

Australian Government

Department of the Environment and Energy

Supervising Scientist

internal report





The Department acknowledges the traditional owners of country throughout Australia and their continuing connection to land, sea and community. We pay our respects to them and their cultures and to their elders both past and present.

Assessment Report:

Ranger Mine Closure Plan Rev #: 0.18.0 May 2018

Supervising Scientist GPO Box 461, Darwin NT 0801

September 2018

(Release status -Unrestricted)



Australian Government

Department of the Environment and Energy Supervising Scientist

How to cite this report:

Supervising Scientist 2018. Assessment Report: Ranger Mine Closure Plan Rev #: 0.18.0 May 2018. Internal Report 658, September 2018, Supervising Scientist, Darwin.

Supervising Scientist Branch is part of the Australian Government Department of the Environment and Energy.

Supervising Scientist Department of the Environment and Energy GPO Box 461, Darwin NT 0801 Australia

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Contents

Ex	Executive Summary			
1.	Introduction		1	
	1.1. Requirement			
	1.2. Statu	itory Framework	1	
	1.2.1.	Atomic Energy Act 1953	1	
	1.2.2.	Commonwealth Environmental Requirements	1	
	1.2.3.	Environment Protection (Alligator Rivers Region) Act 1978 (Cwlth)	6	
	1.2.4.	Mining Management Act (NT) and Authorisation	6	
	1.2.5.	Rehabilitation Approval Responsibilities	6	
	1.2.6.	Rehabilitation and Closure Planning Documents	7	
	1.2.7.	Closure Criteria	7	
	1.3. Supe	rvising Scientist's Rehabilitation Standards	7	
	1.4. Supe	rvising Scientist's Key Knowledge Needs	8	
	1.5. Asse	ssment Report Purpose and Structure	10	
2.	General Observations			
	2.1. RMC	P Structure	11	
	2.2. Inform	nation Gaps	11	
	2.3. Cont	ingency Planning	11	
	2.4. Sumi	mary of Recommendations for the General Observations	12	
3.	Risk Ass	essment	13	
	3.1. Sumı Risk	mary of Recommendations and Additional Comments for the Assessment	15	
4.	Best Pra	cticable Technology	16	
	4.1. Relev	vant Environmental Requirements	16	
	4.2. Appli	cation of BPT	17	
	4.3. Sumi	mary of Recommendations for Best Practicable Technology	17	
5.	Closure Theme: Landform			
	5.1. Relevant Environmental Requirements			
	5.2. Activ	ity Summary	19	
	5.3. Detai	led Activity Description	19	
	5.3.1.	Landform Design	19	
	5.3.2.	Construction Materials	20	
	5.4. Land	form Physical Properties (ER 2.1, 2.2c)	20	
	5.5. Land	form Stability (ER 2.1, 2.2, 11.3)	21	
	5.5.1.	Tailings Consolidation	21	

		5.5.2.	Erosion	22
		5.5.3.	Landform Stability Risks Not Considered	22
	5.6.	Tailing	gs Isolation (ER 11.2, 11.3)	22
		5.6.1.	Tailings Isolation Risks Not Considered	23
	5.7.	Infras	tructure and Contaminated Material Disposal (ER 2.3)	23
		5.7.1.	Pit 3	23
		5.7.2.	Exploration Decline	23
	5.8.	Closu	re Criteria	24
		5.8.1.	Criteria Terminology	27
		5.8.2.	Suspended Sediments	27
	5.9.	Rehal	bilitation Monitoring	27
	5.10). Sum the La	mary of Recommendations and Additional Comments for andform	28
6.	Clo	sure 1	Theme: Water and Sediment	32
	6.1.	Relev	ant Environmental Requirements	32
	6.2.	Activit	ty Summary	34
	6.3.	Detail	ed Works Description	34
	6.4.	Water	and Sediment Quality (ER 3.1–3.4)	35
		6.4.1.	Water Storage, Management and Treatment	35
		6.4.2.	Site Conceptual Models	36
		6.4.3.	Contaminant Source Terms	37
		6.4.4.	Contaminant Transport Modelling	39
		6.4.5.	Water and Sediment Quality Risks Not Considered	40
	6.5.	Proteo of Hu	ction of Ecosystems (ER 1.1, 1.2, 7.1, 11.3) and Protection man Health (ER 1.1c, 1.2c)	41
		6.5.1.	Baseline Aquatic Biodiversity	41
		6.5.2.	Suspended Sediments	41
		6.5.3.	Onsite Water Bodies	41
		6.5.4.	Eutrophication	41
		6.5.5.	Protection of Ecosystems and Human Health Risks Not Considered	42
	6.6.	Closu	re Criteria	42
		6.6.1.	Assessment Approach	46
		6.6.2.	Locations Where Closure Criteria Apply	46
		6.6.3.	Ranger Project Area Human Consumption	47
		6.6.4.	Water Quality for Ecosystem Protection	47
		6.6.5.	Effects of Contaminant Mixtures	48
		6.6.6.	Contaminant Accumulation in Sediments	48
		6.6.7.	Nutrients	48
		6.6.8.	Sedimentation in Billabongs	48
		6.6.9.	Groundwater	49

	6.7.	Rehabilitation Monitoring	49
		6.7.1. Surface Water	49
		6.7.2. Groundwater	49
		6.7.3. Monitoring Program Review	49
	6.8.	Summary of Recommendations and Additional Comments for	
		Water and Sediment	50
7.	Clo	sure Theme: Radiation	56
	7.1.	Relevant Environmental Requirements	56
	7.2.	Activity Summary	57
	7.3.	Detailed Activity Description	57
		7.3.1. Tailings Disposal	57
		7.3.2. Landform Surface	58
	7.4.	Protection of Human Health (ER 1.1, 1.2, 2.2, 5.1–5.3.)	58
	7.5.	Protection of Ecosystem Health (ER 1.1, 5.1)	59
	7.6.	Closure Criteria	59
	7.7.	Rehabilitation Monitoring	61
	7.8.	Summary of Recommendations and Additional Comments for	
		Radiation	61
8.	Clo	sure Theme: Soils	63
	8.1.	Relevant Environmental Requirements	63
	8.2.	Activity Summary	63
	8.3.	Detailed Activity Description	63
	8.4.	Delineation of Contaminated Soils	63
	8.5.	Closure Criteria	64
	8.6.	Summary of Recommendations and Additional Comments for	
		Soils	65
9.	Clo	sure Theme: Ecosystem Restoration	66
	9.1.	Relevant Environmental Requirements	66
	9.2.	Activity Summary	66
	9.3.	Detailed Activity Description	67
		9.3.1. Revegetation Strategy	67
	9.4.	Ecosystem Restoration (ER 2.1, 2.2)	68
		9.4.1. Revegetation Trials	68
		9.4.2. Reference Sites	68
		9.4.3. Seed Availability and Viability	69
		9.4.4. Soil Development	69
		9.4.5. Plant Available Water	69
		9.4.6. Fire	70

