ERA Energy Resources of Australia Ltd

Chapter 6 Development of Closure Criteria

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6 DEVELOPMENT OF CLOSURE CRITERIA

6.1 Introduction

A key component of closure planning for the Ranger mine is the development of closure criteria, which form the performance criteria and will be used to measure the achievement of the rehabilitation closure objectives. These criteria 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.

The mechanisms and processes by which closure criteria are developed are outlined in the Terms of Reference for the Closure Criteria Working Group (CCWG) (Paulka, 2012) and shown in Figure 6-1. The closure criteria address the broader objectives described in the ERs and Ranger Authorisation. Figure 6-1 has been updated to reflect the current status of closure criteria planning and shows the five stage pathway for the development, refinement and approval of these criteria.

As described in Chapter 4, the Ranger ERs contain a number of primary and secondary objectives for the rehabilitation and closure of Ranger. The overall objective for rehabilitation and closure has been based on the rehabilitation goals outlined in the Ranger Authorisation and the ERs (ERA 2014). It is recognised in the wording of Primary Objective 2.1 that there will be differences between the ecosystem of the broader KNP and that of the final landform on the RPA. Specifically, any impacts within the RPA must be as low as reasonably achievable. These differences are reflected within the 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.

The closure criteria for each theme are based on stakeholder consultation (Chapter 5), substantial research and studies (Chapter 7), Best Practicable Technology (Chapter 8) and risk assessments (Chapter 9) over the life of the mine. The proposed closure criteria presented in this MCP have been developed from closure criteria studies and reports, including work completed by the CCWG and the technical working groups, as well as stakeholder feedback to the draft MCP issued in December 2016 (refer Section 6.8). Closure criteria will continue to undergo review and refinement, based on studies and consultation with MTC members.

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. Each closure theme is presented in a separate section below with the following information:

1. Summary of relevant objectives and outcomes.
2. A closure criteria summary table.
3. Justification for outcome, parameter, criteria and method to assess achievement.

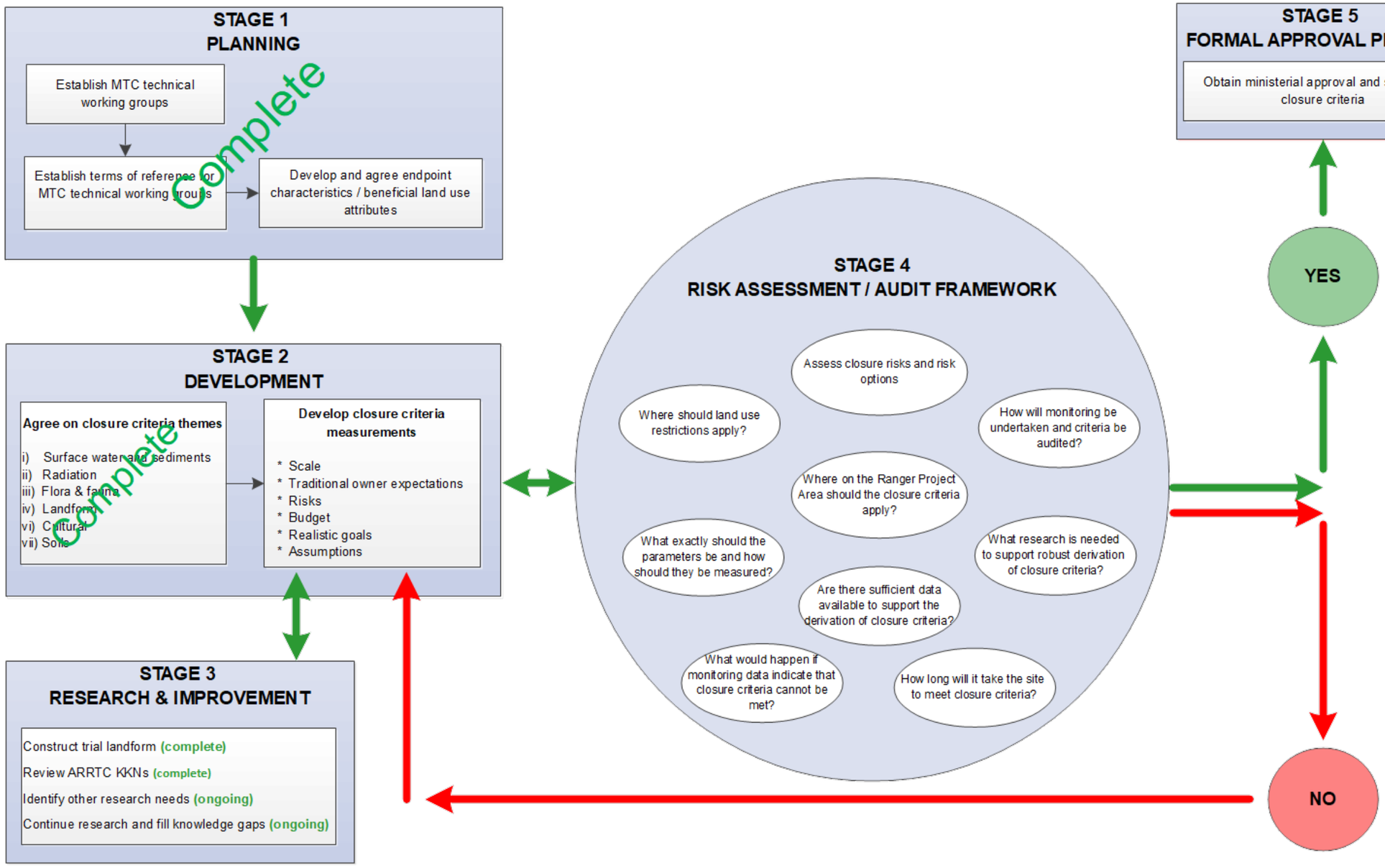

Figure 6-1: Framework for the closure criteria working group, and subsequent closure criteria development and approvals pathway

6.2 Landform

There are four objectives derived from the ERs relating to the landform theme. Each objective, the outcome derived from that objective and explanation are summarised below.

Landform Objective 1:

The first objective comes from ER 2.3 and relates to the removal of site infrastructure

> *Where all the major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation.*

The outcome derived from this objective is that all plant and equipment should be removed from the site with the exception of that approved to remain.

Landform Objective 2:

The second objective comes from ER 11.2 and relates to the final disposal of tailings:

> *By the end of operations all tailings must be placed in the mined out pits.*

The outcome derived from this objective is that stakeholders sign off that this has occurred.

Landform Objective 3:

The third 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 4:

The fourth 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.*

Four outcomes have been derived from this objective, which are:

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 tend slowly towards the natural rates. These timeframes are expected to be quite long so the outcome is to use best available modelling to demonstrate that the erosion characteristics of the final landform will eventually be comparable to natural landscapes.

Second outcome - relates to drainage channels, highlighting the need to ensure that they are appropriately engineered, installed and maintained for each catchment such that unplanned erosion is minimised (Chapter 11, Section 11.2). Drainage channels need to be designed so they are comparable to landforms in the surrounding undisturbed areas.

Third outcome - to ensure sediments created through erosion of the landform do not cause sand to infill Magela and Gulungul creeks and associated billabongs. While this outcome does not directly relate to the objective for erosion characteristics, it was considered an important environmental protection outcome that relates to erosion.

Fourth outcome - applies the concept that turbidity can be used as an indicator of site-scale erosion characteristics. Moliere *et al*. (2004) have shown that turbidity measures are highly correlated to total suspended sediment loads taken as a cumulative total over the wet season. The total suspended sediment can be captured at sites upstream and downstream in a paired before-after-control-impact design (BACIP) to demonstrate landscape stability and the trajectory of sediment fluxes on the rehabilitated landscape toward those of analogue landscapes. This method is further described in Moliere & Evans (2010).

Table 6-1 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcome and the proposed closure criteria. In some cases corrective action is also provided in the case 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.

Section 6.2.1 provides justification the outcomes, parameters, and closure criteria that were derived for each of the key elements of the landform theme: infrastructure; isolation of tailings; and erosion characteristics.

Table 6-1: Closure criteria – landform

ER	Objective	Outcome	Parameter	Final criteria	Corrective Actions	ID	Cultural link
2.3	Where all the major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following the termination of the Ranger Authorisation, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation	Remove all plant, equipment, buildings and other structures; Some infrastructure may remain on the RPA provided approval of the traditional owners and the Commonwealth minister is given.	Confirmation by Supervising Authority	Supervising Authority confirms all items removed with the exception of those agreed under ER 2.3.	Remove structures	L1	C5 C6
11.2	By the end of operations all tailings must be placed in the mined out pits	Stakeholder sign-off that all tailings have been placed in Pit 1 or Pit 3.	Confirmation by Supervising Authority	Supervising Authority confirms all tailings are placed into the mined out Pits	Place tailings in Pit 1 or 3	L2	-
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	Landform evolution model (LEM) predictions of gully erosion	Modelling predictions of final conceptual landform show tailings are not exposed for at least 10,000 years.	Modify/revise landform design	L3	-
				A digital elevation model (DEM) of the final constructed landform is captured. The LEM is the rerun with the final land surface topography to ensure tailings are not exposed for at least 10,000 years.	Re-contour landform sections as identified and rerun LEM	L4	-
2.2 (c)	Erosion characteristics of the rehabilitated landform, as far as can reasonably be achieved, do not vary significantly from comparable landforms in surrounding undisturbed areas	Best available modelling demonstrates that erosion rates return to that of comparable natural landscapes	LEM model predictions of denudation rate	Modelling predictions of the final conceptual landform confirm long term denudation rate (averaged over the entire landform) are approaching background rates (0.01 - 0.04mm/year)	Modify/revise landform design	L5	C2 C3
		Drainage channels are installed and maintained to manage erosion for each catchment and are comparable to landforms in surrounding undisturbed areas	Drainage channel design	Drainage channels are designed and installed based on the outcomes of LEM model predictions for gully erosion.	Re-contour drainage channels as identified	L6	C2 C3
				Design of channels will be to blend in with the constructed landform.	Modify design of drainage channels	L7	C4
			Drainage channels maintained	Post wet season observations show drainage channels are in good condition (e.g. remain functional structures).	Maintenance to drainage channels	L8	C2
			Gully erosion	Post wet season observations show no unplanned gully erosion has occurred.	Earthworks to manage erosion	L9	C2
		Sediments from erosion of the landform do not cause sand to infill in Magela and Gulungul creeks and associated billabongs	Bedload	No bedload coming off site	Modify design, clean out or install new sediment traps	L10	C6
		Suspended sediment loads in Magela and Gulungul Creeks will be approaching background	Turbidity	Event suspended sediment load, evaluated across the wet season, to Magela and Gulungul creeks are approaching background loads.	Monitor trends and develop site specific action plan as required	L11	C7

6.2.1 Justification for Outcome, Parameter and Criteria

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

6.2.1.1 Infrastructure

This closure criterion is a confirmation that infrastructure and tailings have been removed from the surface and placed into mined out pits. The Supervising Authority is the signatory for confirming the removal of infrastructure and placement of tailings into mined out pits has been achieved.

