared among the community (i.e. 1 kg meat per Buffalo per person). The weight of organs consumed has been reduced accordingly to 0.5 kg of each.

Table 8-2: Estimate of annual intake of bushfood of local Aboriginal people in northern Kakadu

Food item	Flesh eaten	Organs eaten	kg/a per person
Buffalo flesh	X		146*
Buffalo kidney		X	18*
Buffalo liver		X	18*
Wallaby	X	X	20
Pig	X		25
Magpie goose	X	X	20
Other water fowl	X	X	3
Fish group 1	X	X	10
Fish group 2	X		20
Mussels	X		4
Turtle flesh (3 species: pig nose, long neck and snapping)	X		5
Turtle liver (long neck only)		X	0.5
File snake	X		3
Crocodile flesh	X		3
Goanna	X	X	2
Yams	X		20
Fruit	X		3
Water Lilly	X		3
Flying fox	X		5

Food item	Flesh eaten	Organs eaten	kg/a per person
Emu	X	X	2
Food total			*330.5*

* this reflects annual intake but see comments above table about Buffalo consumption on the RPA

Significant variables include the fact that some communities engage in hunting and bush food collection more often than others and some people consume certain bush foods that others do not. There are also seasonal variables that affect the availability and access to certain species. Certain foods may be favoured by particular age groups (e.g. internal organs of some animals are favoured by the elderly and flying fox is not always eaten by some younger people).

Organs of certain animals are still regularly eaten. The most frequently consumed are those of buffalo (liver, kidneys, tongue), magpie geese (most organs), macropods (liver, kidneys) and long-neck turtle (liver). The organs of these animals have cultural significance in terms of the preparation of a meal. Bininj usually spend considerable time hunting these animals and the organs are removed quickly and eaten as an entrée dish whilst the main parts of the animal are then prepared for the longer cooking process. Organs such as liver are also considered important food for the elderly.

8.1.3 Culturally important flora and fauna

There are various criteria for establishing the cultural importance of a plant. The widest framework is linguistic reference. If it has a name and can be referred to, it must have some significance in the cultural life of Aboriginal people. A further criterion is utility. If it is used as some form of resource (e.g. food, medicinal, aesthetic, material culture, ritual) it is culturally important. On a number of occasions Bininj have indicated that culturally significant plants also include those that link animals together with other animals (including people). Plants that have flowers, seeds or fruit that attract birds and other animals are important for rehabilitation because they encourage the rapid re-establishment of biodiversity, for example Owenia trees (*Owenia vernicosa*). Although Owenia seeds can take up to five years to germinate, they will grow in very rocky habitats, even in cracks of bare sandstone, their fruit is favoured by black cockatoos and emus and the sap is eaten by sugar gliders. People use the crushed leaves as an ichthycide (fish poison).

It may not be possible for all the floristic species identified in the Garde report to be sourced, propagated and established, or suitable for the Ranger site (for example some rainforest species). The plants listed are those found across the three relevant ecological zones of the RPA – watercourses and billabongs, riparian margins and savanna woodland.

8.2 Closure objectives

Closure objectives set out the long-term goals for closure and are to be based on the post-mining landform and use (DIIS 2016). Closure objectives are an essential component of the rehabilitation process, providing transparency for stakeholders as to what the proponent commits to achieve at Authorisation relinquishment. Development of closure objectives should consider each of the environmental factors impacted by the operation (DMIRS 2020).

The ERs of the section 41 Authority, issued under the *Atomic Energy Act 1953,* and now annexed to the Ranger Authorisation issued under the *Mining Management Act 2001*, also provide specific closure objectives that align to the post-closure land use already discussed. A table of these ERs as closure objectives is provided as Table 8-3. These objectives were developed at the time of the authorisation of mining with the post-mining land use in mind. The objectives have been reviewed with stakeholders throughout the project and have been agreed to as being appropriate for the project impacts and proposed land use.

Section 8.3 presents the current status of closure criteria, as informed by the project impacts, supporting studies and stakeholder engagement.

Table 8-3: Closure objectives

Closure objective	ER reference
Landform	
The tailings are physically isolated from the environment for at least 10,000 years.	11.3 (i)
Erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas.	2.2 (c)
Radiation	
Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice and guidelines; and there is a minimum of restrictions on the use of the area.	2.2 (b) and 11.3 (iii)
In particular, the company must ensure that operations at Ranger do not result in: • change to biodiversity, or impairment of ecosystem health*, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing and subsequently during and after rehabilitation.	1.2 (d, e)
Water and sediment	
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: • protect the health of Aboriginals and other members of the regional community. The company must ensure that operations at Ranger do not result in: • an adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice and guidelines.	3.1, 1.1(c) and 1.2(c)

Closure objective	ER reference
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: • change to biodiversity, or impairment of ecosystem health*, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: • any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	3.1, 1.2(d) and 11.3 (ii)
The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	3.1,1.2(e) and 2.1
Flora and fauna	
Revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu NP, to form an ecosystem the long-term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park.	2.1, 2.2 (a)
Soil	
The company must ensure that operations at Ranger do not result in: • environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	1.2 (e)
Cultural	
The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: • maintain the attributes for which Kakadu NP was inscribed on the World Heritage list.	1.1 (a)
The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	2.1

*Ecosystem health means the ability to support and maintain a balanced, integrative, adaptive community of organisms having a species composition, diversity and functional organisation comparable to that of the natural habitat of the region

8.3 Closure criteria

Closure criteria represent direct measurable and quantifiable values, or tiered assessment processes based on industry best practice frameworks, such as the International Commission of Radiological Protection (ICRP), Inventory Multi-tiered Assessment and Prioritisation (IMAP) and National Environment Protection Measure (NEPM). Closure criteria will be used as the basis for determining the successful fulfilment of closure objectives to enable issuance of close-out certificates. It is acknowledged that further work is required to define quantifiable monitoring parameters necessary to confirm that closure criteria have been met.

The mechanisms and processes by which closure criteria are developed are outlined in the Terms of Reference for the Closure Criteria Working Group (CCWG) (Paulka 2012). The closure criteria address the broader objectives described in the ERs and Ranger Authorisation and consider the views of relevant stakeholders (e.g. the Ecosystem Restoration Forum has recently agreed closure criteria).

To identify closure criteria, key themes were developed by the CCWG (Stage 2), which include: landform, radiation, water and sediment, flora and fauna, soils, and cultural. More recently the flora and fauna theme has been renamed to ecosystem. The topics for cultural closure criteria closely align with each of the closure criteria themes. In this MCP, cultural criteria have been presented as a separate section with links provided via a numbering system to show the relationships.

The closure criteria for each theme are based on stakeholder consultation (Section 4), substantial research and studies (Section 5), Best Practicable Technology (including ALARA approach) (Section 6) and risk assessments (Section 7).

The closure criteria presented in this MCP have been through extensive stakeholder consultation. The majority of criteria have now been agreed. Those where some additional studies are required prior to agreement and finalisation have been noted. The proposed closure criteria may continue to undergo review and refinement, based on new studies and consultation with Minesite Technical Committee (MTC) members with updates provided in future MCPs if required.

Each closure theme is presented in following sections including:

- summary of relevant objectives and outcomes;
- closure criteria summary table; and
- justification for outcome, parameter, criteria and method to assess achievement.

Figure 8-2: Fungi on Trial Landform

8.3.1 Landform

2022 Status Update
All seven landform criteria were finalised and received Ministerial approval on 30 September 2021. However, an adjustment to one criteria is required (denudation rate).

There are two objectives derived from the ERs relating to the landform theme (Table 8-3). For each objective, the outcome derived from that objective and explanation are described.

Landform Objective 1:

The first objective comes from ER 11.3 (i) and relates to the isolation of tailings:

> *The tailings are physically isolated from the environment for at least 10,000 years.*

As it will not be physically possible to monitor and measure this over the defined period of 10,000 years, a model will be required to show that this can be achieved. The outcome derived is based on best available modelling demonstrating that the tailings remain isolated.

Any modelling predictions should be conservative to give confidence that the objective will be achieved, however any worst-case scenarios developed will need to be realistic and reasonable.

Landform Objective 2:

The second objective comes from ER 2.2 (c) and relates to erosion of the landform:

> *Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas.*

Three outcomes have been derived from this objective.

First outcome – derived directly from the objective relating to erosion rates being comparable to natural landscapes. It is expected the erosion rates will be initially high then trend slowly on a trajectory towards the natural denudation rates of the region. As these timeframes are expected to be quite long, best available modelling will be used to demonstrate that the denudation rate will approach that of the background rate.

Second outcome – to ensure sediments created through erosion of the landform do not cause bedload to be transported away from the constructed landform and impact local waterways.

Third outcome – applies the concept that turbidity can be used as an indicator of fine suspended sediment. On an annualised basis, the difference between up and downstream can be used as an indicator of site-scale erosion characteristics.

The proposed landform closure objectives, outcomes, parameters and closure criteria are set out in Table 8-4. Section 8.3.1.1 provides justification for the outcomes, parameters and closure criteria that were derived for each of the key elements of the landform theme. The typical rocky surface of the Trial Landform is shown in Figure 8-3.

Figure 8-3: Typical rocky surface of the Trial Landform

Table 8-4: Final Closure criteria – Landform

ER	Objective	Outcome	Parameter	Summary of criteria[2]
11.3 (i)	The tailings are physically isolated from the environment for at least 10,000 years	Best available modelling demonstrates that tailings will remain isolated for at least 10,000 years.	Digital elevation model (DEM)	A high-resolution digital elevation model of the constructed landform matches the approved landform design, within applicable construction standards.
			Landform Elevation Model (LEM) predictions of gully erosion	Modelling of erosion on the constructed landform matches results of erosion modelling conducted on the approved landform design and confirms tailings will not be exposed for 10,000 years.
			Gully erosion	Gully formation will not expose buried tailings.
2.2 (c)	Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	The denudation rate on the landform is on a trajectory towards the regional background rate.	LEM model predictions of denudation rate	Modelling of erosion on the constructed landform demonstrates that the denudation rate will approach the background rate of 0.07 mm/a.
		No bedload is transported away from the constructed landform.	Bedload	Bedload is not being transported from the constructed landform, in the absence of active management.
		Total fine suspended sediment concentrations in receiving water downstream of the landform have returned to background concentrations.	Turbidity	For Magela and Gulungul Creeks, the difference in net annual turbidity between sites located upstream of the mine-site and downstream at the boundary of the RPA, is similar to background values over five consecutive wet seasons in the absence of active sediment control.

[2] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.1.

8.3.1.1 Justification for outcome, parameter and criteria

The following subsections explain how the outcomes of closure were derived from the objectives, the parameters used to measure outcomes, and the proposed closure criteria for each of the key elements of the landform theme (infrastructure, isolation of tailings and erosion characteristics).

Isolation of tailings

The method used to demonstrate achievement of tailings isolation criteria will be based on the Landform Evolution Model (LEM) predictions, using the CAESAR-Lisflood landform evolution model. The criteria will be achieved if the model demonstrates tailings will not be exposed. The modelling of climate change scenarios and the inbuilt conservatism will mean there is no tolerance assigned to the output and therefore it will confirm the criteria either has or has not been achieved.

Once constructed, the as built topography will be compared to design to confirm it is within the construction tolerances expected. These are currently expected to be in the order of +/- 0.5 m at drainage channels and +/- 1 m elsewhere (Section 9.3.5).

The appropriate design of the landform, erosion mitigations and drainage channels should minimise development of gully erosion. Post wet season inspections will be undertaken to determine the presence or absence of unplanned gully erosion. Significant erosion such as gully erosion is more likely to occur in the initial stages of the life of the landform. Following the initial settling of the landform, significant unplanned erosion should not occur. Gully erosion detected over Pit 1 and 3 will be remediated prior to the following wet season. It is expected that after the first five years, the landform will stabilise and less erosion will occur. This criterion is considered to be achieved when gully erosion, beyond that would ordinarily occur in the region, could not expose tailings occurs after this period.