	9.4.8.	Fauna	71	
	9.4.9.	Contingencies for Revegetation Mortality	71	
	9.4.10	Ecosystem Restoration Risks Not Considered	72	
9.5.	Closu	re Criteria	73	
	9.5.1.	Criteria Terminology	78	
	9.5.2.	Revegetation Establishment Trajectories	78	
	9.5.3.	Vegetation Composition and Structure	78	
	9.5.4.	Fauna	79	
	9.5.5.	Sustainability	79	
9.6.	9.6. Rehabilitation Monitoring			
9.7.	Summ	nary of Recommendations and Additional Comments for		
	Ecosy	stem Restoration	81	
10.Mo	nitorin	g	87	
10.1	I. Rele	vant Environmental Requirements	87	
10.2. Activity Summary			87	
10.3	3. Deta	iled Works Description	87	
10.4	10.4. Monitoring for Environment Protection (ER 13.1–13.3)			
10.5	5. Sum	mary of Recommendations and Additional Comments for		
	Monite	oring	89	
11.Ref	erenc	es	90	

Appendixes

Appendix 1:	List of Acronyms
Appendix 2:	Supervising Scientist's Key Knowledge Needs

Executive Summary

In May 2018, Energy Resources of Australia Ltd (ERA) submitted its Ranger Mine Closure Plan (RMCP) to the Commonwealth and Northern Territory (NT) resources ministers for approval pursuant to Environmental Requirement 9 of the *Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine* (the ERs) attached to ERA's Authority to operate the Ranger uranium mine. The Supervising Scientist is required to advise the ministers as to whether the implementation of the plan will result in achievement of the major rehabilitation objectives as set out in ER 2. This assessment report constitutes this advice.

The ERs stipulate a high level of environmental protection throughout the mining and rehabilitation of the Ranger Project Area, and the long-term protection of people and the environment post-rehabilitation. The ultimate objective of rehabilitation is to restore the site to a standard that allows its eventual incorporation into Kakadu National Park.

The rehabilitation planning process builds on a significant amount of scientific and technical information drawn from research and monitoring work undertaken by ERA and the Supervising Scientist over the past 40 years. The RMCP should present key information on the major rehabilitation activities, including the scientific evidence that justifies the approach and demonstrates that the ERs can be achieved. The RMCP will be updated and submitted for approval annually. In this way, the RMCP provides a mechanism for ERA to describe and seek approval for high level rehabilitation activities at Ranger, identify key research and rehabilitation activities in train, and demonstrate the progressive rehabilitation of the Ranger Project Area over time.

Approval of the less-complex rehabilitation activities can be undertaken through the RMCP. Approval of the more technically complex activities will occur independently of the RMCP, by submission of detailed standalone applications for each activity. These standalone applications will be assessed, and once approved, key information and the assessment outcomes will be documented in the RMCP.

The Supervising Scientist accepts the broad approach to the rehabilitation of Ranger mine presented in the RMCP, however a significant amount of additional evidence is required to demonstrate all the ERs can be achieved. In some cases the RMCP acknowledges existing knowledge gaps and describes the work that will be undertaken to generate the required information. However, uncertainty exists where knowledge gaps are not identified.

This assessment report includes recommendations which provide a framework for ERA to address these knowledge gaps. These recommendations necessarily align with the Key Knowledge Needs (KKNs) for the rehabilitation of Ranger mine. The KKNs detail the additional information required to ensure successful rehabilitation, and to prevent environmental impacts throughout and after rehabilitation. By addressing the recommendations in this report, ERA will obtain sufficient information and knowledge to fulfil the KKNs and demonstrate that the rehabilitation plan will achieve the objectives in the ERs. It is acknowledged that ERA is close to completing feasibilitylevel planning for the rehabilitation of the site. The feasibility study will provide additional information that will need to be included in future versions of the RMCP, and in the standalone assessments.

The RMCP describes the rehabilitation plan at a point in time. It is anticipated that the next version of the RMCP will be updated to include the most recently available information, including more detailed plans and schedules from ERA's feasibility study which is due to be completed in 2018.

Overall, the RMCP does not yet provide sufficient evidence to demonstrate that the current plan for rehabilitation of the Ranger minesite will achieve the required ERs. A significant amount of work needs to be undertaken by ERA to demonstrate that the ERs can be achieved. If sufficient resources are allocated to this work it can be completed in time to inform the rehabilitation process. While some of this work is planned, or currently underway, this assessment report provides many recommendations on which this forward work program can be based.

Some key conclusions of the Supervising Scientist's review:

- Detailed contingency plans should be provided for all key activities outlined within the RMCP.
- Further work is required to provide reliable predictions of surface water contaminant concentrations post-rehabilitation; including (i) the characterisation of contaminant source terms, (ii) verifying the conceptualisation of key groundwater contaminant pathways, (iii) additional information on the interactions between surface water and groundwater, and (iv) more detailed ground and surface water modelling.
- The Revegetation Strategy presented should be expanded to an ecosystem restoration strategy, based upon a suitable ecosystem trajectory model which addresses the interdependencies between flora and fauna.
- Additional information is required to give confidence in the ability of the final landform to support vegetation in the long term, particularly concerning plant available water, soil formation and the establishment of understory species.
- Tailings consolidation modelling should be reviewed to provide greater certainty on consolidation time frames, the volume of contaminants which will express into the groundwater and the ability to capture and treat 99% of the expressed pore water. This should consider the heterogeneous nature of the tailings mass and the direction of solute expression.
- Further information is required on the rehabilitation of the Tailings Storage Facility, including on the extent of contamination within the walls of the dam and the long-term movement of contaminated groundwater from beneath the dam.
- An assessment of radiation dose to humans and biota from the rehabilitated minesite is required to demonstrate that radiation closure criteria can be met. Additional information on the radiological properties of the rock to be used on the surface of the landform is required to inform the dose assessment.
- While there is agreement with many of the proposed closure criteria presented in the RMCP, some criteria need further clarification. All closure criteria should be quantified and accompanied by a suitable monitoring program. In the absence of agreement on an acceptable level of environmental effect outside of the Ranger Project Area, closure criteria should aim to prevent any mine-derived change to biodiversity and be applied at the boundary of the Ranger Project Area.
- As acknowledged within the RMCP, all rehabilitation activities will need to be supported by best practicable technology (BTP) analyses.

1. Introduction

1.1. Requirement

Clause 9.1 of the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (ERs) states:

9.1 The company must prepare a rehabilitation plan which is approved by the Supervising Authority and the minister with the advice of the Supervising Scientist, the implementation of which will achieve the major objectives of rehabilitation as set out in subclause 2.2, and provide for progressive rehabilitation.

The RMCP was submitted for assessment by ERA in May 2018 in accordance with ER 9.1. This assessment report contains the outcomes of a detailed assessment of the RMCP by the Supervising Scientist. It constitutes the advice of the Supervising Scientist to the Supervising Authority, being the Northern Territory minister for Primary Industry and Resources, and the Australian Government minister for Resources and Northern Australia.

The RMCP is required to be updated and submitted for assessment annually.

1.2. Statutory Framework

Ranger is subject to both Commonwealth and Northern Territory legislation. This is because the Australian Government retains ownership of uranium resources in the NT and because Ranger, like all mining operations in the NT, must satisfy stringent obligations imposed by NT law. The following sections provide an overview of statutory requirements pertaining to the rehabilitation of the Ranger mine.