The removal of infrastructure and placement of tailings into mined out pits will be assessed during and at the end of the decommissioning period through site inspections from the Supervising Authority. These inspections will occur throughout the decommissioning phase, with records of the infrastructure removal and tailings placement used to confirm the closure criteria has been met. Failure to complete the activities would require corrective action to remove the infrastructure or tailings material.

6.2.1.2 Isolation of Tailings

The condition for isolation of tailings extends for 10,000 years, which is considered to only be measureable through the use of a Landform Evolution Model (LEM). Best available modelling methods, developed by ERISS, have been employed to predict the location, size and extent of gully erosion. The model will be used to demonstrate that the designed landform will not have tailings exposed for 10,000 years in a probable worst case scenario that accounts for predicted climate changes over the 10,000 year period. Once constructed, the as built topography will be re-modelled with the same scenario to confirm that tailings will not be exposed for 10,000 years.

The method used to demonstrate achievement of the tailings isolation criteria will be based on the LEM predictions. The criteria will be achieved if the model demonstrates that, for a probable worst case scenario, tailings will not be exposed. The modelling of a worst case scenario will mean there is no tolerance assigned to the output and therefore it will confirm the criteria either has or has not been achieved.

6.2.1.3 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 the use of a LEM to predict denudation rates has been selected as the parameter. The model needs to demonstrate that the long term predictions of denudation rate from the designed landform are approaching background rates (previously reported to ARRTC by the Supervising Scientist to be between 0.01 and 0.04 millimetres per year).

Drainage channels will be important for managing gully erosion on the landform. Where the LEM has predicted that gully erosion will form, purpose built drainage channels will be designed and installed. Drainage channel location will be assessed by the supervising authority prior to final contouring of the landform and construction of the drainage channels. The Supervising Scientist has indicated that while it is expected that gullies will form on the landform within the modelled 10,000 years, the tailings will be below the natural landscape and are therefore not expected to be exposed (Supervising Scientist, 2017).

The design of the channels will consider the aesthetics of the landform, such that they blend in as much as possible to the surrounding landscape while still achieving the objective of erosion mitigation. The method for achievement of this criterion will require input from traditional owner representative groups (GAC and NLC).

Following installation, drainage channels will be inspected at the end of each wet season to confirm that they are in good condition (i.e. do not require maintenance) and operating according to design. Initially it is expected that some maintenance may be required, however the need for maintenance should progressively decline as the landform matures and dynamic equilibrium is reached. When drainage channels are considered to have reached functional dynamic equilibrium, this criterion will be achieved. Maintenance is discussed in more detail in Chapter 11.

Significant erosion (e.g. 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. Where significant erosion does occur (e.g. gullies), corrective earthworks will be undertaken prior to the following wet season. Minor erosion (e.g. rills, etc.) will be monitored for potential to impact on landform stability. Corrective actions will only be undertaken if the erosion is considered to pose a risk to the overall landform stability.

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. Where significant erosion does occur (e.g. gullies), corrective earth works will be undertaken prior to the following wet season. It is expected that after the first five years the landform will stabilise should have settled down and less erosion will be occurring. If there is no unplanned gully erosion occurring after this period, then this criterion will be considered to be achieved.

It is considered that the most suitable parameter for measurement of site-scale erosion characteristics is event load suspended sediment tracked on a whole of wet season basis. Suspended sediment loads from the rehabilitated landform to Magela and Gulungul creeks are expected to initially be high, and then trend progressively towards background (analogue) suspended sediment loads. Work completed by the Supervising Scientist has demonstrated that turbidity can be used as an indicator for suspended sediment (Moliere and Evans 2010).

Load of suspended sediment leaving the landform and entering Magela or Gulungul creek will be measured through turbidity monitoring up and downstream of the RPA. Event based loads leaving the site will be tracked across a wet season and compared to background (analogue) loads. It is expected that it will take some time for these loads to return to background levels; therefore achievement of this criterion will be based on the trajectory towards the analogue, which is expected to be between 5 and 10 years.

6.3 Radiation

There are two objectives derived from the ER's relating to the radiation theme.

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 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 6-2), one related to the terrestrial environment and one for the aquatic. This division is based on the guidance for assessment provided within the International Commission of Radiological Protection (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 6-2 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcome and the proposed closure criteria. In some

cases corrective action is also provided in the case 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.

Reflecting the guidance of the 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 6-2 will be met in the post closure phase, ERA commissioned a dose assessment be undertaken, which commenced in the third quarter of 2017. The dose assessment will consider potential radiation exposure to members of the public, as well as terrestrial and aquatic biota. A summary of the proposed radiation dose assessment is provided in Chapter 7, Section 7.10.1.

Section 6.3.1 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 6-2: Closure criteria – radiation

ER	Objective	Outcome	Parameter	Final criteria	Corrective actions	ID	Cultural link
2.2 (b) and 11.3 (iii)	Stable radiological conditions on areas impacted by mining so that, the health risk to members of the public, including traditional owners, is as low as reasonably achievable; members of the public do not receive a radiation dose which exceeds applicable limits recommended by the most recently published and relevant Australian standards, codes of practice, and guidelines; and there is a minimum of restrictions on the use of the area	Radiation doses to members of the pubic are ALARA	Using the agreed restrictions on land use the total above-baseline radiation dose from pathways: External gamma Inhalation of Radon decay products (RDP) Inhalation of dust Ingestion of bush food (including water)	0.3 mSv per year	Modify the design and/or action plan to mitigate identified pathway to ALARA (societal and economic considerations taken into account). Apply additional restriction on the use of the land in consultation with Traditional Owners (using the agreed method).	R1	-
		Radiation doses to members of the public are below limits	Should land use restrictions fail, the total above-baseline radiation dose from pathways: External gamma Inhalation of RDP Inhalation of dust Ingestion of bush food (including water)	1 mSv per year	Modify the design of the landform or other relevant parameters in the decommissioning plan to reduce radiation dose for the specific pathway of concern. Post closure develop an action plan to mitigate identified pathway to ALARA (societal and economic considerations taken into account).	R2	--
1.2 (d,e)	In particular, 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; 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 radiation dose rate to terrestrial plants and animals from internal and external exposures	100 µGy/h to the most highly exposed terrestrial species	Review of species specific effects data to determine the potential for impact to the population, any actions need to consider ALARA.	R3	--
		Minimise the deleterious radiation effects on aquatic biota to a level where they would have a negligible impact on the maintenance of biological diversity; the conservation of species; or the health and status of natural habitats, communities, and ecosystems.	Total above-baseline radiation dose rate to aquatic plants and animals from internal and external exposures	400 µGy/h to the most highly exposed aquatic species	Review of species specific effects data to determine the potential for impact to the population, any actions need to consider ALARA.	R4	--

6.3.1 Justification for Outcome, Parameter and Criteria

6.3.1.1 Radiation Doses to Members of the Public

Two outcomes have been derived from this objective (Table 6-2), the first relates to the requirement to have radiation doses to members of the public remain below limits and the second to also keep these doses as low as reasonably achievable.

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

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

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

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

The recommendations of the ICRP are taken by the International Atomic Energy Agency (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; rather they 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.

They are 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 operation by several pieces of Commonwealth and Northern Territory Legislation and implemented at site through the Ranger Authorisation.

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

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

ERA has adopted a radiation protection policy and developed a Radiation Management System, based on the justification, optimisation and limitation principles established by the ICRP. The policy and system will be applied to the decommissioning phase through the Radiation Management Plan. During the post closure phase, the principles will be applied through the development and demonstration of compliance with closure criteria. The closure criteria presented in Table 6-2 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, 2014). For members of the public this will be 1 milli-Sievert in a year, determined from the sum of effective doses from all possible combinations of exposures.

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

The IAEA system recommends that the final dose to members of the public is to be optimised below the dose constraint. If this is not achievable without any restrictions on the use of the land, then these may be applied with the additional requirement that the dose to members of the public should not exceed the dose limit of 1 milli-Sievert per year in case the restrictions fail. This process is illustrated in Figure 6-2 and forms the basis for setting of the radiation criteria for protection of human health outlined previously in Table 6-2.