Erosion characteristics

Denudation rate is the measure of the weathering or erosion of a landform surface by forces such as water and wind and expressed in terms of millimetres per year. This parameter is considered the most suitable parameter for comparing erosion characteristics of landscapes over time. The denudation rate of the waste rock landform is unlikely to be comparable to natural landscapes in the short term; therefore, a LEM will be used to predict denudation rates. The model needs to demonstrate that the long-term predictions of denudation rate from the designed landform are on a trajectory towards background rate, which was reviewed to be 0.075 ± 0.013 mm/a (Wasson *et al.,* 2021).

Sediments from erosion of the landform will be measured through both coarse sediment (bedload) and finer sediment (sedimentation).

For coarse sediment, the criteria will be to make sure that bedload is not being transported from the constructed landform, in the absence of active management. This parameter will be measured through post wet season observations after the active post closure management has been completed and the sediment controls structures have been removed.

Suspended sediment loads from the rehabilitated landform to Magela and Gulungul creeks are expected to be high initially, and then trend progressively towards background. Work completed by the SSB has demonstrated that turbidity can be used as an indicator for suspended sediment. The method developed involves the comparison of annual difference in turbidity between upstream and downstream site. Achievement of this criteria will be through demonstration of similar to background over five consecutive wet seasons once the active sediment control structures have been removed.

8.3.2 Water and sediment

2022 Status Update
Agreement with stakeholders has been achieved for many water and sediment quality objectives.

8.3.2.1 Water quality management framework

ERA is using the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG 2018) Water Quality Management Framework (WQMF) for developing agreed water and sediment quality objectives (Figure 8-4).

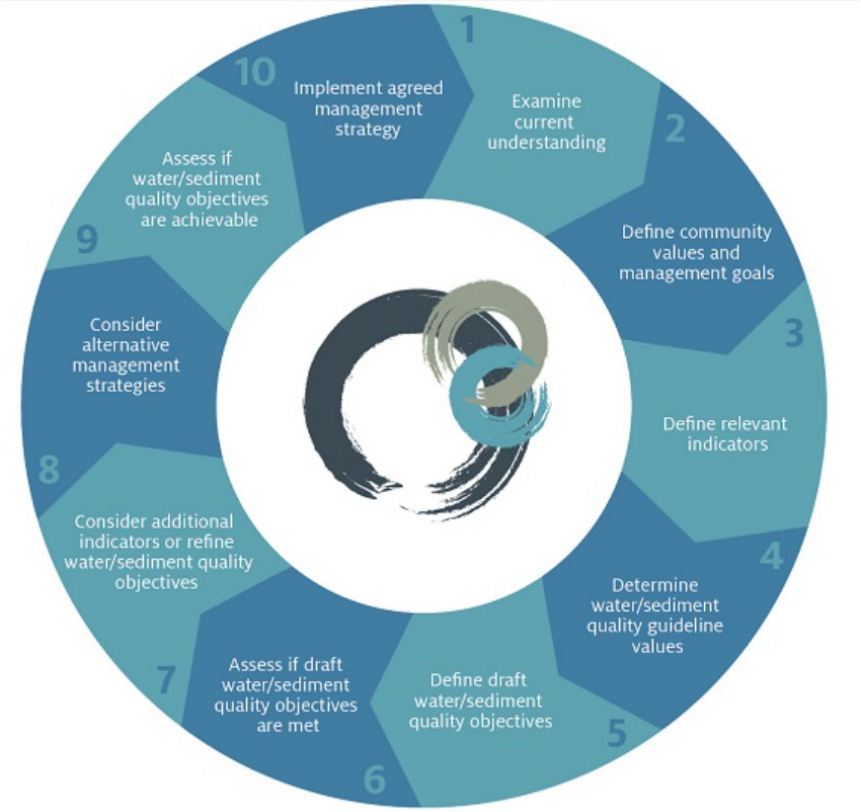

Figure 8-4: The Water Quality Management Framework (ANZG, 2018)

The language of the WQMF differs from that used by ERA and stakeholders in other closure criteria themes. In this section the *outcome* has been replaced with the term *management goal* from the WQMF, *parameter* replaced by *indicator* and *criteria* has been replaced with the term *water or sediment quality objectives (W/SQO)*. As explained in Section 8.3.2.2, under the WQMF, water/sediment quality guideline values (GVs) are identified for each management goal. The most stringent of these GVs is then chosen as the draft or final W/SQO.

The water and sediment *management goals* and *indicators* are set out in Table 8-5. The same indicator appears against several management outcomes but with different GVs (e.g. a higher GV value for drinking water than for ecosystem protection for a given indicator). In most cases the ecosystem protection GVs are more stringent than GVs for other management objectives. The GVs for ecosystem protection are therefore proposed as the final W/SQO for application off the RPA and as draft W/SQO for on the RPA. This is indicated in Table 8-5 by underlined italicised type with the final provided in a separate column for ease of interpretation. This reflects progress against steps one to five in the WQMF.

Steps six to ten in the WQMF provide a framework for assessing if draft W/SQO can be met, gathering more information, revising the draft W/SQO if appropriate, and eventual agreeing on a final W/SQO for each indicator to adopt as closure criteria. This process is important to derive and agree on final W/SQO for waterbodies on the RPA where impacts are to be ALARA. As this final process has yet to be agreed with stakeholders, including Traditional Owners, these remain in a separate table, Table 8-6.

8.3.2.2 Objectives and management goals

There are three objectives derived from the ERs that relate to the water and sediment theme (Table 8-3). These are discussed below and captured in Table 8-5 and Table 8-6. Stakeholder discussions may identify additional goals. Some work has progressed on identifying community values for different water types on and off the RPA. This and other information will be discussed further with stakeholders.

Environmental Requirement 3.1 is central to the first three management objectives:

> *The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.*

This ER directs ERA to ensure that the primary environmental objectives must apply off the RPA to the period following rehabilitation for any surface or ground waters discharged from the RPA. The various primary environmental objectives are then separated into the separate objectives for this closure criteria theme.

Water and sediment objective 1:

The first objective groups ER 1.1(c) and 1.2(c) as both relate to human health:

> *The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:*
>
> *1.1(c) Protect the health of Aboriginals and other members of the regional community*
>
> *The company must ensure that operations at Ranger do not result in:*
>
> *1.2(c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.*

Two pathways were identified for the assessment of the potential risk to human health from chemical pollutants in water (radiation is addressed separately in the radiation theme). Each pathway is the basis of the management goal.

- **Pathway 1**: through ingestion of water and bush food that has bio-accumulated mine derived analytes. The management goal is that diet consumption limits are not exceeded as a result of mine derived contamination.
- **Pathway 2**: through recreational activities. The management goal is that recreational water resources remain safe for their designated use.

Water and sediment objective 2:

The second objective is derived from ER 1.1 (d), ER 1.2(d) and 11.3(ii) and relates to protection of the Alligator Rivers Region, including protection of the environment from tailings contaminants for 10,000 years:

1.1 The company must ensure that operations at Ranger are undertaken is such a way as to …:

(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes

1.2 The company must ensure that operations at Ranger do not result in:

(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region.

11.3 Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:

ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.

Two management goals have been derived from this management objective:

First management goal – mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health off the RPA, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.

Second management goal – mine sourced solutes do not increase contaminants in sediments off the RPA to levels that would be detrimental to ecosystem health off the RPA.

These two outcomes cover the three pathways for contaminant transport for this theme, groundwater, surface water and sediments.

Water and sediment objective 3:

The third objective is from ER 1.2 (e) and ER 2.1. ER 1.2 (e) relates to protection inside the RPA, focusing on impacts to be as low as reasonably achievable

The company must ensure that operations at Ranger do not result in:

(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.

ER 2.1 relates to incorporating the rehabilitated site into Kakadu NP.

the company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.

The management goal for this objective is that impacts on the RPA (water and sediment quality) ALARA.

Table 8-5: Agreed guideline values for each management goal. The most stringent for each indicator (underlined and italicised) is the draft water/sediment quality objective proposed as closure criteria

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme [3]	Draft Water/Sediment Quality Objectives [4] (Closure Criteria)
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community. The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Drinking water: Mn, NO_3, NO_2, SO_4^{2-}, U.	Water quality off the RPA meets the national drinking water health guidelines (at those water bodies and times used by Traditional Owners for drinking). SO_4^{2-} 500 mg/L, Mn 500 µg/L, NO_3 50 mg/L, *<u>NO_2 3 mg/L</u>*, U 17 µg/L (NHMRC, 2011; v3.5 updated 2018).	$NO_2 \leq 3$ mg/L
		Mine derived hazards will not cause unacceptable visual amenity or water quality to exceed recreational guideline values for secondary contact at sites identified for recreational value.	Toxic or irritant chemicals: NO^3, NO_2, U, SO_4, Mn.	Water quality off the RPA meets the national recreational guidelines for secondary contact (at those water bodies and times used by Traditional Owners for drinking). NO_3 500 mg/L, NO_2 30 mg/L, U 170 µg/L, Mn 5 mg/L (i.e., drinking water COPC x 10: NHRMC, 2008). SO_4^{2-} 400 mg/L (ANZECC & ARMCANZ, 2000 irritants, no guidelines for irritants/toxicants in NHMRC, 2008).	-
			Visual clarity and surface films.	No mine related change causes turbidity to be statistically significantly increased over natural background values. Oil and petrochemicals not to be noticeable as a visible film on the water or be detectable by odour.	-
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that:	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Turbidity, ammonia, manganese, uranium, magnesium, (magnesium: calcium mass ratio), sulfate, copper & zinc.	SSB Rehabilitation Standards are met in Magela and Gulungul creeks off the RPA: *<u>Dissolved total ammonia nitrogen; 0.4 mg/L (pH and temperature dependant)</u>* *<u>Dissolved magnesium; 2.9 mg/L (72-hour moving average)</u>* *<u>Dissolved magnesium to calcium (Mg:Ca) mass ratio; no greater than 9:1</u>* *<u>Dissolved sulfate; 10 mg/L (seasonal average)</u>* *<u>Dissolved uranium; 2.8 µg/L (72 h moving average)</u>* *<u>Dissolved manganese; 75 µg/L (72 h moving average)</u>* *<u>Turbidity: no statistically significant increase over natural turbidity</u>* *<u>Dissolved copper; 0.5 µg/L (72 h moving average)</u>* *<u>Dissolved zinc; 1.5 µg/L (72 h moving average).</u>*	Dissolved total ammonia nitrogen ≤ 0.4 mg/L (pH and temperature dependant) Dissolved magnesium ≤ 2.9 mg/L (72-hour moving average) Dissolved magnesium to calcium (Mg:Ca) mass ratio no greater than 9:1 Dissolved sulfate ≤ 10 mg/L (seasonal average) Dissolved uranium ≤ 2.8 µg/L (72 h moving average) Dissolved manganese ≤ 75 µg/L (72 h moving average) Dissolved copper ≤ 0.5 µg/L (72 h moving average) Dissolved zinc ≤ 1.5 µg/L (72 h moving average) Turbidity – no statistically significant increase over natural turbidity.

[3] Most stringent GV are taken as the draft W/SQO. These have been underlined.

[4] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.2.

ER	Objective	Management Goal	Indicator	Guideline Values for each management theme [3]	Draft Water/Sediment Quality Objectives [4] (Closure Criteria)
	ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine sourced solutes do not increase U in sediments off the RPA to levels that would be detrimental to ecosystem health.	Uranium in sediments.	*Uranium in sediments does not exceed 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method)*	Uranium in sediments ≤ 100 mg/kg dry weight (whole sediment; weak acid extractable digestion method).