For the purpose of this report the Australian Government minister for Resources and Northern Australia will be referred to as the 'Commonwealth minister', and the Northern Territory minister for Primary Industry and Resources will be referred to as the 'NT minister'. Collectively they will be referred to as the regulatory authorities.

1.2.1. Atomic Energy Act 1953

The Atomic Energy Act 1953 (AEA) reserves ownership of prescribed substances, including uranium, with the Commonwealth in all Commonwealth Territories.

Ranger mine operates under an s41 Authority issued under the AEA. The Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine are attached to the s41 Authority.

The initial s41 Authority was entered into on 9 January 1979 and subsequently extended for a further 26 years from 9 January 2000.

Under the current s41 Authority, mining and milling activities on the Ranger Project Area must cease on (or by) 8 January 2021, and rehabilitation works must be completed on (or by) 8 January 2026.

The s41 Authority cannot be further extended without amendment to the AEA.

1.2.2. Commonwealth Environmental Requirements

The Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (ERs), attached to the Ranger Authority issued under s41 of the Atomic Energy Act 1953, set out the environmental protection conditions with which the operator must comply. The ERs are also given

effect through the Ranger Authorisation issued under the Northern Territory *Mining Management Act* and are attached to and referenced in a number of other agreements.

The Ranger ERs specify the primary and secondary environmental objectives to be achieved during the life of the mine and after closure. The primary environmental objectives focus on maintaining the World Heritage attributes of Kakadu National Park and the ecosystem health of the wetlands for which Kakadu is listed as a Ramsar site, for protecting the health of people living in the region and preventing change to the biological diversity and ecological processes in the region. Impacts within the Ranger Project Area (Figure 1) are to be as low as reasonably achievable.

The primary environmental objectives specifically relating to rehabilitation are, in summary, to establish an environment with habitats and erosion characteristics similar to the adjacent areas of Kakadu National Park and stable radiological conditions with doses that comply with national requirements and are as low as reasonably achievable. Tailings must be placed into the mined-out pits in a way that ensures physical isolation from the environment and prevents any detrimental environmental impacts from contaminants arising from tailings for at least 10,000 years. Moreover, surface or ground waters discharging from the Ranger Project Area during and after rehabilitation must not compromise the achievement of the above primary environmental objectives.

The primary environmental objectives pertaining to the rehabilitation of Ranger mine are detailed in Table 1.



Figure 1. Location of the Ranger Project Area.

Clause	Relevant Environmental Requirements				
	Environmental protection				
1.1	The company must ensure that operations at Ranger are undertaken in such a way as to be consisted with the following primary environmental objectives:				
	(a)	maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list;			
	(b)	maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park);			
	(c)	protect the health of Aboriginals and other members of the regional community; and			
	(d)	maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes.			
1.2	In particular, the company must ensure that operations at Ranger do not result in:				
	(a)	damage to the attributes for which Kakadu National Park was inscribed on the World Heritage list;			
	(b)	damage to the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park);			
	(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;			
	(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.			
	Rehabilitation				
2.1	Subject to su	bclauses 2.2 and 2.3, the company must rehabilitate the Ranger Project Area to establish			
	an environm	ent 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.				

Table 1. Ranger Environmental Requirements that are related to rehabilitation

Clause	Relevant Environmental Requirements			
2.2	The major objectives of rehabilitation are:			
	 (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; (b) stable radiological conditions on areas impacted by mining so that the health risk to 			
	 (b) 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 restriction on the use of the area; (c) erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from these of comparable landforms in surrounding undisturbed areas. 			
0.0				
2.3	Where all major stakeholders agree, a facility connected with Ranger may remain in the Ranger Project Area following termination of the Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in subclauses 2.1,			
3.1	The company must not allow either surface or ground waters arising or discharged from the Ranger			
	Project Area during its operation, or during or following rehabilitation, to compromise the achievement of			
	the primary environmental objectives.			
9.1	minister with the advice of the Supervising Scientist, the implementation of which will achieve the major			
	objectives of rehabilitation as set out in subclause 2.2, and provide for progressive rehabilitation.			
9.2	All progressive rehabilitation must be approved by the Supervising Authority or the minister with the			
	advice of the Supervising Scientist and subject to the Northern Land Council agreeing that the aim and			
	objectives for rehabilitation as described in clause 2 are met.			
9.3	The company's obligations under clause 9 will cease in respect of any part of the Ranger Project Area			
	over which a close-out certificate is issued by the Supervising Authority subject to the Supervising			
	met the requirements of clause 2.			
9.4	Where agreements under subclause 9.2 or 9.3 cannot be reached the minister will make a determination			
	with the advice of the Supervising Scientist.			
11.1	During mining operations and prior to final placement, covering and rehabilitation of the tailings, tailings			
	must be securely contained in a manner approved by the Supervising Authority or the minister with the			
11.2	advice of the Supervising Scientist which prevents detrimental environmental impact.			
11.2	By the end of operations all tailings must be placed in mined-out pits.			
11.3	Final tailings disposal of tailings must be undertaken, to the satisfaction of the minister with the advice of			
	the Supervising Scientist on the basis of the best-available modelling, in such a way to ensure that:			
	(i) the tailings are physically isolated from the environment for at least 10,000 years			
	(II) any contaminants arising from the tailings will not result in any detrimental environmental impacts for at least 10,000 years			
	(iii) radiation doses to members of the public will comply with relevant Australian law and be			
	less than limits recommended by the most recently published and relevant Australian			
	standards, codes of practice, and guidelines effective at the time of the final tailings disposal.			

1.2.3. Environment Protection (Alligator Rivers Region) Act 1978 (Cwlth)

The Environment Protection (Alligator Rivers Region) Act 1978 (EPARR Act) establishes the position and duties of the Supervising Scientist for protection of the environment of the Alligator Rivers Region from the effects of uranium mining.

The Supervising Scientist conducts research programs into the environmental effects of uranium mining in the Alligator Rivers Region, develops standards and practices for environmental protection, undertakes environmental monitoring, participates in and oversees the regulatory process and provides advice to regulatory authorities and mine operators. The Supervising Scientist plays a fundamental role in communicating research and monitoring results to assure Governments, and the public, that the environment of the Alligator Rivers Region remains protected from the effects of mining.

The Supervising Scientist Branch sits within the Department of the Environment and Energy, supporting the minister for the Environment. The Supervising Scientist is required to provide technical advice to the Commonwealth minister and NT minister on rehabilitation and closure-related activities at Ranger mine.

The Act also establishes the Alligator Rivers Region Technical Committee (ARRTC) to advise the minister for the Environment on the quality and relevance of the research conducted by the Supervising Scientist and ERA. The committee comprises a panel of independent scientists recognised for their expertise in relevant fields, currently focused on the various areas of minesite rehabilitation.

1.2.4. Mining Management Act (NT) and Authorisation

The *Mining Management Act* (MMA) regulates mining in the Northern Territory and ERA undertakes operations and activities at Ranger in accordance with the terms of an Authorisation granted under s35 of the MMA by the NT Minister.

The NT Government is the day-today regulator of Ranger but is required to consult with the Australian Government on key matters. The Northern Territory Department of Primary Industry and Resources chairs the Ranger MTC, which also includes the Supervising Scientist, the Northern Land Council, the Gundjeihmi Aboriginal Corporation and ERA. The MTC has no decision-making authority or approval powers. Rather, the role of the MTC is to provide a forum where all key stakeholders can remain abreast of current activities and have informed discussions before the regulatory authorities make a determination.