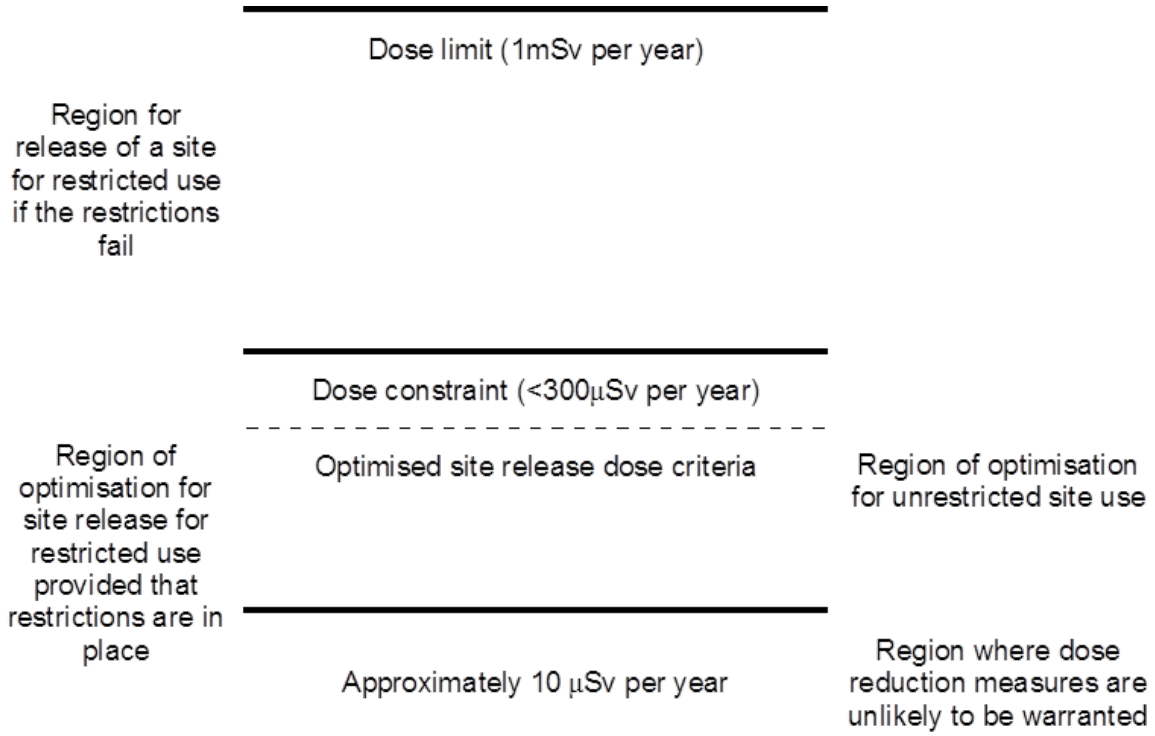

Figure 6-2: Constrained optimisation and regions of effective dose for members of the critical group in the release of sites (IAEA 2006)

In order 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.
- 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, ingestion of food stuffs (including ancillary ingestion of soil and drinking of water). Member of the public dose assessment will consider the following exposure pathways:

- Inhalation of long-lived alpha activity (e.g. radioactive dust).
- Inhalation of radon decay products.
- Ingestion of radioactive material in (or with) food or water.
- External irradiation from gamma radiation.

Given the possible post-closure use of the landform, the representative person will be an Aboriginal person using the site for traditional activities including transient camping and the gathering of traditional bush foods for consumption. Details of the land use, occupancy and diet have all been documented by Murray Garde during consultations with the Mirarr (Garde, 2015).

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

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

A summary of the pre-mining background levels is provided in Chapter 7, Section 7.4.1.

6.3.1.2 Radiation Effects on Biota

Two outcomes have been derived from the objectives in relation to radiation effects on biota (refer Table 6-2), 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 International Commission of Radiological Protection (ICRP) in its publication 124: *Protection of the Environment under Different Exposure Situations* (ICRP, 2014). This document describes the framework for protection of the environment and how it should be applied within the ICRP system of protection.

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

This has been the basis for selection of the outcomes, one related to the terrestrial biota and one for aquatic biota. This division is based on the guidance for assessment provided within the ICRP document (ICRP, 2014).

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

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

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

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

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

If the dose rates are below the benchmark dose rate then 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 particular 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.

6.4 Water and Sediment

There are three objectives derived from the ER's relating to the water and sediment theme.

The ER 3.1 is central to the first three 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 to the period following rehabilitation for any surface or ground waters discharged from the RPA. The various primary environmental objectives are then separated into the separate closure objectives for this closure criteria theme.

Water and Sediment Objective 1:

The first objective groups ER 1.1(c) and 1.2(c) since 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.*

To assess the potential risk to human health from chemical pollutants in water (radiation is dealt with separately in the radiation theme) two pathways were identified:

- The first is through ingestion of water and bush food that has bio-accumulated mine derived analytes, in this case the outcome is that diet consumption limits are not exceeded. This outcome applies to the Magela Creek outside of the RPA.
- The second is through recreational activities and likewise the desired outcome is that recreational water resources remain safe for their designated use. This outcome also applies to secondary contact sites, which will be confirmed through ongoing stakeholder engagement.

Water and Sediment Objective 2:

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

> *1.1 The company must ensure that operations at Ranger are undertaken is such a way as to …:*
>
> *(d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes*
>
> *1.2 The company must ensure that operations at Ranger do not result in:*
>
> *(d) change to biodiversity, or impairment of ecosystem health, outside of the Ranger Project Area. Such change is to be different and detrimental from that expected from natural biophysical or biological processes operating in the Alligator Rivers Region.*

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

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

Two outcomes have been derived from this objective:

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

Second outcome - mine sourced solutes do not increase uranium in sediments off the RPA to levels that would be detrimental to ecosystem health of the region.

These two outcomes cover the three pathways for contaminant transport for this theme, groundwater, surface water and sediments and include the assessment endpoint from the objective for protection outside of the RPA and for changes that would be detrimental on a regional scale (being the Alligator Rivers Region).

Water and Sediment Objective 3:

The third objective is from ER 1.2 (e) and 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.

The outcome for this objective is that impacts on the RPA will be as low as reasonably achievable (ALARA). Assessing impacts off-site as well as on site, and the mitigations in place or possible, is part of the process for understanding:

- ALARA.
- BPT for considering environmental, technical, social and financial aspects.
- The tiered risk assessment/decision framework under development for considering on and off site potential impacts to environmental values

All of the above are tools for assessing what is reasonably achievable.

Table 6-3 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters and process used to measure the outcome and the proposed closure criteria. For most outcomes screening criteria provide a first tier trigger for assessing if narrative closure criteria are met. In some cases corrective action is also provided in case 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. In some instances, the same parameter appears against several objectives. In most cases the ecosystem

protection criteria are more stringent than, for example, human health criteria. Criteria values for each outcome are given so compliance with each particular outcome and objective can be assessed.

Section 6.4.1 provides justification for the outcomes, parameters, risk based approach and the screening and closure criteria for each of the key elements of the water and sediment theme: human health; ecosystem health; and detrimental environmental impacts.

Table 6-3: Closure criteria – water and sediment

ER	Objective	Outcome	Parameter	Final and screening criteria	ID	Cultural link
3.1 and 1.1(c) and 1.2 (c)	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives. The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (c) Protect the health of Aboriginals and other members of the regional community The company must ensure that operations at Ranger do not result in: (c) An adverse effect on the health of Aboriginals and other members of the regional community by ensuring that exposure to radiation and chemical pollutants is as low as reasonably achievable and conforms with relevant Australian law, and in particular, in relation to radiological exposure, complies with the most recently published and relevant Australian standards, codes of practice, and guidelines.	Mine derived analytes will not cause dietary (food and water) resources to exceed limits for human consumption in Magela Creek outside the RPA	Drinking water: Mn, NO_3, NO_2, SO_4^{2-}, U Diet: Mn,	A risk assessment of water quality in Magela Creek outside of the RPA demonstrates mine derived analytes do/will not cause intake levels of those COPC to become intolerable. **First tier screening criteria – drinking water:** Drinking water quality in Magela Creek outside the RPA meets the national drinking water health guidelines. SO_4^{2-} 500 mg/L, Mn 500 µg/L, NO_3 50 mg/L, NO_2 3 mg/L, U 17 µg/L (NHMRC & NRMMC, 2011; v3.4). **First tier screening criteria – diet:** Local diet model demonstrates that ingestion of mine derived COPC via aquatic bush foods and drinking water does not cause annual intakes to exceed national/international tolerable intake levels. Refer to Figure 6-3 for higher tier assessment approaches.	W1	- -
		Mine derived hazards will not cause designated recreational water resources to become unsafe for their designated recreational use in Magela Creek outside the RPA and Gulungul Creek secondary contact sites.	Toxic or irritant chemicals Visual clarity and surface films	Water quality in Magela and Gulungul creeks at secondary contact sites is safe for secondary contact. **First tier screening criteria:** Water quality at MG009 and GCH meets the following the following recreational guidelines: NO_3 500 mg/L, NO_2 30 mg/L, U 170 µg/L (i.e., drinking water COPC x 10: NHRMC, 2008) SO_4^{2-} 400 mg/L, Mn 100 µg/L (ANZECC & ARMCANZ, 2000 irritants, no guidelines for irritants/toxicants in NHMRC, 2008). Refer to Figure 6.4 for higher tier assessment approaches. No mine related change to water quality in Magela and Gulungul creeks causes turbidity to be 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.	W2	C7 C7

ER	Objective	Outcome	Parameter	Final and screening criteria	ID	Cultural link
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 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 outside the RPA do not cause detrimental impact to the ecosystem health of the Alligators River Region. There will be no detrimental environmental impact outside the RPA from tailings contaminants for 10,000 years. There will be no detrimental environmental impact outside the RPA from the accumulation of sediment eroded from the RPA.	Turbidity, Mg, U, Mn, NH_3-N, N, P, SO_4 Sedimentation	Water quality leaving the RPA (measured in Magela Creek downstream of the confluence of Magela and Gulungul Creeks, and at GCLB) does not cause a detrimental environmental impact. **First tier screening criteria:** Magela Creek water quality downstream of the confluence of Magela and Gulungul Creeks, and at GCLB does not exceed: The site specific biological effects criteria: Turbidity: 30 NTU, 6 weeks exceedance duration Mg 5 mg/L: U ≤2.8 µg/L; Mn ≤ 75 µg L-1; NH_3-N ≤ 0.7 mg/L; SO_4 (to be confirmed) ANZECC & ARMCANZ (2000) guidelines for eutrophication protection: NOx 0.010 mg/L, NH_3-N 0.006 mg/L, Total-P 0.010 mg/L or 0.005 FRP) Loads of N and P leaving site are less than the site specific Annual Additional Load Limits for PO_4-P and NO_3-N, and equivalently derived NH_3-N load PO_4-P 2.8 t/y; NO_3-N 4.4 t/yr; NH_3-N (to be derived). Mine derived erosion products do not cause sedimentation in offsite billabongs to exceed the site specific guideline (to be determined). Refer to Figure 6-5 for higher tier assessment approaches.	W3	C7
		Mine sourced solutes do not cause increased uranium in sediments off the RPA to levels detrimental to ecosystem health of the region.	U in sediments	Uranium concentrations in billabong sediments off the RPA do not cause a detrimental impact. **First tier screening criteria:** Average sediment concentrations are less than site specific field based ecotoxicological effects of 94 mg U/kg (dry weight).	W4	-
3.1 and 1.2(e)	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.	Surface water quality on the RPA meets the highest ecosystem protection level that is demonstrated to be as low as reasonably achievable. Accumulation of erosion products in Coonjimba and Georgetown Billabong will be ALARA.	Mg, U, Mn, NH_3-N Sedimentation	On the RPA water quality in Magela and Gulungul Creek and sedimentation in the billabongs will be ALARA.	W5	-

6.4.1 Justification for Outcome, Parameter and Criteria

The closure criteria assessment approach for water and sediment has been developed using a combination of site specific and national water quality guidelines as screening criteria within a risk-based, tiered assessment process. Constituents of potential concern (COPC) present in tailings/process water or waste-rock sources, described in Chapter 7, Section 7.4.3.3, were identified by the water and sediment technical working group as needing a hazard assessment and/or requiring closure criteria (Iles & Humphrey, 2014).