Table 8-6: Draft water and sediment quality objectives under review

ER	Objective	Management Goal	Indicator	Water/Sediment Quality Objectives under review
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary intake of bush food and water to exceed human consumption limits.	Diet parameters TBC with expert opinion	Local diet model demonstrates that ingestion of mine derived constituents of potential concern (COPC) via aquatic and terrestrial bush foods and drinking water does not cause annual intakes to exceed any relevant national/international tolerable intake levels.
3.1, 1.2(e) and 2.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation. The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu NP such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu NP.	Surface water and sediment quality on the RPA is demonstrated to be as low as reasonably achievable.	As for off the RPA listed above.	The predicted water quality for the closure scenario demonstrated (and accepted by stakeholders) to be ALARA following the WQMF and the process outlined in Section 6.
3.1 and 1.2(d) 11.3 (ii)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger Mine do not result in: Change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region. Final disposal of tailings must be undertaken, to the satisfaction of the Minister with the advice of the Supervising Scientist on the basis of best available modelling, in such a way as to ensure that: ii. any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years.	Mine derived analytes from surface or ground waters discharged to surface waters off the RPA do not cause detrimental impact to the ecosystem health, and that there will be no detrimental environmental impact off the RPA from tailings contaminants for at least 10,000 years.	Nutrients	Nutrient criteria for preventing eutrophication are still under review.

8.3.2.3 Justification for outcome, parameter and criteria

ERA is following the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) WQMF to provide a process for stakeholders to develop agreed water quality objectives that apply both on and off the RPA.

The WQMF provides a sequential stepwise approach (Figure 8-4) to setting management goals through to assessing, refining and deriving W/SQO. Steps 1 to 5 are relevant to developing closure criteria for both on and off the RPA. Steps 6 onward are relevant for developing criteria for impacts that are ALARA, which only applies to waterbodies on the RPA.

It is important to note that Traditional Owners have reported concerns about trying to integrate cultural values with the 'scientific, legal and technical domains of a process that will take place within a framework controlled by those from the dominant non-Indigenous culture' (Garde 2015). The application of this framework has been, and will continue to be, discussed with stakeholders, including the representatives of the Traditional Owners through working groups, consultative forums and site visits. This is particularly important for agreeing on management goals for waterbodies on the RPA at step 2 and reviewing the following steps to align with and meet the agreed values for these on-site waterbodies.

The following sections describe the ten-step framework, and a high-level description of information available, for developing a water management plan and assessing a remediation strategy (ANZG, 2018). Both are relevant to deriving closure criteria.

Step 1. Examine current understanding

To inform decisions at subsequent steps, develop conceptual models of how the waterway systems work, the issues they face and how to manage them.

The understanding of how the Magela Creek system works and mine related issues is well advanced after almost 40 years of research and monitoring related to the Ranger Mine and surrounds (refer to studies listed in the SSB bibliography[5] and throughout this document).

Several key assessments and conceptual models relevant to the closure phase for water and sediment inform this step. For example:

- Revised Key Knowledge Needs (KKN) for closure (Supervising Scientist 2017) have been based on source, pathway, receptor models and environmental risk assessments of the Ranger Mine (Pollino *et al*. 2013, Pollino 2014, Bartolo *et al.* 2013). The knowledge base is updated as progress against the KKNs is reported (Section 5).
- An assessment of important ecological processes in the Alligator Rivers Region, to inform an ecological risk assessment (Bartolo *et al*. 2018).

[5] https://www.environment.gov.au/science/supervising-scientist/publications#bibliography

- Peer reviewed groundwater and surface water assessments and models (e.g. ERM 2020a, INTERA 2019, 2020 & 2021a, Water Solutions 2018 & 2021).
- Linkages between ground and surface water (INTERA 2021b) and between hydrological processes and ecosystem dynamics (BMT 2018).
- A site wide Acid Sulfate Soil (ASS) source, pathway, receptor conceptual model (ERM 2020b) and characterisation of ASS on the RPA and in receiving downstream waterbodies (ERA 2021a).
- Assessments of soil and sediment contamination (ERA 2021b, ERM 2020c).
- Discussions of Indigenous world views on the environment, including water (Garde 2015).
- The water pathways risk assessment conducted in early to mid-2021 (report in preparation; refer to Section 5).
- A review by SSB (currently underway) of emerging contaminants.

Step 2. Define community values and management goal

Define community values and establish or refine more-specific management goals (including level of protection) for the relevant waterways at stakeholder involvement workshops.

Environmental requirements specific to the protection of water quality and decommissioning strategies specify:

- waters leaving the RPA do not compromise the achievement of the primary environmental objectives (ER 3.1) related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds (ER 1 and 2);
- impacts on the RPA are ALARA (ER 1.2e);
- all aspects of the Ranger ERs and those environmental matters not covered by the ERs must use Best Practicable Technology (BPT) (ER 12); and
- the RPA must be rehabilitated to a state to allow incorporation into Kakadu NP (ER 2.1).

These ERs provide high-level management goals for rehabilitation of the mine site. Water quality guideline values have been set for some of these goals (Table 8-5).

Additional management goals for water and sediment have been identified that need to be considered by stakeholders. For example:

- The Traditional Owners and the SSB have indicated that a goal of no change to biodiversity on the RPA is preferred.
- Garde (2015) describes the community's cultural expectations and expected uses of the rehabilitated mine. Hunting, cultural and recreational use of water is included.

- Garde (2015) states the waters contained within all riparian corridors (i.e. rivers and billabongs), must be of a quality that is commensurate with non-affected riverine systems and health standards. The ALARA principle should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and level of contamination must be as low as technically possible.
- The NLC and GAC reiterated this and provided additional (draft) information on their position on ALARA for onsite water bodies (Chris Brady, personal communication, 8 April 2020).

  In the response to the 2019 Mine Closure Plan draft, the Traditional Owner representatives emphasise the importance of waterways on the RPA to Traditional Owners. These areas were previously, and should again be, a focus of activity for Traditional Owners. The main focus of activity is likely to be focussed on Georgetown and Coonjimba Billabongs and the Magela Creek channel.

  The ALARA principle therefore should not apply to these areas. Instead, the standard of rehabilitation must be as high as is technically possible and the level of contamination must be as low as technically possible.

  In recognition of this, the BPT process established by ERA for determining water quality of these key waterbodies is adjusted such that cost is not considered, whilst the weighting of cultural value is doubled.

  Additionally, to ensure that the aim is for these key waterways to be utilised by Traditional Owners, for example as seasonal camping area where people fish and come into contact with the water, the water quality at an absolute minimum, will not exceed the Australian recreation water quality guidelines as a result of mine related activities.

  In other water bodies (e.g. sumps, minor drainage lines) Traditional Owners expect that management during the monitoring and maintenance period pending final rehabilitation will be such that they do not pose a credible risk to people or wildlife.

ALARA is discussed in *Section 6 Best Practicable Technology* and Appendix 6.3.

A stakeholder workshop identified the water types on and surrounding the RPA and the environmental values for each water type based on the environmental requirements and stakeholder expectations (BMT WBM, 2017).

During 2021 and 2022 Traditional Owner's visited water bodies on the RPA as part of the cultural reconnection program. Information exchanged at these visits is important for refining the management goals for the waterbodies on the RPA.

The current natural World Heritage Values that occur on the RPA have been recently documented (Everett *et al.* 2021). Plans are in progress to update this work to include cultural values. Aspects of this for water bodies on and off the RPA have commenced (Garde 2015, BMT WBM 2017).

Step 3. Define relevant indicators

Select indicators for relevant pressures identified for the system, the associated stressors and the anticipated ecosystem receptors.

Indicators have been identified for the operational phase of the mine through many years of research, monitoring and application of the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) water quality guidelines. (e.g. Brown *et al.* 1985, Turner & Jones 2010, Frostick *et al*. 2012).

Iles and Humphrey (2014) reviewed the literature on release standards for constituents of potential concern (COPC) present in ore, process water and waste rock sources, and identified those needing a hazard assessment and/or requiring closure criteria.

Other work relevant to selecting indicators for closure water quality management are:

- The development of endpoints and indicators for the protection of biodiversity (Supervising Scientist 2002) and that they reflect the environmental values of water bodies both on and off the RPA. These include indicators for health and cultural uses and the Ramsar and Kakadu NP World Heritage values (BMT 2018, BMT 2019).
- The review of conceptual model endpoints and important ecological processes (Bartolo et al. 2018).
- The definition of key ecological components underpinning the environmental requirements of the RPA and surrounds and the interactions with underpinning processes (BMT 2018).
- The development, in consultation with Traditional Owners, of indicators for cultural closure criteria, including some for water (Section 8.3.6). Specific indicators for remediation goals for wet landscapes on the RPA will need to be identified with Traditional Owners.
- The identification of uranium as the COPC in reports on accumulation of metals in contaminated sediments on the mine site. Other metals showed limited enrichment even in the sediments of the waste water treatment wetlands (Iles et al. 2010, Parry 2016, Esslemont & Iles 2017, ERA 2021b).
- The selection of indicators for drinking water and recreation from NHMRC and NRMMC (2011; v3.5 updated 2018) and NHMRC (2008) based on the surface water COPCs identified by Frostick and others (2012).
- Expert advice will be sought on indicators relevant to a diet assessment. This will include an expert review of the indicators and GVs for drinking water.

A review of COPC for all sources on the Ranger Mine was conducted by ERM Ltd as part of the *Background concentrations of COPC in groundwater* project. No new COPCs have been added to the closure criteria list as a result of this review. COPCs will be reviewed again as a component of the contaminated sites sampling campaign. The list of indicators for W/SQO will be reviewed when outcomes from this project are available.

Radionuclides are discussed in Section 8.3.3.

Step 4. Determine water/sediment quality guideline values

Determine the water/sediment quality guideline values for each of the relevant indicators required to provide the desired level of protection (if applicable) for the management goals for relevant waterways.

Diet and recreation

Guideline values for drinking water are from the Australian drinking water guidelines NHMRC and NRMMC (2011; v3.5 updated 2018).

In addition to comparing predicted COPC concentrations to these guideline values, an assessment of risk from water quality to the traditional diet, including drinking water, will be undertaken. This assessment will be based on the water quality predictions from the surface water model. Radioactive contaminants are dealt with separately under the closure criteria for radiation (Section 8.3.3).

The Australian recreation guidelines (NHMRC 2008) provide recreation water quality guidelines for chemical hazards, pH and dissolved oxygen, and suggest using ten times the drinking water guidelines as a simple screening approach to identify COPC that may merit further consideration where waters might be swallowed during recreation. NHMRC (2008) also says *"… waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes…"* However the NHMRC (2008) guidelines do not provide a list of irritants or guideline values for such chemicals, whereas ANZECC and ARMCANZ (2000) do. The recreational GV for sulfate was therefore taken from ANZECC and ARMCANZ (2000). The same parameters identified for drinking water are used as suggested above. It is noted that the recreational guideline values for sulfate is more restrictive than using the drinking water times ten approach.

The lower range in Magela Creek is less than the pH guideline suggested for poorly buffered low ionic strength waters by NHMRC (2008). Turner and others (2015) demonstrated that the natural range of pH in Magela Creek is 4.7 to 7.9, and highly variable, and considered it *"highly unlikely that a quantity of mine derived water sufficient to significantly alter the pH in Magela and Gulungul creeks could be released"* and removed pH from the list of compliance parameters. Considering this, pH is not considered a parameter that requires a GV for recreation purposes. Should future acid sulfate soils studies indicate a potential risk, consideration will be given to the inclusion of a GV for pH.

Dissolved oxygen is also highly variable in the seasonal waterbodies on and off the RPA and there has been no requirement for compliance monitoring of dissolved oxygen for several decades at Ranger Mine. Dissolved oxygen is also not considered a parameter that requires a GV for recreation purposes.