1.2.5. Rehabilitation Approval Responsibilities

Responsibility for the approval of rehabilitation and closure activities at Ranger is generally shared by the Commonwealth and NT ministers. Both ministers must approve the RMCP, the final disposal of tailings, and the issue of a close out certificate(s) for the Ranger Project Area (all or part). The regulatory framework also provides for consultation with key stakeholders. In addition, the ERs require ministers to seek the advice and, where necessary, the agreement of the Supervising Scientist and the Northern Land Council when making these decisions.

Less complex matters are generally decided by the NT Minister alone. For example, the NT Minister generally approves progressive rehabilitation of the Ranger Project Area with the advice of the Supervising Scientist and agreement by the Northern Land Council that the aim and objectives for rehabilitation as described in ER 2 are met (ER 9.2). The NT Minister may also approve the secure containment of tailings, during operations and prior to final disposal, with the advice of the Supervising Scientist (ER 11.1).

The Commonwealth Minister can make a final determination on specific rehabilitation and closure matters where there is disagreement between the NT Government, Supervising Scientist and Northern Land Council.

The rehabilitation of Ranger mine is not subject to assessment under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Actions that started before the EPBC Act coming into force on 16 July 2000 are exempt from assessment and approval under the EPBC Act, including mining and rehabilitation at Ranger mine which commenced in 1980. The ERs were revised in 1999 and include rehabilitation requirements.

1.2.6. Rehabilitation and Closure Planning Documents

A draft RMCP was submitted by ERA to stakeholders for review in December 2016. ERA was not seeking approval of the RMCP at that time. The Supervising Scientist reviewed the draft RMCP and provided advice to the MTC members, including ERA.

The regulatory authorities and stakeholders agreed that some aspects of rehabilitation works would be approved within the plan, while other more complex aspects that require substantial supporting technical information would be subject to a separate assessment and approval process. A summary of the information included in these standalone applications and the outcomes of their assessment would then be included in subsequent updates of the RMCP.

In parallel with the RMCP, ERA submits an Annual Plan of Rehabilitation (APR), prepared in accordance with the requirements of the Ranger Uranium Project Government Agreement between ERA and the Commonwealth Government. The APR is intended to provide the conceptual specifications for rehabilitation works and methodology for an unplanned premature cessation of operations at Ranger mine, along with a supporting cost estimate. Accordingly, cost estimates for closure have not been included in the RMCP and are therefore not included in this review.

1.2.7. Closure Criteria

ERA's obligation to submit a RMCP will cease where the Commonwealth and NT ministers issue a close-out certificate in respect of any part of the Ranger Project Area (ER 9.3). Prior to taking that decision, ministers must seek the advice of the Supervising Scientist and the Northern Land Council must agree that that specific part of the Ranger Project Area meets the rehabilitation objectives described in ER 2.

ERA have proposed closure criteria to quantify the rehabilitation objectives within the ERs and provide a clear and objective basis for the Supervising Scientist and the Northern Land Council to determine when the rehabilitation objectives have been met.

Closure criteria require approval by both the NT minister and the Commonwealth minister. An assessment of the closure criteria proposed in the RMCP has been included in this assessment report. A commentary is provided in cases where closure criteria require further information.

1.3. Supervising Scientist's Rehabilitation Standards

In accordance with s5c of the *Environment Protection (Alligator Rivers Region) Act 1978*, the Supervising Scientist has developed a series of Rehabilitation Standards for Ranger mine against which the success of rehabilitation can be measured. These standards are advisory only and are available on the Supervising Scientist's website (<u>environment.gov.au/science/supervising-scientist</u>).

The Rehabilitation Standards are based on nearly 40 years of research undertaken by the Supervising Scientist to provide scientific, evidence-based benchmarks that represent the best environmental outcomes for the rehabilitation of Ranger mine. The standards are intended to quantify the key rehabilitation objectives stipulated in the ERs and provide measurable targets against which the success of rehabilitation can be assessed. As such, they provide the basis for the Supervising Scientist's assessment of the closure criteria proposed in the RMCP.

A list of the Rehabilitation Standards is provided in Table 2 below.

Table 2 The Supervising Scientist's Rehabilitation Standards

Closure theme	Title of Rehabilitation Standard
	Magnesium in Surface Water
	Uranium and Manganese in Surface Water
	Uranium in Sediments (In preparation)
Water and Sediment	Ammonia in Surface Water
	Sulfate in Surface Water
	Low-Risk Metals in Surface Water
	Turbidity and Sedimentation (In preparation)
Ecosystem Restoration and Landform	Landform Stability
	Ecosystem Restoration
Padiation	Public Radiation Protection
	Environmental Radiation Protection

1.4. Supervising Scientist's Key Knowledge Needs

The Supervising Scientist's KKNs represent the outstanding knowledge required to ensure that the rehabilitation activities proposed by ERA will achieve the environmental objectives and hence satisfy the ERs.

The KKNs are based on the outcomes of a comprehensive screening-level ecological risk assessment on the rehabilitation of Ranger mine. This risk assessment was conducted in collaboration with ARRTC, ERA, the Northern Land Council, the Gundjeihmi Aboriginal Corporation, CSIRO and other key stakeholders. Regulatory agencies were invited to participate as they saw fit.

The EPARR Act establishes ARRTC to advise the minister for the Environment on the quality and relevance of the research conducted by the Supervising Scientist and ERA. ARRTC has a panel of independent scientists, each recognised for their eminent expertise in fields related to the rehabilitation of impacted sites, including minesites. ARRTC formally endorsed the KKNs in November 2016, and were subsequently published by the Supervising Scientist in 2017 (Supervising Scientist 2017). In early 2018, the Supervising Scientist reviewed the KKNs to consolidate and simplify them, and align them more clearly with the Ranger ERs. This consolidation process ensured that all information from the original KKNs was retained. However, the total number of KKNs was reduced from 125 to 32. The revised KKNs have been attached to this report at Appendix 2. Figure 2 provides an overview of the research planning process undertaken by the Supervising Scientist, based on the KKNs, and resulting in a 10-year research plan to inform the rehabilitation of Ranger mine.



Figure 2. Process for development and review of Supervising Scientist's research program for Ranger mine.

While ultimate responsibility for rehabilitation outcomes at Ranger mine rests with ERA, both ERA and the Supervising Scientist maintain active research programs. The Supervising Scientist's research program is strategically targeted on achieving the KKNs for which it currently has the lead. Research projects to be conducted over the next 8 years have been established and are scheduled against the mine rehabilitation schedule. The KKNs should also form the basis of the research program undertaken by ERA to ensure the adequacy of the proposed rehabilitation activities. To address the KKNs in the time frame required, it will be important for ERA and the Supervising Scientist to continue to maintain a coordinated and collaborative research program.

An evidence-based process has been developed to formally modify, close out or add KKNs. Close out of KKNs can occur when (i) the knowledge required by the KKN has been acquired, or (ii) the KKN is no longer relevant or necessary. Addition of new KKNs may be required where new

issues emerge or additional knowledge is required to inform existing issues. The views of both the MTC and ARRTC will be sought before modifying, closing out and adding new KKNs.