Several metals originating from mill tailings/process water have been excluded from the criteria list based on a risk analysis comparing previous modelling results to guidelines or limits (refer Chapter 7, Section 7.4.3.3). Waste-rock and tailings/process water derived COPC carried through to the criteria list are the same as the key variables that are currently monitored, which were also selected on the basis of risk (Frostick *et al.*, 2012, Klessa, 2000, Turner & Jones, 2010), i.e.:

- Potential toxicants uranium (U), manganese (Mn), ammoniacal nitrogen (NH_3-N), magnesium (Mg).
- Major ions calcium (Ca), which ameliorates Mg toxicity and sulfate (SO_4).
- Stressors with the potential to cause eutrophication N and P (in various forms, including nitrate and nitrite which are also drinking water parameters).
- Turbidity.

Radionuclides are discussed in sections on radiation criteria (Section 6.3).

Concentrations of COPC mobilised from the decommissioned site will be predicted for the dissolved, particulate and accumulated sediment phases and measured during the water and sediment monitoring program (Chapter 11). Predicting concentrations of uranium in sediments will involve accounting for accumulation in sediments based on locally derived sediment partition coefficients (refer Section 7.4.3.3).

The predicted and measured concentrations/loads of these COPC will be compared to screening criteria derived from; (i) national drinking water and recreations guidelines values; and (ii) site-specific and ANZECC guidelines values for ecosystem protection.

This is the first step in a risk based tiered approach in determining whether mine derived analytes have/will cause drinking or recreational criteria to be exceeded, or a 'detrimental impact to the environment'.

The following sections describe the screening criteria and risk based tiered approach for water and sediment closure criteria. The supporting studies for the derivation of site-specific guideline values referred to below are provided in Chapter 7, Section 7.4.3.4.

6.4.1.1 Risk Based Tiered Approach to Water and Sediment Closure Criteria and ALARA

Determining if closure outcomes in the water and sediment theme are met is by an assessment process, rather than compliance with a single numeric criterion. Science and risk based tiered assessments are a standard approach to assess environment and health effects or risk and is the approach recommended in the EnHealth (2012) national guidance for conducting

environmental health assessments, which says *"…an exceedance of a standard or guideline or other indicator of 'safety' by a derived risk assessment number should always trigger further consideration of the situation being assessed."*

Other notable national and international examples of tiered risk assessments triggered by exceeding guideline values (hereafter called 'screening criteria') include: the Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework (NICNAS, 2013); National Environment Protection Measure (NEPM) Schedule B(4) and B(7) (NEPC 2013); the Australian drinking water (NHMRC & NRMMC, 2011) and recreational (NHMRC, 2008); and national water and sediment guidelines (ANZECC & ARMCANZ, 2000, Simpson *et al.*, 2013),. ANZECC & ARMCANZ (2000; p8.5-7) identified the need to adopt such approaches for assessing ecological risks: *"Additionally, the risk-based approach introduced into the new Guidelines needs further development in its own right, and also to make it consistent with other ecological risk assessment approaches, for example, that recently introduced in Australia for contaminated sites."* Radiation dose assessments for humans, plants and animals also use these types of approaches (refer Section 6.3).

The assessment effort of these tiered approaches increases with each tier. In assessing potential environmental and/or health impacts of concentrations greater than the screening value, consideration is given to both the ensuing potential for exposure and consequences of such exposures.

Recreation and diet

Figure 6-3 and 6-4 are indicative of closure criteria decision trees to assess if recreation and drinking water outcomes derived from the Primary ERs are met.

The screening guideline values for the drinking water and recreation are from the Australian drinking water guidelines NHMRC & NRMMC (2011v3.4). In addition to comparing COPC concentrations to these guidelines values, an assessment of risk from water quality to the traditional diet, including drinking water, will be undertaken by a specialist. This assessment will be based on the water quality predictions from the surface water model.

The Australian recreation guidelines (NHMRC, 2008) provide recreation water quality guidelines for chemical hazards, pH and dissolved oxygen, and suggest using 10 times the drinking water guidelines as a simple screening approach to identify COPC that may merit further consideration where waters might be swallowed during recreation. NHMRC (2008) also says *"… waters contaminated with chemicals that are either toxic or irritating to the skin or mucous membranes are unsuitable for recreational purposes…"* However the NHMRC (2008) guidelines do not provide a list of irritants or guideline values for such chemicals, whereas ANZECC & ARMCANZ (2000) do. Screening values for the only irritants on the COPC list (sulfate and manganese) are therefore taken from ANZECC & ARMCANZ (2000).

The same parameters identified for drinking water are used as suggested above. The irritant guideline values for sulfate and manganese are more restrictive than using the drinking water times ten approach and so are used.

The lower range in Magela Creek is less than the guideline suggested for poorly buffered low ionic strength waters by NHMRC (2008). Turner *et al.* (2015) show that the natural range of pH

in Magela Creek is 4.7 to 7.9 and is highly variable. They consider 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 criteria for recreation purposes.

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. Dissolved oxygen is also not considered a parameter that requires a criteria for recreation purposes.

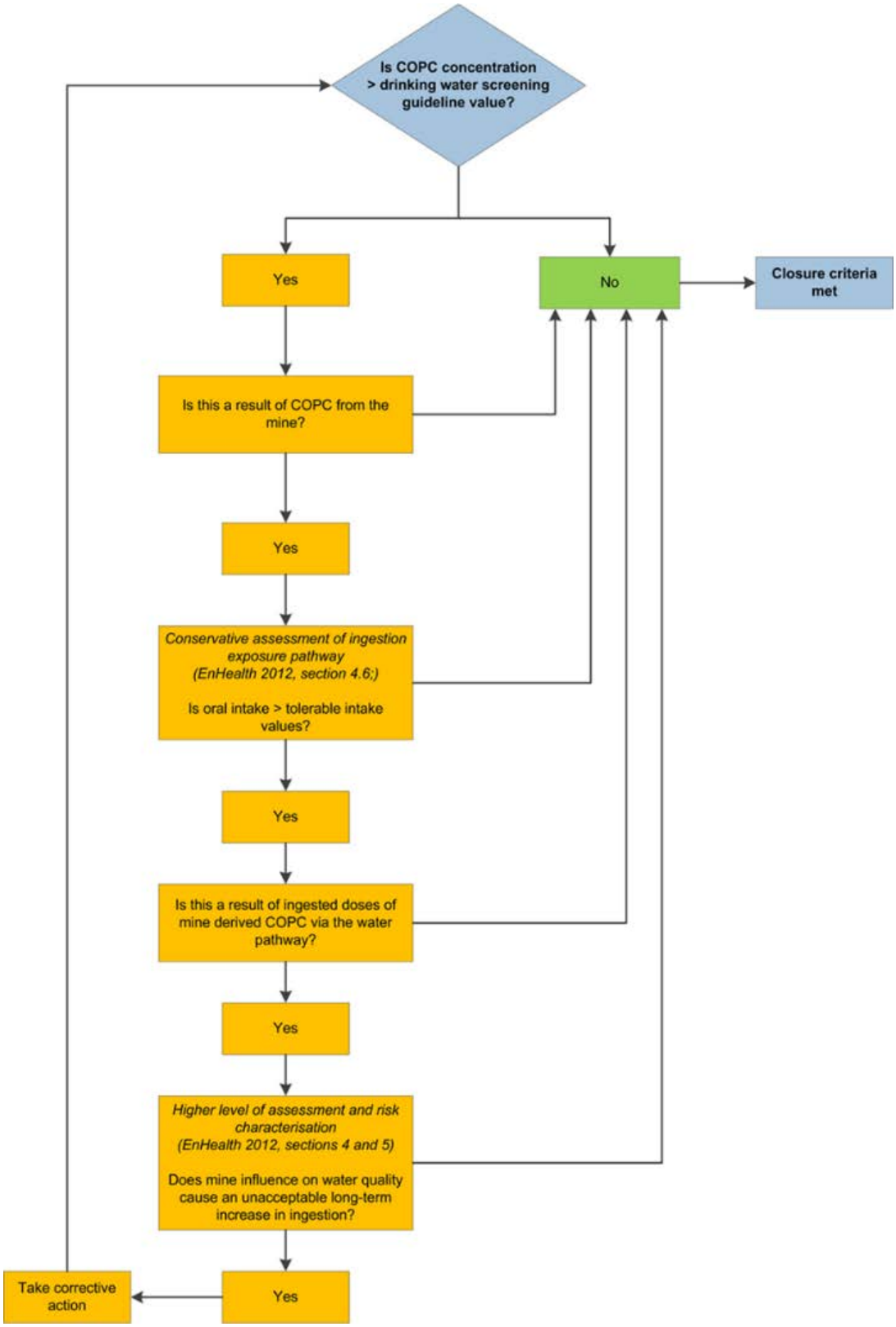

Figure 6-3: Indicative risk based tiered decision tree for *drinking water* outcomes