Ecosystem protection

GVs for high-level ecosystem protection have been derived by the SSB and reported in their Rehabilitation Standard Series[6]. These are identified as being applicable at the lease boundary in Magela and Gulungul creeks. Meeting these GVs at the lease boundary provides an assurance that no change will occur to the offsite biodiversity. The scientific basis for the SSB water quality rehabilitation standards for ammonia, manganese, uranium, magnesium, (magnesium:calcium ratio), sulfate, copper, zinc, turbidity and sedimentation is described in each standard. The GV for uranium in surface water was found to protect against sediment toxicity effects considering the potential for accumulation and de-adsorption from sediment back to surface waters at unacceptable concentrations. This could negate the need for a uranium GV for sediment (SSB 2019). However, ERA has adopted the SSB site-specific guideline values for uranium in both water and sediment as closure criteria.

GVs based on ecotoxicity studies of the SSB are available for species protection levels of 99 %, 95 %, 90 % and 85 %. Guideline values for 99 % species protection are used as the SSB rehabilitation standard for application off the RPA. These are adopted as closure criteria for protecting the ecosystem off the RPA. The closure objective for water quality on the RPA (Table 8-7), reflecting ER 1.2e is *Impacts on the RPA are ALARA (derived following the WQMF and the ALARA process outlined in Section 6, with input from stakeholders).* The following steps of the WQMF are important for deriving the ALARA criteria.

Step 5. Define draft water/sediment quality objectives

Use the guideline values or narrative statements chosen for each selected indicator as draft water/sediment quality objectives to ensure the protection of all identified community values and their management goals (ANZG 2018).

Choose the most stringent of the guideline values for the water/sediment quality objectives (ANZG 2018).

For water, the same indicator appears against several management objectives in Table 8-5. The ecosystem protection GV are more stringent than GVs for the same parameter for other management objectives. The most stringent of the GVs for each indicator is italicised and underlined.

This step of the WQMF would select the most restrictive of the GVs to be proposed as draft water or sediment quality objectives and in the later steps of the WQMF these can be reviewed if not achievable. This is a relevant process for deriving closure criteria that are ALARA for on the RPA. However, for closure criteria off the RPA the most stringent GV is proposed (identified in Table 8-6 in the column draft water/sediment quality objective). It is still relevant to retain less stringent GVs against the relevant management options to support an assessment of each goal.

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

ANZG (2018) supports narrative statements (as opposed to numeric values) as GVs and W/SQO. For waterbodies on the RPA some narrative draft W/SQO are used (Table 8-5 and Table 8-6) to state both the objective and the process by which the numeric criteria for ALARA impacts are being derived.

Step 6. Assess whether draft water/sediment quality objectives are met

Use measurements from the monitoring of each relevant indicator to assess whether current water/sediment quality meets the draft water/sediment quality objectives (ANZG 2018).

ERA has engaged consultants to use numerical models to predict the concentration and loads of a range of contaminants in surface water on, and downstream of, the Ranger Mine after mine closure (Section 5.2). The predicted concentrations of these COPCs were compared to GVs for each theme in the *Water pathways risk assessment project* (see Section 5).

Predicted concentrations of several COPCs (Water Solutions, 2021) are higher that the ecosystem and/or human health GVs at some locations on and off the RPA. The models are being reviewed and mitigation actions have been identified to reduce the concentration of contaminants reporting to the water bodies on and off the RPA (see Section 5).

If concentrations exceed the GVs, this does not necessarily imply that impacts will occur. Rather, further assessment is required to understand the implications of exceeding the GVs. This type of tiered assessment is common to many guideline frameworks (e.g. EnHealth 2012, NHMRC 2008, NHMRC & NRMMC 2011) and is also recommended in the following steps of the WQMF.

The sediment monitoring program (ERA, 2021b) showed that, of the waterbodies sampled, GVs for all metals were met except for three samples in a section of Retention Pond 1 where the GV for uranium was exceeded.

Step 7. Consider additional indicators or refine the water/sediment quality objectives

Assess the need to revise or add to the lines of evidence or indicators and the water/sediment quality guideline values (ANZG 2018).

Guideline values for different levels of species protection are available for most COPC from the ecotoxicity studies of the SSB or from ANZG (2018). Additional indicators and lines of evidence are being reviewed or are already available.

BMT Ltd has been working with ERA and stakeholders since 2017 in a three-phase project to:

- Identify preliminary ecological and cultural endpoints for each of the primary environmental objectives (BMT WBM, 2017).
- Map environmental values for different water types on and off the RPA (BMT, 2018).

- To develop a risk-based vulnerability assessment framework considering impact components such as duration, geographic extent and resilience, to determine how different concentrations of magnesium—potentially the most restrictive contaminant of concern—might affect these endpoints. This involves considering direct sensitivity of multiple ecosystem component indicators to magnesium concentrations and indirect sensitivity via other factors affecting vulnerability, such as habitat, diet, reproduction and dispersion (BMT, 2019) (Section 5 provides a description of the project).

A review of local nutrient data and a risk assessment of eutrophication is being conducted by ERA and SSB to address KKN WS6.

The sensitivity of the following ecosystem components to mine impacted water has been assessed: riparian species, migrating fish, macroinvertebrates at different stages of creek flow, and stygofauna in the sandy creek beds (Hutley *et al.* 2021, Crook *et al.* 2021, Mooney *et al.* 2020, Chandler *et al.* 2021).

Step 8. Consider alternative management strategies

Evaluate the effectiveness of current management strategies to address the identified water quality issues and recommend possible improvements. Improved or alternative management strategies are to be formulated, assessed and prioritised.

The recent *Water pathways risk assessment* project identified risks to the aquatic ecosystem and people related to contaminant levels from the current mine closure strategy. Actions have been identified to assess options to manage the contaminant sources creating these risks.

Consideration of alternative management options, considering community, environmental and cost aspects are common to both ALARA and BPT assessments used at ERA.

The BPT assessment (Section 6) process compares different management options and ranks them against each other based on scores for each of the BPT criteria. This includes criteria categories for water quality and environment protection. All scores are combined to form a single value, and the different options are ranked. The option with the best score is typically deemed the best practicable technology.

ERA has identified a process that iteratively combines management/mitigation options assessments with a risk management framework to identify a closure strategy based on BPT and demonstrates impacts that are ALARA (Figure 8-5 (bottom)). This is a process that is followed as part of the combined ERA BPT process and risk management framework.

ERA proposes that the analyte concentration associated with the option that is considered BPT-ALARA is the water quality proposed ALARA criteria for on the RPA. This aligns with the ALARA approach for radiation protection described by Oudiz and others (1986), shown in the top process chart in Figure 8-5.

Step 9. Assess whether water/sediment quality objectives are achievable

Use information gained from Steps 6 to 8 to assess whether the water/sediment quality objectives are achievable.

As discussed, at step 6 predicted water quality post-closure will be compared with the agreed objectives for ecosystem protection onsite and offsite. This was done in the *Water pathways risk assessment* project and management/mitigation actions identified where GV exceedances resulted in high or critical risks (Section 5). The risk assessment will be conducted again as updated information on predicted water quality for different management options becomes available. As shown in Figure 8-5 this is an iterative process.

Step 10. Implement agreed management strategies

Document and implement agreed management strategies, including, in some cases, a suitable and agreed adaptive management framework.

The results of the iterative management options assessments and proposed management strategies will be discussed with stakeholders through consultative fora. Proposed management strategies will be documented in applications to stakeholders and regulators for approval for key activities. Monitoring and adaptive management frameworks will be developed with input from stakeholders. This is a topic being advanced with guidance from the Alligator Rivers Region Technical Committee. Applications will include descriptions of mitigations and management actions and the results of BPT and risk assessments to demonstrate the proposed strategy and resulting water quality results in impacts that are ALARA.

Stakeholder feedback will occur again at this stage. Future MCPs will be updated with a record of progress.

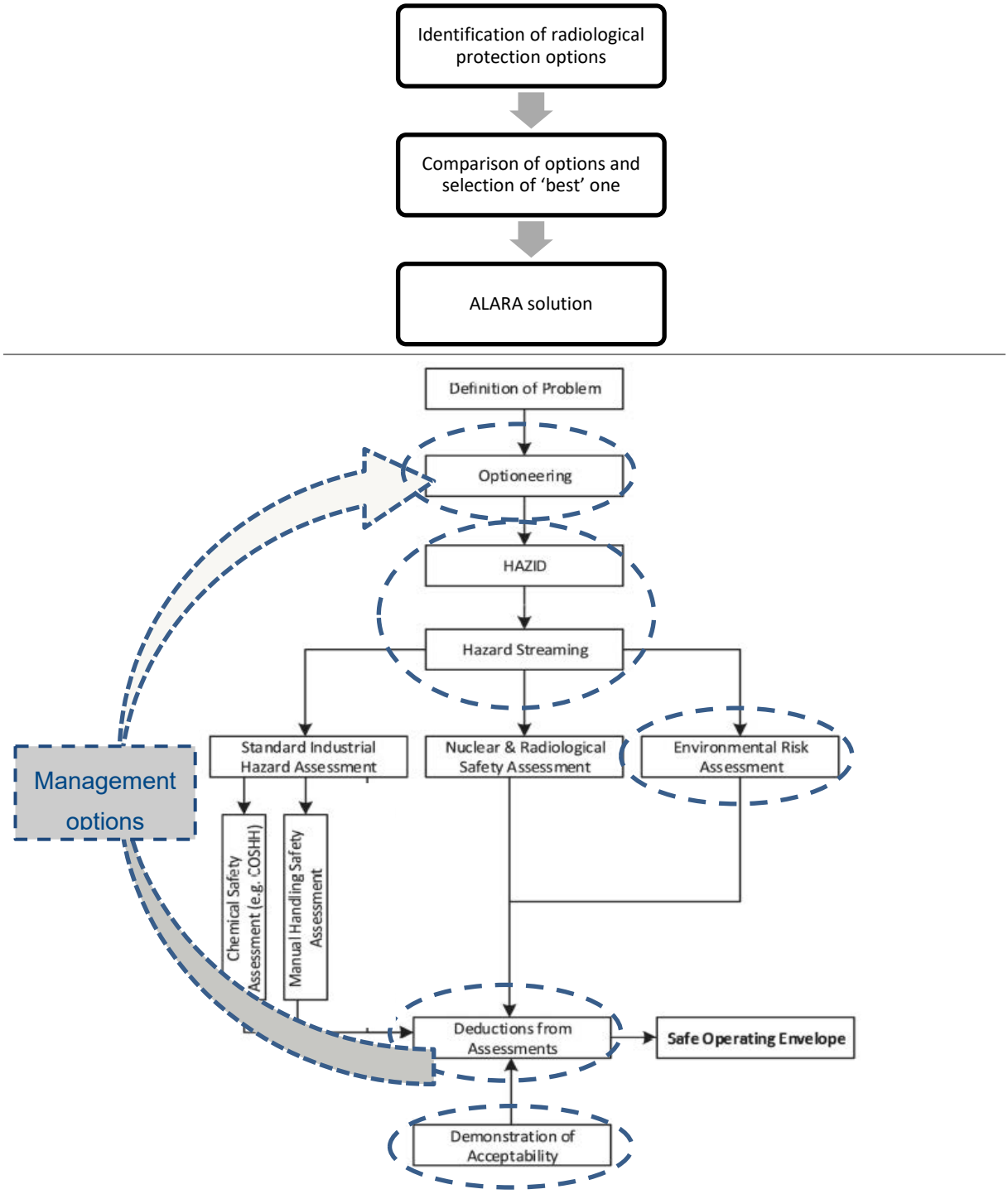

Figure 8-5: (Top) The main features of the ALARA procedure (Oudiz *et al*. 1986) and (Bottom) Framework for the integration of risks from multiple hazards into a holistic ALARA demonstration (from Bryant *et al.* 2017). Aspects related to the surface water risk assessment are circled.