The recommendations within this assessment report have been cross-referenced with the KKNs. Where sufficient information has been provided in the RMCP to fully address a KKN, its close out should be proposed. Alternatively, where additional knowledge needs have been identified through this review, a new KKN may be required. As such, the KKNs represent the additional research information required to underpin the RMCP and demonstrate the ERs can be achieved.

1.5. Assessment Report Purpose and Structure

This assessment report documents the outcomes of the Supervising Scientist's technical review and assessment of the RMCP. It also includes recommendations for further work required to provide additional information to support the rehabilitation activities included in the RMCP.

This report will be provided to the Ranger MTC and the regulatory authorities as the advice of the Supervising Scientist in accordance with ER 9.

This report assesses whether sufficient information was provided in the RMCP to:

- describe the proposed rehabilitation activities and detail how and when these activities will be conducted, including any environmental protection measures to be implemented while works are underway
- demonstrate that these activities will result in the achievement of the environmental objectives in the ERs
- demonstrate that proposed closure criteria appropriately represent the environmental objectives in the ERs, and are sufficiently clear and measurable to allow for the future determination of their achievement
- demonstrate that appropriate provisions have been made to enable the implementation of effective contingency measures in the event that the rehabilitation works do not occur as planned (e.g. long-term water treatment to manage contamination issues should they occur).

Chapters 3 and 4 considers whether:

- environmental risks associated with rehabilitation process, and the rehabilitated site, have been identified and adequately assessed and mitigated
- proposed rehabilitation strategies are based on the best available science, including reference to relevant international experience and the principles of the BPT.

Chapters 5 to 9 divides the Supervising Scientist's advice on the RMCP according to these closure 'themes':

- Landform
- Water and Sediment
- Radiation
- Soils
- Ecosystem Restoration.

The ERs relevant to each theme have been listed in each chapter, along with an indication on whether sufficient information has been presented in the RMCP to demonstrate that each ER will be achieved.

Chapter 10 details the Supervising Scientist's advice on the proposed post-closure monitoring programs.

The Cultural Criteria presented in the RMCP were not considered by the Supervising Scientist, and hence are not discussed in this report. Both the Northern Land Council and the Gundjeihmi Aboriginal Corporation will provide advice on the suitability of the Cultural Criteria.

2. General Observations

The RMCP is a substantial document that provides a good overview of the planned rehabilitation approach for the Ranger mine, and a sound base for future versions. Some inconsistency throughout the document was noted, both in the description of key rehabilitation activities and in some of values and figures quoted. Additionally, while it is accepted the RMCP describes the rehabilitation plan at a point in time, some of the information presented within the plan has now been superseded. The majority of the information presented in the RMCP is from 2016. As such much of the work undertaken over the last 2 years is not presented. It is anticipated that the next version of the RMCP will be updated to include the most recently available information.

2.1. RMCP Structure

The RMCP is a generally well-presented document and structured following the Western Australian guidelines for mining rehabilitation plans. Consideration should be given to modifying the structure to strengthen the link between each of the rehabilitation activities and the research and information that underpins them, and the closure criteria against which they will be assessed. A thematic structure is recommended, and may include:

- a description of the proposed activity
- a schedule for undertaking the proposed activity, including clear milestones
- supporting evidence to demonstrate that the activity will result in achievement of the relevant ERs
- associated closure criteria that will be used to assess the success of the activity
- associated monitoring program(s).

2.2. Information Gaps

ERA made a significant attempt to identify knowledge gaps in the RMCP. It would be useful to include a standardised table to identify why the knowledge is needed and detail the work that is planned to obtain the knowledge. References to the stand-alone applications for certain rehabilitation activities are useful for identifying when future information will be provided. It is also important to ensure all rehabilitation activities have specific timeframes allocated to key milestones, and that these timeframes and milestones are consistent throughout the different plans and reports. Once complete, ERA's Feasibility Study is expected to provide a greater level of detail in this regard.

2.3. Contingency Planning

The RMCP describes the activities and schedule for the successful rehabilitation of Ranger mine, based on the scenario that the project meets budget and timeline. The plan doesn't adequately account for a range of factors that introduce significant uncertainty in this scenario, including rainfall, schedule slippage or the failure of rehabilitation works to achieve the required outcomes. Future versions of the RMCP need to address the possibility that key aspects of the plan may fail and include detailed contingency measures. The existing risk assessment should be expanded to incorporate more failure scenarios and demonstrate how contingency measures will mitigate the associated environmental risks (e.g. which scenarios would require water treatment beyond 2026 and how would this be implemented?).

2.4. Summary of Recommendations for the General Observations

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 3 below.

Table 3. Summary of recommendations and additional comments about the general observations

Recommendation				
In the next version of the RMCP include of	detailed contingency plans for all key rehabilitation activities.			
Additional comments				
A thematic report structure is recommend	led, and may include:			
 a description of the proposed ac a schedule for undertaking the p supporting evidence to demonst ERs an associated closure criteria the associated monitoring program(tivity proposed activity, including clear milestones rate that the activity will result in achievement of the relevant at will be used to assess the success of the activity s).			

3. Risk Assessment

The risk assessment detailed in the RMCP has been conducted following generally accepted methods of risk assessment and includes risks to human health, safety and the natural environment. This section of the plan could be improved by simplifying and standardising the risk-related terms and definitions.

In general, more detail is required to demonstrate that the identified risks have been adequately assessed and that the existing and proposed controls are appropriate. The level of detail provided in the RMCP is insufficient to justify the assignment and ranking of risk classes and control effectiveness. To address this issue, the risk assessment should include:

- evidence to substantiate the likelihood and consequence rankings, including key assumptions and any uncertainty associated with the information used in this evaluation
- a clear distinction between existing and proposed controls, and evidence to support control effectiveness rankings, including consideration of control applicability or availability during the three closure phases (i.e. decommissioning, stabilisation and monitoring and post-closure)
- a plan to obtain additional information to inform the risk assessment, as required.

Given the long time frame for the life of the project, it might be necessary to reconsider the likelihood classifications, particularly for risks that span the full 10,000-year period such as exposure of tailings through erosion (TB1-01 and TB1-02). If this event is predicted to occur once in every 100 years over a 10,000-year period, the risk would be more appropriately be classified as being highly likely rather than rare.

Where possible, the common risks across different locations on the minesite should be standardised. Where a different risk class has been assigned to similar risks, this should be clearly discussed and justified. For example, further explanation is required to demonstrate why the risk of poor-quality water entering offsite water bodies from Pit 1 (TA2-01) is considered to be lower compared to the same risk for Pit 3 (TA2-02), particularly given that the existing/proposed controls for both locations are similar.

Table 9-6 in the RMCP shows a summary of class III risks across the risk subcategories. This table should include:

- reference to the existing controls and the phase of closure for which the risk is being
 assessed (e.g. risk TA3-01: Uncontrolled release of contaminated material into the onsite
 environment during tailings transfer to Pit 3 will only be a risk during the decommissioning
 phase, whereas risk TA3-05: Potential migration of contaminants from tailings dam plumes
 will be a risk that may require management throughout all three phases of closure)
- risk TC4-03: Delays to rehabilitation and/or closure activities extending beyond 2026 in the Aquatic Ecosystem risk category (TA), as well as the People risk category (TC).