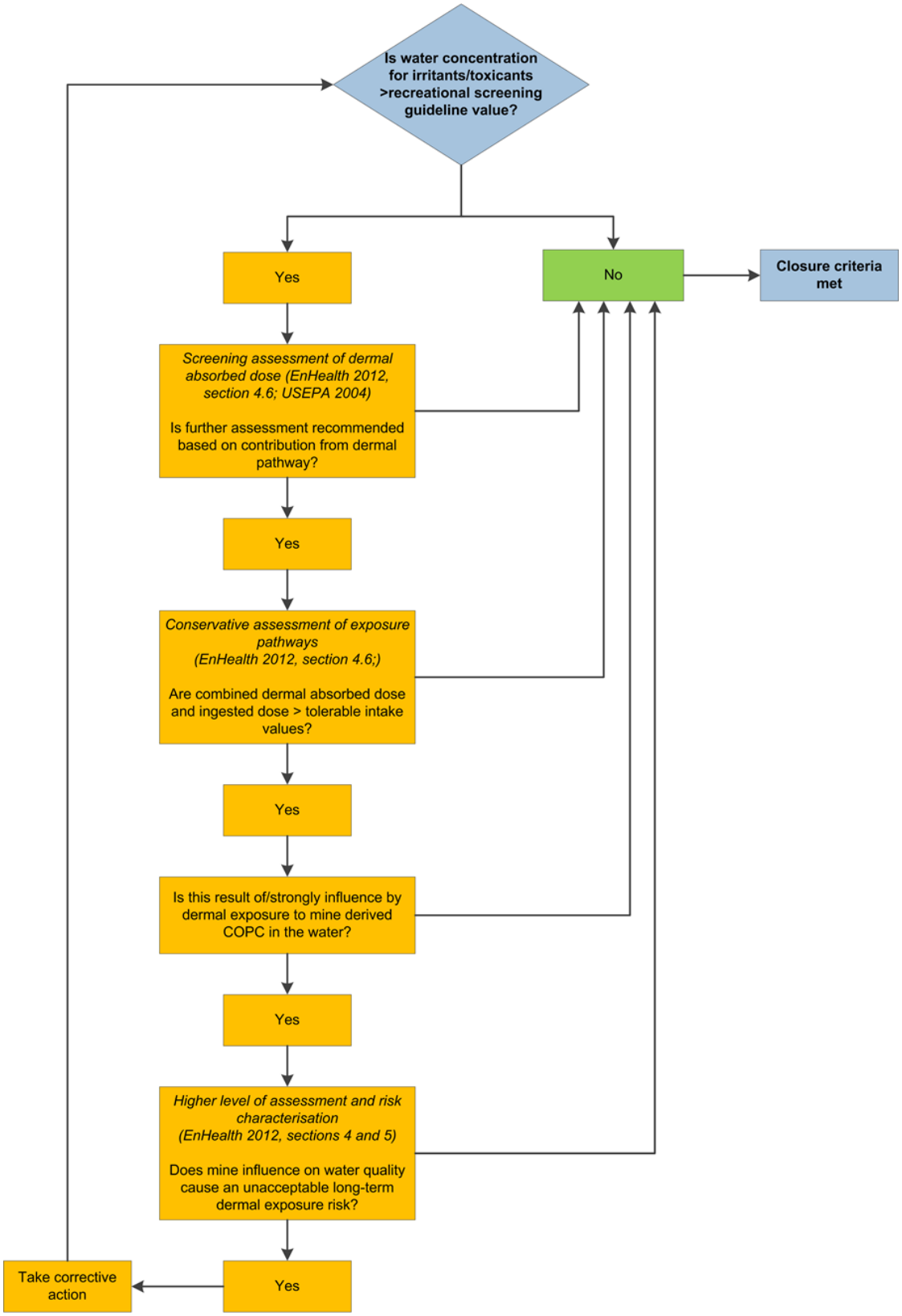

Figure 6-4: Indicative risk based tiered decision tree for *recreation water* outcomes

The screening values for ecosystem protection are the site-specific guideline values summarised in Table 6-3 and described further in Chapter 7, Section 7.4.3. Information from additional studies (planned or underway) to address identified key knowledge needs (e.g. toxicity of mixtures; site specific eutrophication assessments, acid sulfate soil potential and effects) may result in changes to guidelines. Such updates and changes will be captured in future iterations of the closure plan.

Ecosystem protection

ERA has contracted BMT WBM Pty Ltd to assist in further developing the decision tree and framework approach for assessing if an exceedance of a screening criteria results in a unacceptable change to the ecosystem, including whether any biodiversity changes are different from, and detrimental to, the biodiversity of the Alligator Rivers Region considering impact components such as duration of impact, geographic extent of impact and impact recovery. Figure 6.5 shows how a decision tree approach can be used for such purpose. This tree will be updated to incorporate improvements suggested recently by the Supervising Scientist Branch to align it with the revised national Water Quality Management Framework and from the GAC to incorporate the relevant cultural criteria (refer Section 6.7).

The framework will consider impact components such as duration of impact, geographic extent of impact and impact recovery, and assesses other environmental values from the Primary Environmental Objectives.

The proposed approach, which is being developed with stakeholder input, will improve understanding and increase transparency of this assessment process through the following key points:

1. Drive agreement on the environmental values present in affected waterbodies noting these need to reflect the World Heritage, Ramsar, Community Health and Biodiversity and Ecosystem Function objectives from the Primary Environmental Objectives.

2. Acknowledging that these values need to be expressed at a practical geographic scale for management from the highly localised scale (such as an individual billabong or creek reach) through to sub-catchment, catchment and broader Alligator Rivers Region scale.

3. Determine corresponding water quality and/or biotic indicator values or limits that must be met to protect the stated environmental values. (It is likely that the guideline values for protecting biodiversity will be the most stringent.)

4. Develop more sophisticated measures of whether changes are detrimental noting changes to water quality and/or to assemblages of macroinvertebrates and aquatic flora may not necessarily mean a change to ecosystem state or the loss of a key ecosystem function.

5. Where biodiversity and ecosystem function cannot be assured (either temporarily or permanently), being able to better understand and communicate what are the implications of that loss.

The approach will be particularly important to decision-making about the acceptability of any expected changes to biodiversity values off the RPA and will contribute to guide ALARA on site (see Chapter 11, Section 11.3.1). This work should be completed in 2018, and will result in improved decision trees and possibly changes to the screening criteria, which will be reflected in the next iteration of the MCP.

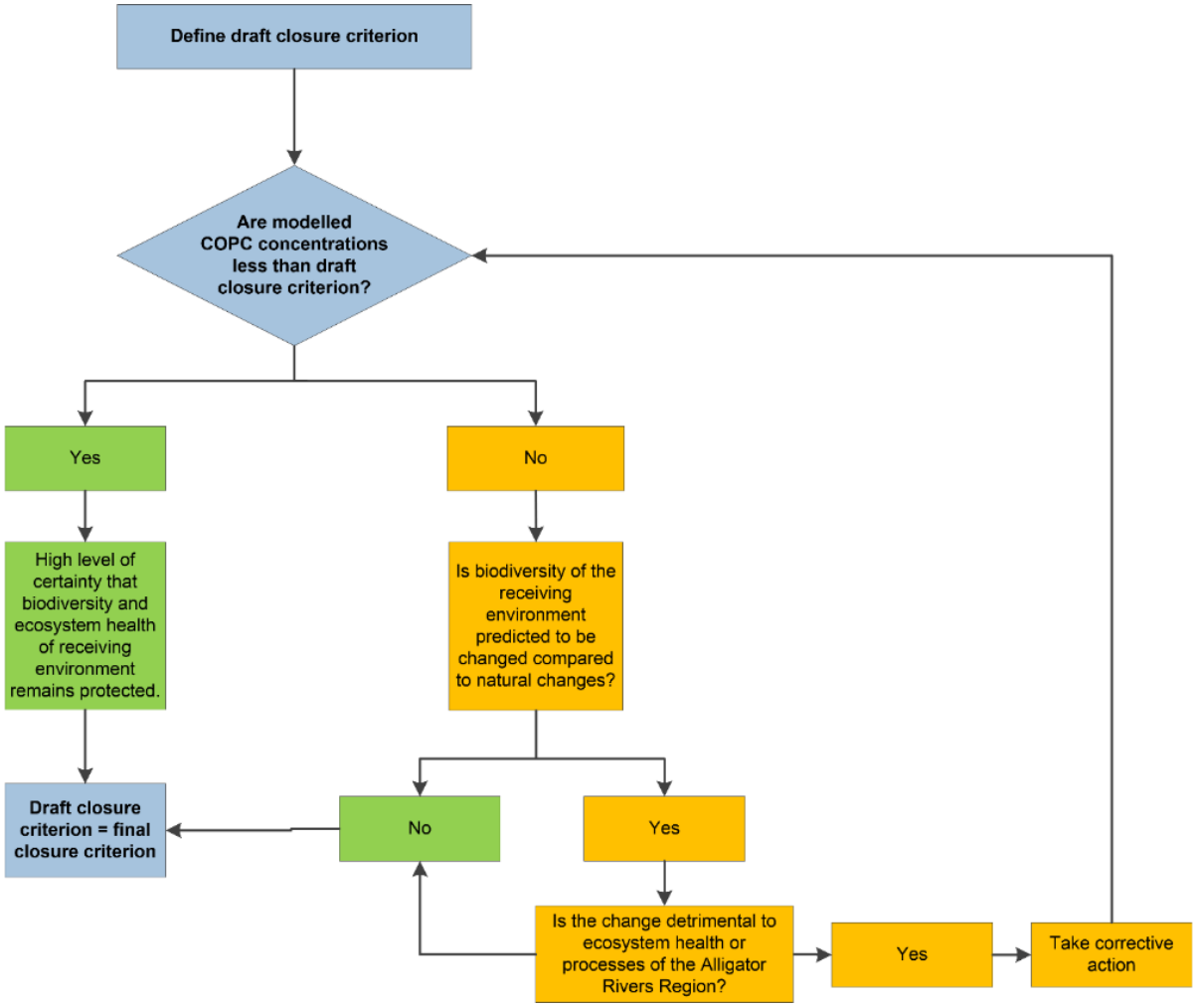

Figure 6-5: Indicative risk based tiered decision tree for *ecosystem protection* off the RPA

6.5 Flora and Fauna

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

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

Three outcomes have been derived from this objective:

First outcome - relates to the use of local native plant species;

Second outcome - relates to the species composition and community structure being similar to Kakadu National Park (KNP); and

Third outcome - relates to the long term viability of the ecosystem and the associated maintenance regime.

Table 6-4 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcome and the proposed closure criteria. In some cases corrective action is also provided in the case 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.

Section 6.5.1 provides justification for the outcomes, parameters, and closure criteria for each of the key elements of flora and fauna.