8.3.3 Radiation

2022 Status Update
All radiation criteria have now been finalised, receiving ministerial approval on 30 September 2021.

There are two objectives derived from the ERs relating to the radiation theme (Table 8-3).

Radiation objective 1:

The first objective comes from ER 2.2 (b) and 11.3 (iii):

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

Radiation objective 2:

The second objective comes from ER 1.2 (d and e):

In particular, the company must ensure that operations at Ranger Project Area do not result in:

> *(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and*
>
> *(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.*

Two outcomes have been derived from these objectives (Table 8-7), one related to the terrestrial environment and one for the aquatic. This division is based on the guidance for assessment provided within the ICRP document. Both outcomes are based on the potential risk to the environment (plants and animals) from above background radiation exposures sourced from the mine. The outcomes have been derived from the guidance provided by the ICRP in its publication 124 *Protection of the Environment under Different Exposure Situations* (ICRP 2014). This document describes the framework for protection of the environment and how it should be applied within the ICRP system of protection.

The ICRP states that the aims in terms of environmental protection are to prevent or reduce the frequency of deleterious radiation effects on biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities and ecosystems. The biological endpoints of most relevance are therefore those that could lead to changes in population size or structure.

Table 8-7 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcomes and the proposed closure criteria. In some cases, corrective action is also provided in the event that the expected outcome is not accomplished. Some criteria also have linkages to cultural criteria. Where this occurs, reference has been made to the cultural criteria section for more details. These criteria are all consistent with the SSB Rehabilitation Standards on radiation (SSB, 2018a; SSB, 2018b)

Reflecting the guidance of the International Atomic Energy Agency (IAEA) (2006) and the ICRP (2014), radiation closure criteria are provided as radiation dose rates. To confirm that the radiation closure criteria proposed in Table 8-7 will be met in the post-closure phase, ERA commissioned a radiological impact assessment to be undertaken, which commenced in the third quarter of 2017. The radiological impact assessment considers potential radiation exposure to members of the public, as well as terrestrial and aquatic biota. The finalisation of this radiation assessment is dependent upon the outputs of the surface water model that is undergoing review and refinement based on the feedback received from the Pit 3 application. The outcomes of the radiation assessment are expected to be available for the 2023 MCP.

Section 8.3.3.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of the radiation theme: radiation doses to members of the public and radiation doses to terrestrial and aquatic biota.

Table 8-7: Closure criteria – radiation

ER	Objective	Outcome	Parameter	Summary of criteria[7]
2.2 (b) and 11.3 (iii)	Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including Traditional Owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area.	Radiation dose constraints to members of the public are ALARA.	Using the agreed restrictions on land use the total above-baseline radiation dose from pathways: External gamma Inhalation of Radon decay products (RDP) Inhalation of dust Ingestion of bush food (including water).	0.3 mSv/a.
		Radiation dose constraints to members of the public are below limits.	Should land use restrictions fail, the total above-baseline radiation dose from pathways: External gamma Inhalation of RDP Inhalation of dust Ingestion of bush food (including water).	1 mSv/a.
1.2 (d,e)	In particular, the company must ensure that operations at the Ranger do not result in: (d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region; and (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	Minimise the deleterious radiation effects on terrestrial biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.	Total above-baseline absorbed dose rates to the most highly exposed terrestrial plants and animals.	100 µGy/h to the most highly exposed terrestrial species.
		Minimise the deleterious radiation effects on aquatic biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.	Total above-baseline absorbed dose rates to the most highly exposed aquatic plants and animals.	400 µGy/h to the most highly exposed aquatic species.

[7] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.3.

8.3.3.1 Justification for outcome, parameter and criteria

Radiation doses to members of the public

Two outcomes have been derived from this objective, the first relates to the requirement to have radiation doses to members of the public remain below limits, and the second to also keep these doses as low as reasonably achievable.

The premier international body for radiation protection is the ICRP. The limits for exposure to radiation and recommendations of the ICRP have been generally adopted worldwide.

The primary aim of the ICRP is to contribute to an appropriate level of protection for people and the environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions that may be associated with such exposure.

The ICRP has recommended a three-tier approach to radiation protection, called *the Fundamental Principles of Radiation Protection*:

- **The principle of justification:** Any decision that alters the radiation exposure situation should do more good than harm.
- **The principle of optimisation of protection:** The likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors (the ALARA principle).
- **The principle of application of dose limits:** The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the ICRP.

The recommendations of the ICRP are taken by the IAEA to develop radiation safety standards and guidelines that are then used internationally to protect human health and the environment.

The recommendations of the ICRP have no regulatory power in Australia; but are adopted in a joint Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and National Occupational Health and Safety Commission (NOHSC) document. Likewise, the various standards and guidelines published by the IAEA are adopted in Australia through various codes of practice and safety guides published by ARPANSA. The recommendations are also applied to the mining industry through the Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing. This Code is applied to the Ranger Mine operation by Commonwealth and Northern Territory legislation and implemented at site through the Ranger Authorisation.

In the international standards, human activities that add radiation exposure to that which people normally incur due to background radiation, or that increases the likelihood of their incurring exposure, are termed ‘practices'. For uranium mining and processing, the various stages of the practice are: design; construction; operation; decommissioning; and release of regulatory control.

The radiation protection principles of justification, dose limitation and optimisation apply to all these stages of the practice.

ERA has adopted a radiation protection policy and developed a Radiation Management System, based on the justification, optimisation and limitation principles established by the ICRP. The policy and system will be applied to the decommissioning phase through the Radiation Management Plan. During the post-closure phase, the principles will be applied through the development and demonstration of compliance with closure criteria. The closure criteria presented in Table 8-7 have been set so that radiation exposures to the public, and risk to the environment, post-closure are ALARA.

The IAEA guidance document *Release of Sites from Regulatory Control on Termination of Practices* (IAEA, 2006) sets an upper level structure for the development of radiation closure criteria. The release of sites from regulatory control is the final stage in the decommission process and is also the final stage of the practice; therefore, the radiation protection principles of justification, dose limitation and optimisation apply.

The principle of justification is applied at the adoption of the practice of uranium mining as a whole, which includes construction, operation, decommissioning and final close-out of the project. Therefore, it can be assumed that the decommissioning and closure phases of the practice are justified.

The normal dose limitation for the uranium mining practice will apply, which is set out in the ARPANSA National Directory for Radiation Protection (ARPANSA, 2017). For members of the public this will be 1 mSv/a, determined from the sum of effective doses from all possible combinations of exposures.

The optimisation process for decommissioning and release from regulatory control starts with the setting of a dose constraint. The IAEA recommend that the dose constraint should take into account multiple pathways of exposure and should not exceed 300 µSv/a above background; however, each dose constraint should be site specific. When setting a public dose constraint, consideration must be given to the potential for other exposure pathways in the region. Given the Koongarra lease has been relinquished, the only remaining uranium mining lease in close proximity is Jabiluka. Based on the limited exposure pathways in the region, a dose constraint of 0.5 mSv (500 µSv/a) would be in keeping with the principles for setting dose constraints. However, ERA has elected to keep the recommended 300 µSv/a from the IAEA.

The IAEA system recommends that the final dose to members of the public is to be optimised below the dose constraint. If this is not achievable without any restrictions on the use of the land, then these may be applied with the additional requirement that the dose to members of the public should not exceed the dose limit of one milli-Sievert per year in case the restrictions fail. This process is illustrated in Figure 8-6 and forms the basis for setting the radiation criteria for protection of human health outlined previously in Table 8-7.

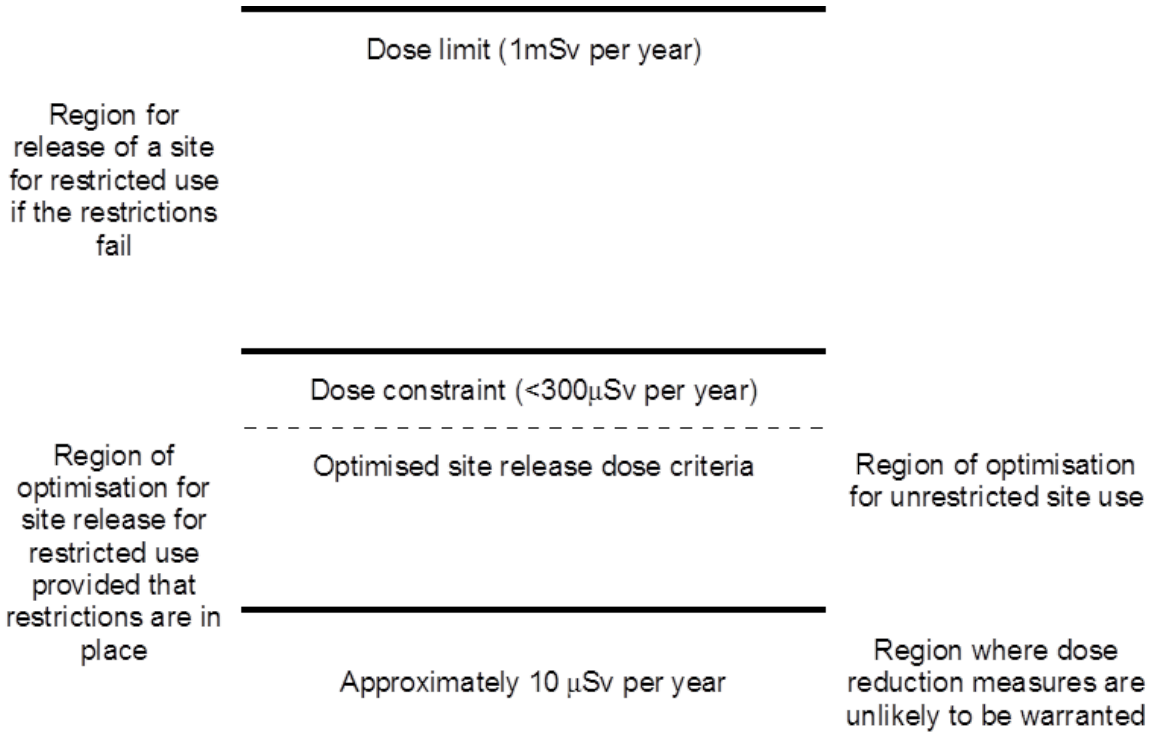

Figure 8-6: Constrained optimisation and regions of effective dose for members of the critical group in the release of sites (IAEA, 2006)

To assess if the radiation criteria for human health have been achieved, the following process will be undertaken:

- documentation of baseline radiological conditions for the site;
- identification of the representative person;
- definition of the probable habitation scenarios and identification of the exposure pathways;
- compilation of data for these scenarios and pathways, including definition of all sources; and
- development of radiation dose model for rehabilitated site.

The four main exposure pathways for human exposure to radiation will be direct external radiation, inhalation of dusts, inhalation of radon and its decay products, and ingestion of food stuffs (including ancillary ingestion of soil and drinking of water). Member of the public dose assessment will therefore consider the following exposure pathways:

- inhalation of long-lived alpha activity (e.g. radioactive dust);
- inhalation of radon decay products;
- ingestion of radioactive material in (or with) food or water;
- external irradiation from gamma radiation.

Given the anticipated post-closure use of the landform, the representative person will be an Aboriginal person using the site for traditional activities including transient camping and the gathering of traditional bush foods for consumption. Details of the land use, occupancy and diet was discussed in Section 8.1.

To assist with estimating the dose, and subtraction of natural background, several radiological studies have been undertaken on the RPA, these include:

- pre-mining, area-wide radiological conditions, as a first step to assessing post-mining changes and the success of rehabilitation from a radiological perspective (e.g. Bollhöfer *et al.* 2014, Bollhöfer *et al.* 2011, Esparon *et al.* 2009); and
- above background radiation doses through different pathways, to the public that may access the RPA post-closure (e.g. Akber & Lu 2012, Akber *et al.* 2011a, b & c, Akber & Marten 1991, Lu *et al.* 2009). These studies have primarily focused on potential post-closure occupation in the LAAs on the RPA.