All listed controls should be clearly defined as existing or proposed, and of the existing controls those that may be removed during decommissioning should be flagged and discussed. The risk assessment has been based upon the assumption *all existing ERA controls will continue to be applied where applicable.* This assumption may lead to an underestimation of the level of risk during some or all three phases of closure. For example, the groundwater interception trenches installed to the west of the Tailings Storage Facility and around the Western Stockpile currently play a significant role in reducing the risk to the offsite environment from contaminants transported away from the site in the shallow aquifer system. These interception trenches are planned to be decommissioned

during rehabilitation works, and as such may not available to mitigate risk to the offsite environment from contaminants during the stabilisation and monitoring and post-closure phases. The effectiveness ranking for controls should also account for controls that are ineffective at the time of reporting, such as the operation of an underbed pump to keep the underdrain at atmospheric pressure, maximising the downwards consolidation flow as a control to manage risk TB1-03: Consolidation settlement is significantly greater than predicted in Pit 3. This pump is currently not working. However, the control effectiveness ranking for this particular risk is C1 (considered to be operating effectively on almost all occasions). Risk TB1-03 should also consider the possibility that the time taken for tailings to consolidate could be significantly greater than predicted.

While the outcomes from the screening-level ecological risk assessment conducted by Supervising Scientist Branch (SSB) and ERA during 2014–15 (as recommended and overseen by ARRTC) have been considered in the risk assessment, examining risks individually is no longer considered to be best practice as it does not account for the potential interactions between risks. ERA and SSB are undertaking a cumulative risk assessment to address a KKN (CT1), which will examine the effects of combined and integrated risks. It is indicated in the RMCP that the outcomes of this work will be used to update the risk assessment.

3.1. Summary of Recommendations and Additional Comments for the Risk Assessment

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 4 below.

Table 4. Summary of recommendations and additional comments pertaining to the risk assessment

Recommendation

In the next version of the RMCP provide further information to justify the assignment and ranking of risks, risk classes, controls and control effectiveness, and including the outcomes of an assessment of cumulative risks to the success of rehabilitation and to the protection of the offsite environment (CT1).

Key Knowledge Needs to be addressed:

• CT1. Assessing the cumulative risks to the success of rehabilitation and the protection of the offsite environment.

Additional comments

To justify the assignment and ranking of risks, risk classes, controls and control effectiveness, the risk assessment should include:

- evidence to justify the likelihood and consequence rankings, including key assumptions and the level of certainty associated with the information informing this evaluation
- a clear distinction between existing and proposed controls, and evidence to support control effectiveness rankings including consideration of control applicability or availability during the three closure phases (i.e. decommissioning, stabilisation and monitoring and post-closure)
- a clear plan to obtain additional information to inform the assessment of each risk, to improve the control effectiveness, or to identify new risks as further information is obtained, where required.

Terms and definitions should be simplified and standardised.

The likelihood classifications may need to be reconsidered given the long time frame for the life of the project (10,000 years).

Additional discussion around control effectiveness and contingencies should be provided for existing controls that:

- might be removed during decommissioning
- are known to be ineffective at the time of reporting.

Table 9-6 should include:

- reference to the existing controls
- the phase of closure for which the risk is being assessed
- risk *TC4-03: Delays to rehabilitation and/or closure activities extending beyond 2026* in the Aquatic Ecosystem risk category (TA), as well as the People risk category (TC).

Risks that are present at more than one location across the site should be standardised.

4. Best Practicable Technology

4.1. Relevant Environmental Requirements

Section 12 of the ERs requires that all aspects of the ERs must be implemented using the best practicable technology (BPT), as shown in Table 5.

The ERs define BPT as the technology relevant to the Ranger Project that produces the maximum environmental benefit that can be reasonably achieved, considering various relevant matters including current world leading practice, available resources, evidence of environmental impacts, location, the ages of equipment and facilities, and social factors. Proposals to undertake rehabilitation activities on the Ranger Project Area must be supported by a BPT analysis, the rigour of which should be commensurate with the potential environmental significance of the proposal.

Clause	Environmental Requirements				
12.1	All aspects of the Ranger Environmental Requirements must be implemented in accordance with BPT.				
12.2	Where there is unanimous agreement between the major stakeholders that the primary environmental objectives can be best achieved by the adoption of a proposed action which is contrary to the Environmental Requirements, and which has been determined in accordance with BPT, that proposed action should be adopted. Where agreement cannot be reached the minister will make a determination with the advice of the Supervising Scientist.				
12.3	All environmental matters not covered by these Environmental Requirements must be dealt with by the application of BPT.				
12.4	BPT is defined as:				
	That technology from time to time relevant to the Ranger Project which produces the maximum environmental benefit that can be reasonably achieved having regard to all relevant matters including:				
	 (a) the environmental standards achieved by uranium operations elsewhere in the world with respect to (i) level of effluent control achieved (ii) the extent to which environmental degradation is prevented 				
	 (b) the level of environmental protection to be achieved by the application or adoption of the technology and the resources required to apply or adopt the technology so as to achieve the maximum environmental benefit from the available resources (c) evidence of detriment, or lack of detriment, to the environment (d) the physical location of the Ranger Project (e) the age of equipment and facilities in use on the Ranger Project and their relative 				
	 effectiveness in reducing environmental pollution and degradation (f) social factors including the views of the regional community and possible adverse effects of introducing alternative technology. 				

Table 5. Ranger Environmental Requirements relevant to best practicable technology

Clause	Environmental Requirements
12.5	Proposals to amend or introduce operational approaches, procedures or mechanisms must be supported by a BPT analysis. The rigour of the BPT analysis must be commensurate with the potential environmental significance of the proposal. The BPT analysis must involve consultation with and having regard to the views of the major stakeholders and copies of the BPT analysis must be provided to each of the major stakeholders.
12.6	A precautionary approach is to be exercised in the application of BPT in order to achieve outcomes consistent with the primary environmental objectives.

4.2. Application of BPT

ERA has a rigorous BPT assessment process that has been reviewed previously and endorsed by the Ranger MTC.

Chapter 8 of the RMCP includes the BPT analysis undertaken in relation to tailings/brine disposal and final landform construction. Additional BPT assessments will be undertaken for other proposed rehabilitation activities and submitted for approval as part of the standalone applications. All BPT assessments should include a wide range of options, particularly considering relevant national and international experience and precedents where they exist.

4.3. Summary of Recommendations for Best Practicable Technology

A summary of the recommendations discussed in this chapter is provided in Table 6.

Table 6. Summary of recommendations about best practicable technology (BPT)

Recommendation

In the next version of the RMCP identify the full range of planned (or potentially required) BPT assessments.

5. Closure Theme: Landform

5.1. Relevant Environmental Requirements

The Landform closure theme covers the physical aspects of the final landform that will cover the disturbed footprint of the minesite. It includes rehabilitation activities undertaken to ensure the long-term isolation of tailings and geotechnical stability of the final landform. Minimising erosion and the release of sediment to the surrounding environment will prevent changes to water and sediment quality in the receiving environment that could result in impacts to ecosystems and human health.