Table 6-4: Closure criteria – flora and fauna

ER	Objective	Outcome	Parameter	Final Criteria	Corrective Action	ID	Cultural link
2.2 (a)	Revegetation of the disturbed sites of the Ranger Project Area using local native plant species similar in density and abundance to those existing in adjacent areas of Kakadu National Park, to form an ecosystem the long term viability of which would not require a maintenance regime significantly different from that appropriate to adjacent areas of the park	Revegetate the disturbed sites of the RPA using local native plant species.	Provenance	Revegetation has used local native species from within KNP.	Revise revegetation list before planting	F1	C10
		Species composition and community structure is similar to adjacent areas of KNP	Species composition (tree and shrubs) and species relative abundance	Bray-Curtis similarity index ≥15 – 30 percent. Total species number over 400 ha ≥ 35.	Infill planting Soil amelioration Weed management Fire management	F2	C10 C12
			Canopy architecture	Presence of multi-strata. Presence of ground floor shrubs and grasses developed appropriate to the substrate.		F3	C9 C10
			Canopy cover index, ground cover index	Comparable to analogue sites, using standard NT vegetation survey methods.		F4	C9
			Tree distribution	Trees are planted in a manner to appear 'natural'.	Plant thinning and/or infill planting	F5	-
		Long term, viable ecosystem requiring maintenance similar to adjacent areas of KNP	Reproduction (flowering and seeding)	Evidence of flowering and fruiting of 80 percent of framework species or characteristic species (based on species present).	Infill planting	F6	C10
			Recruitment / regeneration	Presence of seedlings and/or 'suckers' of 80 percent of framework species or characteristic species (based on species present).	Infill planting Weed management Fire management	F7	C9 C11
			Nutrient cycling	Accumulation of litter and organic matter. Evidence of decomposition of litter. Presence of soil animals and saprophytic fungi. The above criteria occur in 90 percent of the survey plots.	Infill planting Soil amelioration	F8	-
			Fire resilience	Vegetation demonstrates resilience similar to analogue sites in response to fire	Infill planting Weed management Fire management	F9	-
			Resilient to wind and drought	Woodland ecosystem demonstrates survival under natural condition, similar to analogue.	Infill planting of resilient species	F10	C8
			Plant available water	Modelling predicts the store-release waste rock cover layer will provide sufficient plant available water for long-term vegetation growth.	Modify landform construction methods prior commencement of material movement.	F11	
			Weed composition and abundance	No Class A weeds. Class B weeds similar to surrounding KNP. Presence of other introduced species would not require a maintenance regime significantly different from that appropriate to adjacent areas of KNP.	Increase weed management activities	F12	C11
			Native fauna	Presence of major functional groups (vertebrate and invertebrate). Feral animals (specifically buffalo, horses and pigs) are similar in density on the RPA compared to the adjacent areas of KNP.	Habitat creation/improvement Correct plant species Feral management	F13	C12

6.5.1 Justification for Outcome, Parameter and Criteria

Derivation of the flora and fauna criteria is underpinned by an understanding of both general ecological restoration principles (McDonald *et al.*, 2016), ecosystem dynamics in northern Australia, and the knowledge gained through 30 years of flora and fauna studies, revegetation trials and research on RPA and surrounding areas, particularly in relation to the establishment of overstorey/framework species. Background information on the various aspects of analogue site selection and the research underpinning the trial landform; plant available water; flora and fauna baseline monitoring; landform design, performance and properties; and, ecosystem establishment is provided in Chapter 7, Sections 7.3, 7.5 and 7.6, respectively.

The closure criteria for flora and fauna were developed through information from reference sites and trials; while also taking into account the permanent and irreversible changes to the site. The topography hydrology and substrate of the final landform will be different to the pre-mining environment and there is no real analogue in the natural surroundings, which means that a local indigenous ecosystem more ecologically appropriate to the changed conditions may be used as a guide for revegetation of the site (McDonald *et al.*, 2016). Therefore, the reference ecosystem in the case of Ranger mine will be a conceptual model synthesised from numerous reference sites, field indicators, and historical and predictive records.

When assessing rehabilitation performance, there are some criteria that can be considered 'critical', stand-alone criteria necessary to ecosystem establishment, such as the use of only local native flora species. However, some criteria such as canopy architecture and ground cover index, are better assessed collectively, or within the context of meeting the overall closure criteria as a whole.

Further information on the justification for each component of the flora and fauna theme is provided in Sections 6.5.3 to 6.5.5 including: locally native species; species composition and community structure; and long term viability of the ecosystem.

6.5.1.1 Local Native Plant Species

The first outcome for flora and fauna is that the disturbed site must be revegetated using local native plant species. In order to determine what would be considered as "local" a number of studies have been conducted on seed provenance and consultations have occurred with GAC (refer Chapter 7, Section 7.6).

In order to achieve this criterion, a revegetation species list was developed in consultation with stakeholders, in particular this was based on:

- Previous analogue vegetation studies in undisturbed areas of the RPA and surrounding areas by ERISS-ERA (125 studied analogue sites, including 10 sites from KNP with land surface similar to Ranger’s final landform).
- Recent list of culturally important plant species, identified by the Mirarr traditional owners in Garde (2015).
- Learnings from progressive revegetation activities and in particularly the learnings from the trial landform.

The species list will undergo refinement from a local native seed expert (Kakadu Native Plants Pty Ltd) for assessment of appropriateness based on their local expertise on vegetation, habitats, and seed availability, viability, germination and nursery production rates. A final revegetation species list will be included in the revegetation implementation plan.

Achievement of this criterion will be prior to planting, through confirmation that the agreed species list has been used.

6.5.1.2 Community Composition

The second outcome is that species composition and community structure is similar to adjacent areas of KNP. Four parameters are being proposed to measure the achievement of this outcome, which are described in the following sections.

Species composition and relative abundance

Plant species composition and relative abundance in the RPA and surrounding natural analogue sites have been studied extensively and have been summarised in Chapter 7, Section 7.6.3. As described in Chapter 7, Section 7.6.3, the Bray-Curtis similarity index will be used as the parameter to demonstrate that the re-established vegetation in similar to the surrounding areas. Different types of natural vegetation studied by ERISS and ERA showed similarity (relative percent density) ranging from about 10 percent to 30 percent. As a criterion, any similarity that falls within this range shall be acceptable (refer Chapter 7, Section 7.6.3).

Supervising Scientist has recommended that the total number of species be assessed over an area of 400 hectares. The total number of species that will be planted during Phase 1 of the revegetation program is 49 (refer Chapter 7, Table 7-23 for the flora species list). Considering the various confounding factors to success that include availability of seeds, success of seed germination, raising seedlings, suitability of the substrate, and natural recruitment, a criterion of 70 percent (or greater than or equal to 35 species) is being proposed.

Canopy architecture, ground cover index

Natural vegetation communities in the KNP are multi-strata, providing complex habitats which attract diverse fauna species. The revegetation will comprise upper storey, middle storey and understorey species to create habitats similar to those in the surrounding KNP.

The canopy cover index and ground cover index are two indices commonly used to assess the structure of vegetation communities. It is expected that the canopy cover index will fall within the natural range of the analogue vegetation.

Ground cover is an indicator of the quality of the habitat for ground dwelling fauna and also the surface resistance to erosion. Therefore the ground cover shall include cover provided by a range of items including vegetation, rock, and debris (Catling & Burt, 1995).

Assessment of achievement of these criteria will be based on surveys conducted according to the Northern Territory vegetation survey guidelines (Brocklehurst *et al.*, 2007).

Tree distribution

The GAC has proposed cultural criteria that the revegetation shall look natural, rather than as a planting (Garde, 2015). Therefore, the design of revegetation will aim to simulate natural distribution, rather than planting in rows. Assessment of achievement will be through consultations with the GAC and NLC.

6.5.1.3 Long Term Viability of the Ecosystem

The third outcome is to achieve a long term, viable ecosystem requiring maintenance similar to adjacent areas of KNP. There are eight parameters proposed to measure the achievement of this outcome, which are described in the following sections.

Reproduction (flowering and fruiting)

Under normal conditions reproductive (sexual) propagation is the key to the survival of the vegetation population. Flowering and seeding also provides other vital ecological functions such as pollen, nectar and seeds for various insects, birds and other animals, and cultural function such as bush foods and traditional produce (such bush soaps). Considering the time frame over which revegetation will be assessed, it is not considered reasonable to expect 100 percent species will flower or seed. Therefore, a target of 80 percent of framework or characteristic species (based on species present) is reasonable and achievable.

Recruitment and regeneration

Under current land management practices in the area, particularly fire management regimes, the majority of the successful natural regeneration of terrestrial plants is via vegetative propagation (e.g. root suckers). Therefore, recruitment and regeneration of vegetation will include regeneration from both seedlings and root suckering. Based on the number of plant species that will be used on the final landform and estimated survival rates, a target of 80 percent of framework or characteristic species (based on species present) is reasonable and achievable.

Nutrient cycling

The process of nutrient cycling will be important for the ongoing sustainability of revegetation, and can be assessed through observing the development of litter cover, its depth and type, and on the degree of decomposition (Ludwig *et al.*, 2003). ERA will also assess the presence of soil organisms including saprophytic fungi (including wood rotters for woody stems and logs). To further qualify this criterion, the presence of litter, organic matter, and soil organisms in 90 percent of the plots is considered reasonable.

Fire, wind and drought resilience

The revegetation will use locally native species in similar proportions to surrounding communities, and it is considered their fire resilience characteristics should be similar. The other main determinant of fire resilience is plant size. While almost all Eucalypts recover from fire at 8 months of age (CSIRO fire trial at Territory Wildlife Park[1]), it disrupts normal plant growth. ERA research

[1] A. Anderson 2016, pers. comm., 29 July.

found that a diameter of greater than six centimetres is an indicator of when trees are resilient to fire and regrowth could take place without significant impact (Gardener *et al.*, 2007). Based on ERA's trial landform studies and also other studies on the RPA, it is expected that the majority of the species planted as tubestock would attain a diameter of six centimetres within five to seven years after planting. The proposed revegetation strategy therefore requires fire exclusion of the revegetation area for five to seven years.

Following this initial exclusion timeframe, fire will be introduced in a controlled manner prior to allowing uncontrolled fire entry. This end state has been selected as the final criteria, where the vegetation must demonstrate similar resilience to that of the surrounding analogue areas. Assessment of achievement will be through a post-fire vegetation survey of an area determined in consultation with the Supervising Authority.