A summary of the pre-mining background levels is provided in *Section 5 KKN Supporting Studies*.

Radiation effects on biota

Two outcomes have been derived from the objectives in relation to radiation effects on biota (Table 8-7), with both based on the potential risk to the environment (plants and animals) from above background radiation exposures sourced from the mine. The outcomes have been derived from the guidance provided by the ICRP in its publication 124: *Protection of the Environment under Different Exposure Situations* (ICRP, 2014). This document describes the framework for protection of the environment and how it should be applied within the ICRP system of protection.

As noted in objective 2, the ICRP states that the aims in terms of environmental protection are to prevent or reduce the frequency of deleterious radiation effects on biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities and ecosystems.

The risk assessment and management of radionuclides entering or present in the environment has historically been based on human health considerations alone. This approach has been underpinned by the ICRP (1991) recommendations that state: *"… if man is protected then it can be assumed that the environment is protected."*

More recently there has been increasing awareness of the potential vulnerability of the environment and of the need to be able to demonstrate that it is protected against the effects of industrial pollutants, including radionuclides. The ICRP, in its publications (ICRP 2007, 2008 & 2014), has addressed this by recommending that assessments be undertaken of the risk from radiation to animals and plants.

Recommendations for assessment of radiation risk to the environment have been published by multiple international organisations, including the ICRP, IAEA and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). These detail frameworks for assessment of risk through the comparison to a benchmark dose rate value that is considered to provide an acceptable level of protection to the environment (i.e. prevention of deleterious impacts to wildlife populations and ecosystem biodiversity). Studies conducted by ERISS have reviewed the international literature relating to benchmark dose rates and determined that the values published by UNSCEAR were considered to be the most appropriate to apply to the Ranger closure criteria (Doering & Bollhöfer, 2016).

In order to assess if the radiation criteria for radiation effects on biota have been achieved, the framework documented in ICRP (2014) or similar international guidance will be used to:

- determine the radiation dose rate to a reference set of both terrestrial and aquatic biota; and
- compare this to the benchmarks documented as the closure criteria.

The benchmark dose rates documented as closure criteria are based on the recommendations of UNSCEAR (2008) and recommended for use under the SSB rehabilitation standard for the Ranger uranium mine - Environmental Radiation (SSB, 2018a). If the dose rates are below the benchmark dose rate, it can be concluded that there is an acceptable level of protection to the environment (i.e. that deleterious impacts to wildlife populations and ecosystem biodiversity will be prevented).

If dose rates are above the benchmark dose rate, a more detailed review of the doses to that organism will be undertaken along with a review of the actual radiation effects for that organism. An assessment will be made to determine if actual effects will occur and therefore if mitigations are required.

8.3.4 Soils

2022 Status Update
All soil criteria have now been finalised, receiving ministerial approval on 30 September 2021.

There is one objective derived from the ERs relating to the soils theme (Table 8-3), which is one of the primary environmental protection objectives, ER 1.2 (e).

> *1.2 In particular, the company must ensure that operations at Ranger do not result in:*
>
> *(e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.*

The outcome derived from this objective is that impacted soils are remediated to as low as reasonably achievable to protect the environment.

Table 8-8 provides a summary of the closure objectives, the outcome, parameters used to measure the outcome, and a summary of the proposed closure criteria. Section 8.3.4.1 provides justification of the outcomes, parameters and closure criteria that were derived.

8.3.4.1 Justification for outcome, parameter and criteria

The objective and outcome for closure is that, where needed, soils will be remediated to a level where the environmental impact is ALARA. This is adopted in relevant BPT assessments where the preferred option (I.e. the highest ranking option against specified criteria) will be progressed. Outcomes of contaminated sites assessments will be included in future versions of the MCP.

Achievement of the outcome will either be through demonstration that contamination levels are currently, or remediated to be, low enough that no action is required or through development of a site management plan based on ALARA.

Table 8-8: Closure criteria – soils

ER	Objective	Outcome	Parameter	Summary of criteria [8]
1.2 (e)	The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	Impacted soils are remediated to as low as reasonably achievable to protect the environment.	Contaminated soil assessment for uranium and manganese in LAA.	Demonstrate risk is ALARA.
			Contaminated assessment of identified COPCs for other soils identified as not being part of the larger decommissioning works.	Demonstrate risk is ALARA.

[8] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.4.

8.3.5 Ecosystem

2022 Status Update
Ecosystem criteria have been developed for both revegetation and fauna which have changed in structure and detail since receiving Minister approval.

There is one objective derived from the ERs relating to the ecosystem theme (previously termed flora and fauna). This is one of the primary rehabilitation objectives, ER 2.2 (a):

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

There are two aspects to this objective. The first, referred to as the 'ecosystem similarity', requires the flora and fauna species composition and community structure of revegetated areas within the RPA to be similar to Kakadu NP. The second, referred to as 'ecosystem sustainability', requires rehabilitated areas to contain functioning ecosystems that are long-term viable and require a maintenance regime similar to those in adjacent areas of Kakadu NP.

The qualitative criteria relating to this objective cover these two aspects of ER 2.2 (a) and were finalised with SSB, NLC and ERA input in August 2022. These criteria are provided in Table 8-9. The table provides a summary of the attribute, sub-attribute, goal and indicator (or criteria) that will be used to measure the outcome. These criteria include both ecosystem similarity as well as ecosystem sustainability elements.

Table 8-9: Closure criteria – Ecosystems

Attribute	Sub-attribute	Goal	Indicator
Ecosystem Similarity			
Species composition and relative abundance	Species composition of vegetation	The assemblages of overstorey species and understorey functional species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of species in overstorey assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
			Functional composition of understorey species refers to the following lifeforms: Legumes: Minimum number of legume species and variety of lifeforms. Perennial grasses: Minimum number of perennial grass species, including specified species. Annual grasses: Minimum number of annual grass species. Forbs: Minimum number of forb species from a minimum number of families. Climbers and vines: Minimum number of climber and vine species used as a food source. Non-legume woody species (shrubs): Minimum number of non-legume woody species and specified species (including woody ground cover species).
	Species richness of vegetation	Species richness of overstorey and understorey are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species abundance of vegetation	Abundance of overstorey and understorey species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total abundance of (i) overstorey species, and (ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Community structure	Structure	Vegetation structure similar to, or on a trajectory towards that of the reference ecosystem(s).	Size class distribution of overstorey is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

Attribute	Sub-attribute	Goal	Indicator
	Vegetation strata	Overstorey and midstorey cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The distribution of percentage canopy cover is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
		Understorey vegetation cover is similar to, or on a trajectory towards, that of the reference ecosystem(s).	Percentage cover of understorey vegetation is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of native vertebrate species	Species composition of native vertebrate species	The assemblages of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Species richness of native vertebrate species (number of species)	Species richness of mammals, birds and reptiles is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of: i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native vertebrate species	Abundances of mammal, bird and reptile species, are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total abundance of i) mammals (including bats); ii) birds; and iii) reptiles are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of threatened species	Species composition of threatened native vertebrate species	The assemblage of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of targeted threatened fauna species is statistically similar to, or on a trajectory towards, that of the reference ecosystem.
	Abundance of threatened vertebrate species	Abundance of threatened vertebrate species is similar to, or on a trajectory towards, that of the reference ecosystem.	Total abundance of targeted threatened vertebrate species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Composition and abundance of ants	Species composition of native ant species	The assemblages of native ant species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	The contribution in relative abundance of species in native ant assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).

Attribute	Sub-attribute	Goal	Indicator
	Species richness of native ant species	Species richness of native ants is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
	Abundance of native ant species	Abundance of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).	The total number of individuals of native ant species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem Sustainability			
External exchanges	Key vegetation-dispersing fauna	Abundances of nectivorous and frugivorous bird species are similar to, or on a trajectory towards, that of the reference ecosystem(s).	Total number of individuals of: i) nectivorous; and ii) frugivorous bird species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).
Ecosystem function	Habitat availability for fauna	Habitat for fauna is present, or is forming.	Habitat for fauna is, or indicators of habitat formation are, present.
	Nutrient cycling	Chemical, physical and biological indicators provide evidence that nutrient cycling will sustain ecological processes.	Litter decomposition rates necessary for supporting ecological processes are consistent with, and within the ranges of, those reported for northern savanna ecosystems.
			Appropriate soil microbial community functions that support nutrient cycling are present.
			Soil organic carbon and nitrogen are accumulating at a rate necessary for supporting ecological processes.
			Soil mineral nitrogen and soluble organic nitrogen stocks and rates of mobilisation are at a level necessary to support ecological processes.
	Resilience to fire	Ecosystem resilience to the appropriate fire regime.	Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.
			Post-fire mortality rates of juvenile and adult overstorey species do not exceed those of the reference ecosystem.

Attribute	Sub-attribute	Goal	Indicator
	Resilience to extreme weather events, pests and disease	Ecosystem resilience to natural disturbances (wind, drought, disease) is similar to the reference ecosystem.	In the event of natural disturbances (e.g. wind, drought, or disease), all other closure criteria must be shown to have been met, demonstrating recovery.
Threats	Weeds	No Class A weeds or Weeds of National Significance (WoNS).	Class A and/or Weeds of National Significance are either absent from the Ranger Project Area (RPA), or have been eradicated from within the RPA for a period of time that exceeds the seed bank longevity of any given species.
		Abundance of Class B weeds no greater than the reference ecosystem(s).	The incidence and abundance of all Class B weeds within the RPA is no greater than the reference ecosystem, at a landscape-scale.
		Abundance of other introduced flora species would not require a maintenance regime different from that appropriate to adjacent areas of Kakadu NP.	The presence and abundance of other introduced flora within the RPA is no greater than those in adjacent areas of Kakadu NP.
	Abundance of exotic fauna species	Abundances of buffalo, horses, pigs, cats and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.	The total abundance of: i) buffalo; ii) horses; iii) pigs; iv) cats; and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.

8.3.5.1 Justification for outcome, parameter and criteria

Derivation of the qualitative ecosystem criteria is underpinned by an understanding of general ecological restoration principles (SERA, 2021), ecosystem dynamics in northern Australia, and the knowledge gained through over 30 years of flora and fauna studies, revegetation trials and research on RPA and surrounding areas. The ecosystem criteria were developed through a process of stakeholder consultation, benchmarking against relevant contemporary practices at other operations and within other jurisdictions, as well as consideration of information from appropriate reference sites and rehabilitation trials.

Work is ongoing regarding reference site selection for indicators and the overall Ranger conceptual reference ecosystem (CRE, for more information see *Section 5 KKN ESR1*). This work is key to defining the target ecosystem(s) and will determine the quantitative closure criteria for assessment of success. It is generally understood that the ecological attributes and parameters proposed for the assessment by ERA are sound, however the criteria may be further revised once the CRE(s) are further developed and/or finalised.

Further information on the justification for each component of the ecosystem theme is provided below.

8.3.5.2 Ecosystem Similarity

The first outcome is that species composition and community structure is similar to adjacent areas of Kakadu NP.

The ecosystem similarity aspects of the ecosystem closure criteria have been grouped under vegetation similarity and fauna similarity attributes

Vegetation Similarity

Species composition of vegetation

Species composition is the array and relative proportion of organisms, in this case vascular plants, within an ecosystem (Gann *et al.* 2019). This measure is valuable for understanding how an ecosystem works and how important different species are to an environment. In mature, successful revegetation, these criteria should indicate that a good diversity of characteristic species (based on the agreed CRE) have been established and/or that there is improved potential for colonisation of more species over time (SERA, 2021). Species composition is generally expressed as a percent (so that all species components add up to 100 %) and can be considered on either an individual species basis, or by species groups depending on the objectives of the revegetation or monitoring program (e.g. Eucalyptus spp., perennial grasses, etc.). For closure criteria it is commonly expressed using similarity measures which quantify the similarity in the species and their relative abundances between two vegetation.