Table 7 provides a summary of the ERs that are relevant to the Landform closure theme (in addition to the primary ERs presented in Table 1). Table 7 also provides the outcomes of the Supervising Scientist's detailed assessment of the RMCP, indicating whether or not the information provided in relation to the Landform closure theme is sufficient to demonstrate that each of the relevant ERs can be met.

Landform aspect	Clause	Environmental Requirements	Does RMCP demonstrate ER can be met?
Landform Physical Properties	2.1	Subject to subclauses 2.2 and 2.3, the company must rehabilitate the Ranger Project Area to establish an environment similar to 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.	Further information required
Landform Stability	2.2	(c) Erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those comparable landforms in surrounding undisturbed areas.	Further information required
Tailings Isolation	11.2	By the end of operations all tailings must be placed in the mined-out pits.	Yes
	11.3	(i) The tailings are physically isolated from the environment for at least 10,000 years.	Further information required
Infrastructure Disposal	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 Authority, provided that adequate provision is made for eventual rehabilitation of the affected area consistent with principles for rehabilitation set out in subclauses 2.1, 2.2 and 3.1.	Yes

Table 7. Ranger	Environmental Research Sector 2018	equirements	relevant to	the Landform	closure theme

5.2. Activity Summary

The RMCP proposes that all tailings will be placed in the mine pits, which will then be backfilled with waste rock. The remaining waste rock, including the waste rock used to construct the Tailings Storage Facility walls, will then be progressively distributed across the site to form a final landform, which will be progressively revegetated with local native plant species.

These proposed activities comply with the relevant ERs.

5.3. Detailed Activity Description

5.3.1. Landform Design

Approval of the final landform design will be the subject of a standalone assessment. The final design will be assessed for its long-term stability (over 10,000 years) using the CAESAR–Lisflood erosion model. This information requirement has been identified as a KKN (LAN3). Before approval ERA will also need to demonstrate that the landform will be able to sustain a vegetation community, which will include providing evidence to show that sufficient soil, plant available water and nutrients will be available in the waste rock substrate. These issues and related recommendations are discussed in more detail in Chapter 9 (Closure Theme – Ecosystem Restoration) and have been identified as KKNs (EE6, EE7).

The RMCP presents and discusses information on the proposed landform design, providing detailed descriptions of the backfill methodology that will be used to fill the mine pits and construct the final landform. The landform design must be optimised to minimise erosion, and outcomes of iterative erosion modelling undertaken by the Supervising Scientist have been used to assist with this.

Additional information to be provided for assessment should include:

- detailed construction plans and timelines
- engineering designs, construction tolerances and a digital elevation model
- mass or material balances
- assumed availability rates or capacities of key equipment.

The description of the Pit 3 tailings deposition method in section 10.3.2 of the RMCP is based on the original plan which was unable to be implemented due to larger than expected process water volumes. This section should be updated to reflect that tailings deposition has generally been onto either a small beach or down the pit wall and directly into the water.

Section 10.6.2 of the RMCP states that infrastructure will be demolished to set distances below the *finished surface level*. Clarification is required if this level is the surface of the waste rock landform, and therefore much of the infrastructure would remain in situ and simply be buried.

Section 10.6.2.2 of the RMCP does not discuss the placement of contaminated material from RP2 and RP3 in the Exploration Decline as indicated in Figure 10-14.

Section 10.7.4 of the RMCP states that 4.6 million tonnes of mineralised material from the northern wall of the Tailing Storage Facility will be placed in Pit 3 in 2025. However, Table 10-1 indicates that backfilling of Pit 3 will be completed in 2024. ERA has committed in other sections of the RMCP that all *mineralised* material will be placed in the lower sections of the pits. It should be clarified how this material will be placed below the *low-grade 2 rock cap* referred to in section 10.7.6.

Component 2 of section 10.7.8 (pp. 10–72) refers to planting *weeds* in drainage lines for stabilisation. The section refers to *natural ecological succession processes* that will replace the initial fast-growing weed species, but there is a high likelihood this will be ineffective. Further detail is required before the deliberate introduction of weeds would be supported.

5.3.2. Construction Materials

The general strategy for final landform construction presented in the RMCP involves the placement of the more mineralised grade 2 waste rock below the less mineralised grade 1 waste rock. While this strategy is supported, more detailed information should be provided to demonstrate adequate planning and monitoring of material movements, including a basis upon which the progress of landform construction can be assessed over time. Further information should include:

- mapped locations of material grades
- quality control procedures to be employed during construction
- a schedule showing material movements as the landform is constructed.

It is noted that the material movement areas shown in Figure 10-31 do not include the area to the north-west of the Tailings Storage Facility surrounding the trial landform and RP1 as shown in Figure 10-36. This should be clarified.

5.4. Landform Physical Properties (ER 2.1, 2.2c)

The elevation and slope of the final landform is intended to be as similar to the surrounding terrain as possible. It is stated in the RMCP that the maximum slope on the final landform will be 4.6%, but it is unclear how this figure was calculated. The Supervising Scientist estimates that slopes as high as 8% may occur in some areas of the landform. Details should be provided on how predicted maximum final landform slopes were calculated.

The RMCP suggests the use of the trial landform as a reference site that can be used to inform the design and indicate the potential long-term success of revegetation on the final landform. While the trial landform is currently supporting a vegetation community, it has not yet achieved the ERs in terms of ecosystem similarity (nor sustainability). The Supervising Scientist has concerns about how representative the trial landform is likely to be of the final landform but acknowledges that data from the trial landform are useful to inform the design and construction of the final landform.

Other concerns related to the establishment of an environment similar to adjacent areas of Kakadu National Park include:

- there is no assessment on the effect of variable landform thickness on ecosystem establishment, function and sustainability.
- there is no assessment of the thickness of waste rock required to isolate plants from underlying contamination (e.g. soils and/or shallow groundwater) which may impact on plant health.
- there is a lack of evidence to demonstrate that the final landform would support the establishment of, and sustain, a vegetation community similar to the surrounding environment (e.g. substrate properties, weathering rate, water-holding capacity, plant available water, internal water transport and contaminant availability).
- there is no assessment of the risks and benefits associated with the proposed 4 m compaction layers.

Much of the information outlined here is required to assess the adequacy of the final landform to support a sustainable ecosystem that is similar to the surrounding environment ER 2.2, which is discussed in more detail in Chapter 9 (Closure Theme — Ecosystem Restoration).

The adequacy of existing monitoring data from historical revegetation trials and analogue sites to address the above concerns should be assessed. If existing data are insufficient or inappropriate, further data should be collected from the trial landform or relevant reference sites.

5.5. Landform Stability (ER 2.1, 2.2, 11.3)

5.5.1. Tailings Consolidation

The areas of the final landform located over the mine pits will be susceptible to differential surface settlement as the tailings below the waste rock mass compress through consolidation. Therefore, a detailed understanding of the tailings characteristics and likely consolidation behaviour is required to effectively address risks related to landform stability.

The validation of the Pit 1 consolidation model against recovered pore water volumes and the three-dimensional surface shape of the tailings (as opposed to a bulk consolidation volume) would provide additional confidence in the Pit 1 consolidation model. A pit water balance is necessary to support the statement in section 7.1.2 that > 99% of the process water expressed by consolidation will be recovered for treatment by January 2026.