Resilience to wind and drought of the revegetated area will be dependent upon the development of the root system. Early watering of the revegetation post planting can decrease the risk of mortality; however, long term watering can lead to shallow root development and decrease resilience to wind and drought. The current revegetation strategy involves early watering, then periods of no water to ensure appropriate root development. Assessment of achievement of this criterion will be through surveys conducted post any events.

Plant available water

A key parameter in long term revegetation success is the availability of water for the mature revegetation. As there are limited mitigations available to correct any identified issues with the landform, landform design and the construction methods will be key to ensuring that water will be available in the long term. The criterion being proposed is therefore to utilise modelling to predict the plant available water in the store and release waste rock cover. This will need to be sufficient to allow long term vegetation growth.

Studies have been conducted on the potential plant available water in the waste rock substrate of the trial landform, refer Chapter 7, Section 7.3.5. The current landfill construction and pit backfill design and methods outlined in Chapter 10 have been based on these studies.

Weeds

In order to have a maintenance regime similar to that of the surrounding KNP, weed populations will need to be similar. Criteria being proposed are based on the Northern Territory legislation. No class A weeds will be allowed on the site and class B weeds will be similar to the surrounding areas. In addition to the prescribed weeds there are also some introduced species that have the potential to increase the maintenance programs above that of the surrounding KNP, for example Annual Pennisetum. Any weed that is assessed as presenting this risk will be monitored and demonstrated to be in similar density to the surrounding area.

Demonstration of achievement will be through weed survey conducted according to the Northern Territory Weed Management Branch Guidelines (2015a, b).

Native fauna

An extensive body of work has been undertaken regarding the terrestrial fauna species known to occur on the RPA and is summarised in Chapter 2, Section 2.4.4. In light of the above studies, ERA proposes the following criteria:

- Presence of major functional groups (vertebrate and invertebrate) that will be assessed using the methods outlined in Corbett (1999).
- Feral animal numbers on the RPA (specifically buffalo, horses and pigs) are similar in density to the adjacent areas of KNP, as per the Primary ERs. ERA's revegetation and post planting land management plan will clearly state the commitment to control feral animals, the selected feral animals are those that have the ability to be controlled.

One potential challenge with the ability to determine achievement of the feral animal criterion is that KNP currently do not currently have data on the feral density. This data will be requested from KNP during the closure process in order to clarify this criterion.

A summary of how the closure criteria for flora and fauna will be assessed is provided in Table 6-4.

6.6 Soils

ERA maintains a register of all contaminated sites on the RPA, which includes information on the location, land use activity, potential contaminants and an assessment of the risk the contaminants pose to the surrounding environment, including human health (refer Chapter 7, Section 7.4.2). Targeted assessments have been undertaken, predominantly focussing on identifying groundwater contamination. However, soil profiles were also completed at known contaminated sites to define the lateral extent of contaminating processes on site in the soils and shallow groundwater.

These data have been used to develop conceptual site models for known areas of contamination, which are used to understand migration of Ranger COPC through soils, groundwater, and surface water under current and post-closure conditions (Chapter 7, Sections 7.4.2 and 7.7). Modelling indicates that contaminants in the shallow soils are in the near vicinity of the source (refer Chapter 7, Sections 7.7.1.10 and 7.7.1.11). In relation to the potential risk of contaminated soils within the RPA impacting the environment outside the RPA, the land application areas for example, will be remediated during decommissioning and are unlikely to be a significant source of solutes during post-decommissioning.

From the perspective of closure criteria, there is one objective derived from the ERs relating to the soils theme, 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.*

Based on this, the outcome for any contaminated soils is that they will be remediated to ALARA to protect the environment.

Table 6-5 provides a summary of the closure objectives, the outcomes derived from this objective, parameters used to measure the outcome and the proposed closure criteria. For the case of soils no link to cultural criteria has been identified to date. This may change for future updates of this MCP

Section 6.6.1 provides justification for the outcomes, parameters, and closure criteria for each of the key elements of the soils theme.

6.6.1 Justification for Outcome, Parameter and Criteria

Preliminary site investigation will be completed for all identified contaminated soils that are not already in the process of remediation as part of the larger decommissioning works (i.e. land application areas).

If soil concentrations in these locations are shown to be below either local background concentrations or the published investigation levels (i.e. Health Investigation Level (HIL) and/or Environment Investigation Levels (EIL)) then no further remediation or assessment will be required.

If they are above the these levels then a more detailed site investigation will be required to determine if the risk to public health and/or the environment from the soils will be ALARA. If adequate information is already available, a remediation plan will be developed.

Achievement of this criterion will be either 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 6-5: Closure criteria – soils

ER	Objective	Outcome	Parameter	Final criteria	ID	Cultural link
1.2 (e)	The company must ensure that operations at Ranger do not result in: (e) environmental impacts within the Ranger Project Area which are not as low as reasonably achievable, during mining excavation, mineral processing, and subsequently during and after rehabilitation.	Impacted soils are remediated to as low as reasonably achievable to protect the environment.	Contaminated soil assessment for uranium and manganese in LAA.	Demonstrate risk is ALARA	S1	-
			Contaminated assessment of identified COPCs for other soils identified as not being part of the larger decommissioning works	Demonstrate risk is ALARA	S2	

6.7 Cultural

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

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

ER 1.1 (a) requires that ERA maintains the attributes for which KNP was inscribed during the operational phase. 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, stating that it must be rehabilitated to a standard that could be incorporated into KNP, linking rehabilitation to the requirement to no impact on the World Heritage Values of KNP.

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

Table 6-6 provides a summary of the closure objectives, the outcomes derived from these objectives, parameters used to measure the outcome and the proposed closure criteria. Each cultural criterion has been numbered to show links to the various other closure criteria listed in the previous sections.

Section 6.7.1 provides justification for the outcomes, parameters, and closure criteria for each of the key elements of the cultural theme.

Table 6-6: Closure criteria – cultural

ER	Objective	Outcome	Parameter	Final criteria	ID #	Other criteria link
1.1 (a) 2.1	The company must ensure that operations at Ranger are undertaken in such a way as to be consistent with the following primary environmental objectives: (a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list; The company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park.	Landform design supports cultural land use: An-berrk, savannah woodland An-bouk, riparian margins An-gabo, water courses An-labbarl, billabongs Traditional owners satisfied with the landform.	Size of rocks	≥7 Surface rock suitability verified by Bininj monitoring - confirm mostly correctly sized	C1	
			Presence / absence of erosion	≥7 Erosion verified by Bininj monitoring – limited to very minor concerns and only small areas	C2	L5, L6, L8, L9
			Accessibility, traversability[2]	≥7 Traversibility verified by Bininj monitoring – limited to minor difficulties only and few in number	C3	L5, L6
			General aesthetics (does it look 'natural')	≥7 Natural aesthetic verified by Bininj monitoring – confirm most areas look natural, limit of a few not satisfactory	C4	L7
		Traditional owners are observing improvement in the progression of revegetation on the landform	Vegetation growth rate	≥7 Growth rate verified by Bininj monitoring – relative to the number of seasons, the growth of plants across all areas is satisfactory and is improving	C8	F10
			Vegetation diversity	≥7 Diversity verified by Bininj – all of the expected species are present in a natural combination in nearly all of the area	C9	F3, F4, F7
			Correct species for ecological zone	≥7 Species verified by Bininj – all of the species are correct for nearly all ecological zones	C10	F1, F2, F3, F6
			Presence of weeds	≥7 Weeds verified by Bininj – weeds are present in only a minor portion of the area, low level of concern	C11	F7, F12
		Traditional owners are satisfied that there are not additional water bodies present	Presence or absence of artificial water bodies	Absence of water bodies verified by Bininj monitoring – no artificial water bodies present	C5	L1
		Traditional owners satisfied with the water quality and that no silting or sedimentation is occurring	Visual impressions of water quality (colour, flow, expected clarity, visible contaminants), silting, sedimentation.	≥7 Water quality verified by Bininj monitoring – water appears to be of high quality in most areas, only very minor water quality concerns	C7	L1, L11, W2, W3
		Traditional owners satisfied that the riparian zones are in good condition	Condition of water course margins, creek banks	≥7 Watercourse margins and creek banks verified by Bininj monitoring – appear to be in a natural condition in most of the area, only minor concerns	C6	L1, L10
		Traditional owners are observing improvement in biodiversity on the landform	Natural species numbers and diversity appropriate for stage of rehabilitation	≥ Species numbers and diversity verified by Bininj monitoring – natural species occurring according to expectations for natural rate relative to the number of seasons and is improving	C12	F2, F13
		Traditional owners are satisfied with the final landform and state of key landmarks	Line of sight assessment prior to finalising landform design	Visual connection with key cultural sites verified by Bininj monitoring – sites visible from the same areas and to the same extent as prior to disturbance	C14	-

[2] Bininj may pragmatically 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.

6.7.1 Justification for Outcome, Parameter and Criteria

In determining the success of the rehabilitation over time, significant emphasis will be placed on ensuring that culturally important flora and fauna are present on the final landform. Garde (2015) speaks to the importance of social organisation, moieties, and conceptions of landscapes; all of which, if not satisfactorily addressed, will ultimately influence the assessment by Mirarr of the rehabilitation.

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

The cultural health indices described in Garde (2015) have been taken as the parameters for cultural closure criteria with proposed final endpoints presented in Table 6-6. 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 traditional owners' attitudes towards the progress of rehabilitation are largely based on visual and aesthetic factors proposed in Garde (2015), provided in Table 6-7.

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

Table 6-7: Suggested indicators of cultural health of rehabilitated site (Garde, 2015)

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

The design of the program will involve long-term periodic assessment of attitudes and opinions of traditional owners and their kin in relation to the dynamics of rehabilitation over time. These assessments will be undertaken annually and will determine whether or not the traditional owners feel that rehabilitation in the RPA is progressing towards a desirable trajectory.

Measurements of impressionistic responses are scalar and individual indices are averaged out to provide a score. Scalar numeric assessment will also be accompanied by discursive data that provides a rationale for the score given. There is provision to provide other comments; these are hoped to provide an indication of areas that require management. Scores are to be calculated annually and then compared to determine whether or not perceptions of rehabilitation are moving in a trajectory that demonstrates achievement of cultural objectives as determined by traditional owners and their relevant kin.