Despite the functional importance of dominant species for the long-term sustainability and stability of plant communities, they are not the major components of species diversity in the eucalypt-dominated open woodlands typical of the region. Annual and perennial grasses and forbs in the ground layer often dominate total plant species diversity (measured as species richness, abundance etc). However, these components can be very ephemeral in nature, resulting in considerable year-to-year variation in both species diversity and composition, even at a single natural woodland site (e.g. Fensham, 1992, Williams *et al.* 2003). In particular, the frequency, timing and intensity of fire can cause large changes in the composition of the ground stratum in these woodlands within a single year. As a result, measures of understorey species composition can be quite dynamic and variable in a manner that is largely unrelated to the overall functional performance of the plant community. Recognising this, it was agreed that understorey composition should be assessed based on functional groups rather than species. At an understorey-dedicated workshop held on the 24th of June 2021 involving ERA, SSB, NLC, as well as experts from Charles Darwin University and Kakadu Native Plants Pty Ltd, six functional understorey groups were identified for the understorey composition indicator based on the ecosystem services each group provides (draft report Bellairs, 2021).

The relevant criteria are:

- *The contribution in relative abundance of species in overstorey assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *Functional composition of understorey species for each functional group as follows:*
    - *Legumes: Minimum number of legume species and variety of lifeforms.*
    - *Perennial grasses: Minimum number of perennial grass species, including specified species.*
    - *Annual grasses: Minimum number of annual grass species.*
    - *Forbs: Minimum number of forb species from a minimum number of families.*
    - *Climbers and vines: Minimum number of climber and vine species used as a food source.*
    - *Non-legume woody species (shrubs): Minimum number of non-legume woody species and specified species (including woody ground cover species).*

Minimum numbers and specified species for each understorey functional group are yet to be agreed on. It is likely that minimum numbers will be a threshold defined by the lowest number of species in that lifeform across the set of reference sites. Specified species will be determined based on characteristics such as ubiquitousness across the reference ecosystem, its critical role for fauna food or habitat, and/or cultural significance.

Species richness of vegetation

Species richness is simply a count of the number of different species represented in an ecological community, landscape or region, and is a key component of species diversity (along with relative abundance of each species).

The relevant criterion is:

- *The total number of i) overstorey species, and ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Species abundance of vegetation

Species abundance can mean the number of individuals per species (density), or the percent cover per species, within a given area.

The relevant criterion is:

- *The total abundance of i) overstorey species, and ii) understorey species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Community Structure

Community structure refers to the architecture and spatial patterns of vegetation strata (SERA 2021), and can include height, diameter and size class distribution of stems, or the depth and total leaf area of each stratum. The Ranger rehabilitated site will have a very simple structure during the initial stages of ecosystem establishment because tubestock will be similar ages and sizes when planted. However, as the ecosystem matures, localised conditions (e.g. substrate properties, topography, weather and disturbance events etc.) will result in different rates of tubestock growth, self-recruitment and external colonisation of new species, resulting in a more complex community structure.

The relevant criteria are:

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

Two previously contemplated closure criteria related to vegetation structure are no longer proposed due to these aspects being adequately addressed through other criteria. Basal area of overstory is closely correlated with vegetation cover and is considered to be effectively assessed through the measurement of canopy cover (noting that this can also be measured remotely). The measurement of basal area will continue to form part of the monitoring within rehabilitation and reference site plots as an explanatory/diagnostic metric but will not be used as a separate closure criteria. The distribution of vegetation or “naturalness” had also previously been considered as a possible sub-attribute however all stakeholders have agreed that this attribute is difficult to measure objectively and the core diagnostic features relative to naturalness are covered in other ecosystem metrics. Cultural closure criteria (which necessarily include subjective considerations) are also considered to capture aspects of ‘naturalness’.

Fauna Similarity

It is recognised that the rehabilitated landform will not replace the pre-mining landscape with an identical ecological system, and will have no real analogue in the natural surroundings (due to the topographic, hydrological and substrate properties of the waste rock landform). However, in consideration of fauna, it should be recognised that the surrounding fauna communities form the only source for fauna recolonisation, and thus comparison of fauna communities within rehabilitation with suitable reference populations is a valid approach. Closure criteria have been developed for both invertebrate and vertebrate fauna. Invertebrates are important indicators for ecosystem reconstruction as they are abundant, respond to ecological system changes relatively quickly and many species have important roles as ecosystem engineers (e.g. Anderson *et al.* 1996, Andersen & Sparling 1997, Folgarait 1998). Invertebrates have been studied in Kakadu NP, and at Ranger specifically (Andersen 1993, Anderson *et al.* 1996, Andersen & Oberprieler 2019). Much of the vertebrate fauna is expected to recolonise later in the recovery trajectory of the site, in response to the development of invertebrate and vegetation resources. Vertebrates have been monitored across Kakadu NP over the last 25 years as part of Department of Environment and Natural Resources' Three Parks Fireplot Monitoring Program (reviewed by Einoder *et al.* 2018) and a series of more recent surveys have been conducted within and surrounding the RPA (Eco Logical Australia 2014, Eco Logical Australia 2016, SLR Consulting 2019).

Assessment of the development of invertebrate and vertebrate fauna communities, designed to demonstrate progress toward communities similar to those in adjacent areas of Kakadu NP, will be based on a combination of metrics.

Composition and abundance of native vertebrate species

The similarity of fauna richness and diversity with pre-mining or reference ecosystems is the most frequently studied indicator of fauna responses to mine rehabilitation globally (see reviews by Cristescu *et al.* 2012, Cross *et al.* 2019b). Empirical evidence demonstrates that fauna richness and diversity can be expected to increase over time, and that values approach (or in some cases exceed) values in reference ecosystems for a range of fauna groups (e.g., Nichols & Grant 2007, Brady & Noske 2010, Gould 2011, Frick *et al.* 2014, Triska *et al.* 2016, Houston *et al.* 2018).

In addition to measures of diversity, comparison of the similarity of fauna community assemblages to reference ecosystems provides a more sophisticated assessment of the development of faunal communities. In contrast to the evidence suggesting that fauna species diversity approaches reference values, similarity of community composition is generally more difficult to achieve (e.g., Woinarski *et al.* 2009, Brady & Noske 2010, Gould 2011, Craig *et al.* 2012, Cristescu *et al.* 2012, Triska *et al.* 2016), although some studies have recorded rehabilitated sites with community composition approaching that of reference sites (Nichols & Grant 2007).

Criteria for abundance, richness and community composition are being proposed for birds, mammals (including bats) and reptiles. Separate criteria are also included for threatened vertebrate species within the rehabilitated areas. The relevant criteria are:

- *The contribution in relative abundance of i) mammal (including bats); ii) bird; and iii) reptile species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of: i) mammal (including bats); ii) bird; and iii) reptile species are similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of individuals of: i) mammals (including bats); ii) birds; and iii) reptiles are similar to, or on a trajectory towards, that of the reference ecosystem(s).*
- *The contribution in relative abundance of targeted threatened fauna species is statistically similar to, or on a trajectory towards, that of the reference ecosystem.*
- *Total abundance of targeted threatened vertebrate species is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Composition and abundance of ants

Ants have been widely used as ecological indicators of habitat disturbance in the Australian tropics (King *et al.* 1998, Andersen *et al.* 2002, Hoffmann & Andersen 2003, Lawes *et al.* 2017), and were the dominant ground-active invertebrates on the Ranger Trial Landform and reference sites surrounding the mine surveyed by Andersen and Oberprieler (2019). As such ants are being proposed as the indicator for invertebrate species.

As with vertebrates, the criteria being proposed are composition, richness and abundance. The relevant criteria are:

- *The contribution in relative abundance of species in native ant assemblages is statistically similar to, or on a trajectory towards, that of the reference ecosystem(s)*
    - *Total number of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).*
    - *Total number of individuals of native ant species is similar to, or on a trajectory towards, that of the reference ecosystem(s).*

8.3.5.3 Ecosystem Sustainability

As discussed earlier, ER 2.2(a) requires the rehabilitated areas to contain long-term, viable ecosystems 'which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park'. The following components relate to the long-term viability/ functioning of the established ecosystems.

External exchanges

Edible fruit-bearing trees and shrubs provide resources for a range of bird and mammal fauna, which in turn facilitate dispersal of plant species across and into the rehabilitated ecosystem (Caves *et al.* 2013, Frick *et al.* 2014). Vertebrate pollinators and frugivores perform key ecological functions as vegetation dispersing fauna. Nectivorous and frugivorous bird species (which both indicate that suitable habitat resources are available, and facilitate dispersal and pollination of plant species) are thus considered important to include for closure criteria.

The proposed key vegetation-dispersing fauna closure criteria is:

- *Total number of individuals of: i) nectivorous; and ii) frugivorous bird species are statistically similar to, or on a trajectory towards, that of the reference ecosystem(s).*

Although previously considered, closure criteria covering recruitment or regeneration of species and the presence of flowing and fruiting material in vegetation are no longer deemed necessary. This is due to other closure criteria relying on these attributes to be present to be satisfied (e.g. criteria on flora species composition, relative abundance and community structure, as well as nectivorous and frugivorous bird criterion). Ongoing monitoring of flowering, fruiting and recruitment attributes will still be undertaken for early warning/explanatory/diagnostic purposes.

Fauna habitat

Fallen timber, rocks, bushy vegetation (eg. *Livistona* and *Heteropogon tricieus*) and tree hollows provide important habitat for amphibian, bird, mammal and reptile species. Many species are hollow-using or hollow-dependent (Taylor *et al.* 2003, Goldingay 2009, Goldingay 2011, Lindenmayer *et al.* 2014), and generally use multiple hollows selected on a number of characteristics, which potentially include tree size, height of hollow, entrance size, hollow form and position, hollow aspect and/or hollow depth (Goldingay 2009 & 2011). Hollows (particularly uncommon large hollows) occur most frequently in large, old trees and Goldingay (2011) estimated that most trees used as mammals dens (including those in the NT) were >100 years of age. The development of a self-sustaining array of tree hollows (where recruitment of new hollows balances attrition of existing hollows) suitable to support hollow-using or dependant fauna is therefore predicted to occur far beyond the 25-year timeframe for achievement of closure criteria. Recognising this limitation, it was agreed by ERA, SSB and NLC in an August 2022 forum that if key habitat formation attributes are present (eg. hollow-forming tree species, termites and an appropriate fire regime) that is an indication that hollows are likely to form over time.

The relevant criteria are:

- *Habitat for fauna is, or indicators of habitat formation are, present.*

Nutrient cycling

The process of nutrient cycling will be important for the ongoing sustainability of revegetation. Insufficient cycling of nutrients (due to limited availability and/or amounts of nutrients) can directly affect ecosystem attributes, including community structure, species composition and biodiversity. Nutrient cycling relies on a synergistic combination of physical, chemical and biological changes, therefore a range of factors require monitoring to ensure sustainable cycling is occurring.

The waste rock substrate that will form the Ranger final landform has significantly different physical, chemical and biological characteristics to the ancient soils of the unmined surrounding savanna (Section 5). Considering this, most of the nutrient cycling indicators are focussed on supporting essential ecological processes necessary for a sustainable ecosystem rather than returning to reference levels.