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

The assessment scale will be in a bilingual format that includes information in both Gundjeihmi and English. Each site will not necessarily be assessed for all indicators as some may not be relevant. For example, an indicator such as size of rocks will only be relevant at those sites where high levels of disturbance has required reconstruction of the landform with waste rock. Riparian sites will be assessed for relevant indicators which will not apply to other areas e.g. condition of water course margins will obviously not apply to assessment of areas away from water courses. An example of what the scalar measurement tool has been provided in Table 6-8.

Table 6-8: 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 Gundjeihmi Aboriginal Corporation has proposed a series of workshops and meetings with Mirarr participation to progress this work.

Cultural criteria for closure monitoring will be conducted at a number of sites that collectively provide a cross section of the range of site types where rehabilitation has been undertaken. An assessment of cultural criteria will need to be completed at each of the selected sites on an annual basis. The monitoring of these sites is described in Chapter 11, Section 11.6.

6.8 Status of Closure Criteria

As outlined previously, ERA released the draft MCP to stakeholders in late 2016, and received comments on the plan and criteria in mid-2017. Feedback from the Supervising Scientist on the criteria in the 2016 draft MCP was that 53 percent were agreed to, 43 percent were partially agreed to and 4 percent not agreed to. The breakdown of the agreement status by closure theme at the time is shown in Table 6-9 and Figure 6-7.

Cultural criteria have been developed in direct consultation with the Gundjeihmi Aboriginal Corporation, initially through consultation with anthropologist and linguist Murray Garde and more recently refined. SSB have not commented on the cultural criteria so these have not been included in this section.

Table 6-9: Stakeholder acceptance of ERA draft criteria in mid-2017

Theme	Number of criteria	Acceptable	Partially acceptable	Not acceptable
Landform	11	6	5	0
Radiation	4	4	0	0
Water and sediment	5	0	3	2
Flora and fauna	13	3	10	0
Soil	1	0	1	0
Total	**47**	**25**	**20**	**2**

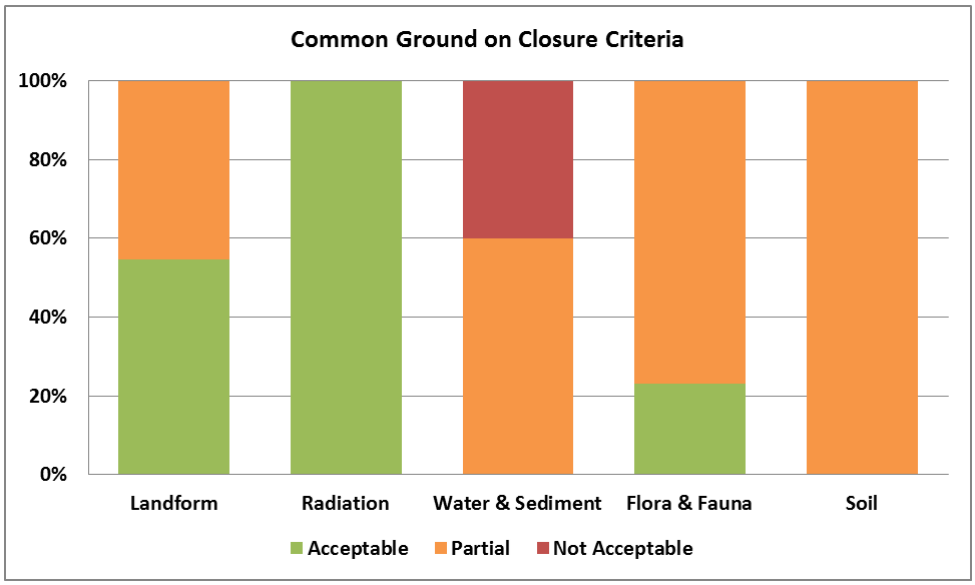

Figure 6-6: Stakeholder acceptance of ERA draft criteria in mid-2017

Updates to the MCP address many aspects of disagreement in each theme. Since the 2016 draft criteria and responses from Supervising Scientist Branch (SSB) both ERA (and consultants) and SSB (and consultants) have completed or progressed several projects to address outstanding issues for closure criteria finalisation and agreement.

ERA is responsible for the development of closure criteria. The Supervising Scientist is developing a series of rehabilitation standards. They are the standards the Supervising Scientist considers must be met to achieve the rehabilitation objectives. They are advisory only but will form a key component of the Supervising Scientist's advice on rehabilitation activities at Ranger.

As of mid-2017 (when SSB provided comments on ERA's draft criteria), their draft rehabilitation standards were in various stages of development (Table 6-10). Drafts for radiation (for humans and wildlife), and uranium, manganese and magnesium in surface waters are essentially complete, while advanced drafts exist for others including ammonia in surface waters, sulfate in surface waters (for acid sulfate soils), landform stability and erosion, and flora. For others, further work is underway or being scoped, to provide the necessary information to complete them.

Table 6-10: Progress of the Supervising Scientist's rehabilitation standards as at June 2017 (source: Supervising Scientist Annual Technical Report 2016-17)

Closure theme	**Rehabilitation standard**	**Estimated percentage completion**
Landform	Landform – stability and erosion	80%
Radiation	Dose to humans	95%*
	Dose to wildlife	95%*
Water and sediment	Magnesium (surface water)	95%*
	Uranium and manganese (surface water)	95%*
	Uranium (sediment)	50%
	Ammonia (surface water)	70%
	Nutrients (surface water)	50%
	Turbidity (surface water) and sedimentation	30%
	Sulfate – acid sulfate soils (surface water)	80%
	Herbicides (surface water)	10%
	Other contaminants of potential concern (surface water)	80%
Flora and fauna	Flora	80%
	Fauna	0%
Soils	Contaminants of potential concern	0%
* Drafts are essentially completed, with stakeholder consultation to commence in early 2017-18.		

6.8.1 Landform

In 2017, the SSB indicated that just over half the proposed ERA landform criteria were acceptable. The Supervising Scientist's rehabilitation standard for this theme at the time was 80 percent complete. Word changes to the criteria should shift several to agreed status.

The SSB had four projects in 2016-17 to inform landform closure criteria,[3] due for completion by mid-2018 or earlier. A further four SSB projects are underway to refine methods to assess criteria being met.

ERA is updating the final landform model to include the latest material balance and sediment control features. This will be analysed by the Supervising Scientist Branch to determine the likelihood of criteria being met.

The SSB has projects planned for the next 5 years related to biological effects of suspended sediment,[4] which they plan to use to develop water quality standards to protect the ecosystem.

6.8.2 Radiation

While all criteria have been agreed, ERA will continue to undertake radiation studies to ensure they can be met. For example, closure atmospheric dispersion modelling of radon and particulate matter has recently been completed by SLR Consulting. These data will inform the closure radiological dose assessment currently underway by JRHC Enterprises Pty Ltd (Chapter 7, Section 7.10).

Supervising Scientist Branch have five projects recently completed or underway to inform assessing criteria achievement and several more for later years. Their rehabilitation standards for this theme are close to completion.

6.8.3 Water and Sediment

The Supervising Scientist Branch agreement rate to the criteria in this theme was just over half partially agreed and the remainder not agreed to. ERA proposed a tiered risk assessment framework in-line with international and national assessment approaches. All stakeholders support the process. However, Supervising Scientist Branch wants the outcome to result in a single numeric criterion.

ERA believes this is overly conservative as short lived events in isolated locations have shown not to impact the ecosystem. ERA has contracted consultants to lead a consultative project to develop the framework further to assess the likely impacts of any guideline value exceedance on the biodiversity and broader Environmental Requirements.

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[3] Erosion and infiltration studies on the Ranger trial landform. Model the geomorphic stability of pre-mine landform for up to 10,000 years (to calibrate the suspended sediment outputs of SSB models). Analysis of historical unpublished erosion studies in the Alligator Rivers Region. Calibration of landform evolution model for different surfaces.

[4] Effect of mine derived suspended sediments (cf natural suspended sediments) on the growth of juvenile mussel (2019). Direct effects of suspended sediment on tropical freshwater biota (2018 – 2021; suspended in 2017). Impact of suspended sediment-associated contaminant (2021-23).

This framework will assist in developing agreed criteria and address related issues of:

- How to define and measure two phrases in the Environmental Requirements, i.e. “detrimental impact” (to ecosystems off the Ranger Project Area (RPA) and “as low as reasonably achievable’ on the RPA.
- Criteria to protect the diet of Aboriginal people.

ERA projects are underway or in scoping phase (Chapter 7, Section 7.10) to address:

- Human health risk assessment (scoping phase).
- Environmental and cultural values for on and offsite water bodies.
- Cumulative risk assessment of the surface water pathway (planning phase; lead by SSB and CSIRO).
- Potential for acid sulfate sediments in billabongs (scoping phase).

6.8.4 Flora and Fauna

SSB recently undertook a cumulative risk assessment of the revegetation and rehabilitation risks for the site. The report is being finalised. The outcomes will assist in gaining agreement on closure criteria for this theme.

Several ERA projects are underway or planned:

- A collaborative study with the Centre of Mined Land Rehabilitation, University of Queensland is underway to measure some key soil and plant attributes indicative of nutrient cycling processes, which are to be interpreted against foliage nutrient status (Chapter 7, Section 7.10).
- SSB and Charles Darwin University are planning a project on eco-hydrology and sensitivity of riparian flora, which will include ERA collaboration.

The SSB rehabilitation standards for fauna and flora were 0 percent and 80 percent complete, respectively, in July 2017, with the flora standard expected in late March 2018. Yet, SSB list two active projects due in late 2018 and one due in 2021 to inform development of flora criteria. SSB have one project to determine closure criteria for fauna planned for late 2018- early 2019.

6.8.5 Soils

ERA is undertaking a series of soil assessments as part of the feasibility study (Chapter 7, Section 7.10). Soil sampling (phase II) has recently been completed in the land application areas, pending analysis and reporting. These data will be used to determine if additional tiered assessment tasks for uranium levels in the land application areas is required (phase III). The outcomes of this study will be included in the next iteration of mine closure plan.

6.8.6 Cultural

The cultural criteria provided in Table 6-6 incorporates feedback recently provided by the NLC (C. Brady 2018, pers. comm., 21 March). As outlined in this communication, further consultation will be required to establish 'pathways' on the final landform associated with ripping; and, a mechanism by which the intended cultural criteria monitoring will occur.

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