The relevant criteria are:

- *Litter decomposition rates necessary for supporting ecological processes are consistent with, and within the ranges of, those reported for northern savanna ecosystems*
- *Appropriate soil microbial community functions that support nutrient cycling are present.*
    - *Soil organic carbon and nitrogen are accumulating at a rate necessary for supporting ecological processes.*
    - *Soil mineral nitrogen and soluble organic nitrogen stocks and rates of mobilisation are at a level necessary to support ecological processes.*

Soil physical structure attributes are no longer proposed as a closure criteria due to the long duration required for waste rock substrate to become 'similar' to surrounding natural soils through weathering and biological processes. This attribute is not determinative of ER 2.2(a) being satisfied, and instead, soil physical properties will be monitored as key diagnostic variables for the other nutrient cycling indicators.

Resilience

A resilient ecosystem can experience the range of reasonably anticipated, 'natural' disturbance events and maintain (or return to) its pre-disturbance condition (given natural degrees of inherent variation). Resilience to prevailing disturbances is an important ecological characteristic of Australia's tropical savannas as they experience various fire regimes, periods of prolonged drought (due to distinct but variable wet and dry seasons) and destructive wind events including powerful storms and cyclones. The rehabilitated ecosystem will be exposed to these conditions, and therefore needs to demonstrate resilience and recovery to be considered sustainable.

Fires are frequent in the surrounding Kakadu NP and most local native woodland species have inherent attributes that enable them to persist after fire (*Section 5 KKN ESR8*). However, developmental stages also influence resilience. The rehabilitated ecosystem will be vulnerable to fire during the initial establishment phase when all stems are still relatively small. Following an exclusion timeframe, fire will be introduced in a controlled manner appropriate to the ecosystem's stage of development.

The relevant criteria are:

- *Following implementation of an appropriate fire regime, all other closure criteria must be shown to have been met, demonstrating recovery.*
- *Post-fire mortality rates of juvenile and adult overstorey species do not exceed those of the reference ecosystems.*
- *In the event of natural disturbances (e.g. wind, drought, or disease), all other closure criteria must be shown to have been met, demonstrating recovery.*

Threats – Exotic flora and fauna

In order to have a maintenance regime that is not significantly different from that of the surrounding Kakadu NP, the presence of introduced species will need to be comparable or better.

The closure criteria for weeds are based on the applicable Federal and Northern Territory legislation. In addition to the prescribed weeds, other, non-legislated introduced species have the potential to require considerable management, and therefore need to be present at levels not requiring a maintenance regime significantly different than adjacent areas of Kakadu NP.

The relevant criteria are:

- *Class A and/or Weeds of National Significance are either absent from the RPA, or have been eradicated from within the RPA for a period of time that exceeds the seed bank longevity of any given species.*
- *The incidence and abundance of all Class B weeds within the RPA is no greater than the reference ecosystem, at a landscape-scale.*
- *The presence and abundance of other introduced flora within the RPA is no greater than those in adjacent areas of Kakadu NP.*

Feral animals are present within surrounding areas of Kakadu NP and are subject to different management practices depending on specific species. Due to the population of feral animals in the park and their highly mobile nature, presence of introduced species on the RPA (in particular buffalo, horses, pigs and cats) is expected. The ERA revegetation and post-closure land management program will continue to actively control feral animals whilst revegetation establishes and develops to a mature, resilient ecosystem. Thereafter, the revegetated ecosystem should have the same degree of resilience to these pressures as the adjacent areas of Kakadu NP, and therefore should not require a significantly different management regime.

In addition to the currently known feral animals both on the RPA and within Kakadu NP, there may be the potential for additional introduced species, both vertebrate and invertebrate, that may have a future legislative requirement for control. The criteria have allowed for this future proofing.

The relevant criterion is:

- *Total number of individuals of: i) buffalo; ii) horses; iii) pigs; iv) cats; and any other fauna where there is a legislative requirement for control on the Ranger Project Area are no greater than adjacent areas of Kakadu National Park.*

8.3.6 Cultural

2022 Status Update
The cultural criteria presented in this MCP have been developed in consultation with the GAC and NLC.

There is one objective for closure under the cultural closure criteria theme, which is the combination of two ERs: ER 1.1 (a); and ER 2.1:

> *1.1 The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives:*
>
> *(a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list;*
>
> *2.1 The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.*

ER 1.1 (a) requires that ERA maintains the attributes for which Kakadu NP was inscribed on the world heritage list. These world heritage values have multiple criteria that are based on the cultural values in the park. ER 2.1 is the overall objective for closure of Ranger Mine, stating that it must be rehabilitated to a standard that could be incorporated into Kakadu NP, linking rehabilitation to the requirement that there is no impact on the World Heritage Values of Kakadu NP.

Several outcomes have been extracted from these objectives. These outcomes were all based on consultation work completed by Murray Garde in 2014 (Garde, 2015) and finalised by the GAC and NLC (Brady *et al.,* 2021). This work built upon a large body of previous consultation work and studies into cultural closure criteria completed by ERA, NLC and GAC.

A summary of the closure objectives, the outcomes derived from the objectives, parameters used to measure the outcome and the proposed closure criteria are provided in Table 8-10. Section 8.3.6.1 provides justification for the outcomes, parameters and closure criteria for each of the key elements of the cultural theme.

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

The committee has been working a landform and ecosystem re-establishment design that is informed by a view of country that recognises the interrelationship, via local kinship and moiety systems, of all things — the rocks, plants, animals, people, stories, weather, ceremonies and tradition. Incorporating an Indigenous view of the landscape provides an opportunity to better integrate the rehabilitation into the surrounds, with co-benefits from a Western science perspective, such as increasing species diversity of plants and animals.

Table 8-10: Closure criteria – cultural

ER	Objective	Outcome	Parameter	Summary of criteria[9]
1.1 (a) 2.1	The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list; The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.	Landform design supports cultural land use: An-berrk, savanna woodland An-bouk, riparian margins An-gabo, water courses An-labbarl, billabongs Traditional Owners satisfied with the landform.	Size of rocks.	≥7 Surface rock suitability verified by Bininj monitoring - confirm mostly correctly sized.
			Presence / absence of erosion.	≥7 Erosion verified by Bininj monitoring – limited to very minor concerns and only small areas.
			Accessibility, traversability[10].	≥7 Traversability verified by Bininj monitoring – limited to minor difficulties only and few in number.
			General aesthetics (does it look ‘natural’).	≥7 Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory.
		Traditional Owners are observing improvement in the progression of revegetation on the landform.	Vegetation growth rate.	≥7 Growth rate verified by Bininj monitoring – relative to the number of seasons, the growth of plants across all areas is satisfactory and is improving.
			Vegetation diversity.	≥7 Diversity verified by Bininj – all of the expected species are present in a natural combination in nearly all of the area.
			Correct species for ecological zone.	≥7 Species verified by Bininj – all of the species are correct for nearly all ecological zones.
			Presence of weeds.	≥7 Weeds verified by Bininj – weeds are present in only a minor portion of the area, low level of concern.
		Traditional Owners are satisfied that there are not additional water bodies present.	Presence or absence of artificial water bodies.	Absence of water bodies verified by Bininj monitoring – no artificial water bodies present.
		Traditional Owners satisfied with the water quality and that no silting or sedimentation is occurring.	Visual impressions of water quality (colour, flow, expected clarity, visible contaminants), silting, sedimentation.	≥7 Water quality verified by Bininj monitoring – water appears to be of high quality in most areas, only very minor water quality concerns.
		Traditional Owners satisfied that the riparian zones are in good condition.	Condition of water course margins, creek banks.	≥7 Watercourse margins and creek banks verified by Bininj monitoring – appear to be in a natural condition in most of the area, only minor concerns.
		Traditional Owners are observing improvement in biodiversity on the landform.	Natural species numbers and diversity appropriate for stage of rehabilitation.	≥ Species numbers and diversity verified by Bininj monitoring – natural species occurring according to expectations for natural rate relative to the number of seasons and is improving.
		Traditional Owners are satisfied with the final landform and state of key landmarks.	Line of sight assessment prior to finalising landform design.	Visual connection with key cultural sites verified by Bininj monitoring – sites visible from the same areas and to the same extent as prior to disturbance.

[9] Criteria to be read in conjunction with the closure criteria details provided in Mine Closure Plan Section 8.3.6.

[10] Bininj may agree that ripping of landform will lead to a better revegetation outcome, therefore there will be a need to consider and consult on 'pathways' through the landscape.

8.3.6.1 Justification for outcome, parameter and criteria

The success of the rehabilitation over time will be measured against the specified closure criteria (Table 8-10), including the presence of culturally important flora and fauna on the final landform at the appropriate stage of rehabilitation. Garde (2015) speaks to the importance of social organisation, moieties, and conceptions of landscapes, all of which, if not satisfactorily addressed, will ultimately influence the assessment by Mirarr of the rehabilitation.

Garde (2015) also describes a process by which to monitor the success of rehabilitation using a set of cultural health indices. The following discussion is provided as an example only and should not be considered the final agreed mechanism for cultural criteria monitoring.

The cultural health indices described in Garde (2015) have been taken as the parameters for cultural closure criteria with proposed final endpoints presented in Table 8-11. Garde (2015) states that there are very few established models or methodologies to inform such a program. One notable example comes from New Zealand: *Cultural Health Index for Streams and Waterways: Indicators for Recognising and Expressing Maori Values* (Tipa & Teirney, 2003 & 2006). The index attempts to apply indicators that Maori land owners use to assess the health of waterways.

The proposed indicators that could be used to reflect the attitudes of Traditional Owners towards the progress of rehabilitation are largely based on visual and aesthetic factors proposed in Garde (2015), provided in Table 8-11.

In addition to the cultural health indices, one additional criterion has been included at the request of GAC, being that traditional burning practices have resumed.

Table 8-11: Suggested indicators of cultural health of rehabilitated site (Garde, 2015)

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

Assessments of attitudes and opinions of Traditional Owners will occur at the appropriate time to determine whether or not the Traditional Owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.

Measurements of impressionistic responses are scalar and individual indices are averaged out to provide a score. Scalar numeric assessment will also be accompanied by discursive data that provides a rationale for the score given. There is provision to provide other comments; these are hoped to provide an indication of areas that require management. Scores are to be calculated annually and then compared to determine whether perceptions of rehabilitation are moving in a trajectory that demonstrates achievement of cultural objectives as determined by Traditional Owners.

There are several options for determining final scores. The first option is for sites to be individually assessed by a number of Indigenous stakeholders (barriredweleng 'Traditional Owners' and djunggai 'mother's country managers') and their scores collated and averaged. The second option is for the assessment to be done as a group activity where consensus on a score is established by the group at each site during visitation. This will be determined closer to the completion of decommissioning in consultation with GAC.

The assessment scale will be in a bilingual format that includes information in both Gundjeihmi and English. Each site will not necessarily be assessed for all indicators as some may not be relevant. For example, an indicator such as size of rocks will only be relevant at those sites where high levels of disturbance requires reconstruction of the landform with waste rock. Riparian sites will be assessed for relevant indicators which will not apply to other areas (e.g. condition of watercourse margins will obviously not apply to assessment of areas away from watercourses). An example of the scalar measurement tool is provided in Table 8-12.

Table 8-12: Example of scalar measurement tool for cultural criteria monitoring

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

Work is continuing to ensure the final landform delivers the appropriate cultural outcome, and ensure the right species are planted in the right places. This includes overlaying the final landform design with the Gundjeihmi system of ecological zones (an-gabo, an-labbarl etc.), and then within each of these zones prescribe the layout/placement of various flora species. The GAC and NLC have created a cultural reconnection working group to progress this work. The group has held several visits to Ranger to provide feedback on the rehabilitation, revegetation and habitat recreation plans.

Closure monitoring for cultural criteria will be conducted at a number of sites that collectively provide a cross section of the range of site types where rehabilitation has been undertaken.

An assessment of cultural criteria will need to be completed at each of the selected sites on an annual basis. The approach to monitoring of cultural criteria is described in Section 10.5.

Figure 8-7: Georgetown Creek

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