The tailings in Pit 3 are known to be segregated, with finer tailings in the western section of the pit and coarser tailings in the eastern section. This segregation will affect the rate and extent of tailings consolidation, possibly extending the consolidation time frame reported in the RMCP which was predicted based on assumed homogenous tailings. The finer tailings in the western section of the pit are likely to consolidate more slowly than the coarser tailings in the eastern section. This may lead to differential settlement of the landform above Pit 3 which can have implications for stability in this area. ERA has indicated that differential settlement of the landform will be managed by recontouring the landform surface after construction is completed.

To decrease the degree of segregation of tailings during deposition, ERA is planning to implement a new deposition process. This will be assessed in a standalone application and information from the application should be included in future versions of the RMCP. There is a high degree of uncertainty associated with the tailings consolidation modelling for Pit 3, as the tailings characteristics used in the modelling are not representative of the tailings in the pit. ERA commenced a significant program of work in August 2018 to characterise the Pit 3 tailings and update the consolidation model accordingly. Section 7.1.3 incorrectly states that *up-to-date parameters* have been used in the Pit 3 consolidation model. However, these data are only being obtained at the time of writing this report.

Until the updated modelling results have been assessed, the Supervising Scientist does not support the claim that *consolidation could be achieved by 2026*.

Reliable tailings consolidation modelling is required for both pits to predict consolidation behaviour. This modelling will provide an estimate of the time frame for consolidation, and may also indicate the area and rate of differential settlement of the landform over the pits. This information is required to assess the long-term stability of the landform, and may also be used to plan material movements accordingly. This information requirement has been identified as a KKN (LAN3).

5.5.2. Erosion

5.5.2.1. Denudation

Erosion modelling and field observations undertaken by the Supervising Scientist indicate that denudation rates on the landform are likely to reduce substantially within the first 100 years, but are unlikely to reach background denudation rates for at least 1000 years (Lowry 2016a,b; Lowry et al. 2017). The RMCP acknowledges this, but it also needs to recognise that the quoted rates are derived from a single modelled scenario. This information requirement has been identified as a KKN (LAN3). Under worst-case scenarios, it may take significantly longer for the denudation rate on the landform to reflect background rates.

5.5.2.2. Gully Formation

To assess the significance of predicted erosion gullies on the final landform, baseline information on gully formation rates in areas surrounding the Ranger Project Area should be presented in the RMCP. This information requirement has been identified as a KKN (LAN1). It should also be acknowledged in the RMCP that landform erosion modelling results are only indicative and should not be used or referenced as providing precise locations or depths of potential gully formation on the final landform.

5.5.2.3. Bedload Movement

The risk of bedload sediment transport offsite is considered to be low because of its ability to be managed through appropriate mitigation measures. The following information is required for the assessment of proposed flow and sediment control structures:

- design
- program of maintenance
- volume of bedload requiring disposal
- potential impacts and planned mitigation measures if the controls are ineffective.

To assess the potential impacts associated with bedload transport to Magela and Gulungul creeks, information on background bedload yields is required. The requirement for this information has been identified as a KKN (LAN1).

5.5.3. Landform Stability Risks Not Considered

5.5.3.1. Extreme Events and Landscape-scale Processes

The potential impact of extreme events and landscape-scale processes (e.g. flood events in Magela Creek) on the stability of the final landform (e.g. mass failure, subsidence), particularly in the Pit 3 area, is not considered in the RMCP. The information required to assess this risk should be included in the RMCP and has been identified as a KKN (LAN2).

A landform flood study is presented in section 7.5.2 of the RMCP, although this does not include consideration of major flood events on landform stability or the use of synthetic rainfall datasets that have been supplied to ERA by the Supervising Scientist.

5.6. Tailings Isolation (ER 11.2, 11.3)

The ERs require tailings are not exposed for 10,000 years. Gully erosion is the key mechanism that can lead to tailings exposure. The erosion modelling presented in Figure 9-9 shows the formation

of a gully over the southern portion of Pit 1. The gully is predicted to extend to a depth of 5 metres above the surface of the tailings. The digital elevation model used to represent the landform surface in this modelling had a vertical resolution of approximately 10 metres. Hence the error associated with the predicted depth of the modelled gully is likely to be \pm 10 metres, indicating that the gully could potentially expose tailings in the long term.

The final landform design should be revised to avoid gully formation over tailings for both Pit 1 and Pit 3. As stated above, erosion modelling results are indicative only and should not be referenced as providing precise locations or depths of potential gully formation on the final landform. Approval of the final landform design will not be supported by the Supervising Scientist if the modelling indicates there is the potential for gully formation on top of the buried tailings.

5.6.1. Tailings Isolation Risks Not Considered

5.6.1.1. Tailings Deposition in Pit 3

The current status of tailings in Pit 3, as discussed above, and the intention to revise the deposition strategy (moving from subaerial to subaqueous) should be discussed in the RMCP. The control effectiveness rating of C1 for the tailings consolidation risk should be reconsidered.

5.7. Infrastructure and Contaminated Material Disposal (ER 2.3)

5.7.1. Pit 3

More information is required on the disposal of site infrastructure and contaminated materials (including contaminated soil) and how this may affect tailings consolidation and landform settlement. Currently, there is insufficient detail to enable assessment of the planned waste disposal. Additional information should include:

- types and volumes of contaminated material that will require disposal (e.g. hydrocarbons, soil, waste from high density sludge plant)
- plans for material segregation (if required)
- disposal methods to be used (e.g. mixing with waste rock, layering, cells, etc.)
- schedule for plant demolition and disposal.

Section 7.5.1 states that *all material with the potential for environmental impact* will be placed at the *bottom of the mined-out pits*. It is suggested this statement is removed from the plan as it is not readily achievable given grade 1 waste rock has the *potential for environmental impact*.

As these processes will not commence for some years this information should be provided in future versions of the RMCP.

5.7.2. Exploration Decline

A standalone application for the rehabilitation of the Ranger 3 Deeps exploration decline was submitted for assessment in July 2018 and is currently under review. This application does not propose the complete backfill of the decline. The information contained within the application should be incorporated into (or appended to) future versions of the RMCP.

The exploration decline should be included in Table 10-1: Current schedule of closure tasks.

Figure 10-14: 2025 closure summary shows contaminated material being placed in the exploration decline. This is not currently reflected in the standalone application or other sections of the RMCP. This needs to be clarified.

5.8. Closure Criteria

Closure criteria proposed in the RMCP pertaining to the final landform have been assessed and the outcome is described as being either a) Accepted or b) Further Information (Table 8). For criteria that require further information (or clarification), comments are provided in the following sections.

Table 8. Supervising Scientist position on proposed Landform closure criteria

RMCP reference	Proposed Landform closure criteria	Assessment outcome	Relevant Rehabilitation Standard
L1	Supervising Authority confirms all items removed with the exception of those agreed under ER 2.3.	Accepted	-
L2	Supervising Authority confirms all tailings are placed into the mined- out pits.	Accepted	-
L3	Modelling predictions of final conceptual landform show tailings are not exposed for at least 10,000 years.	Further Information	To be completed in the initial approval.
L4	A digital elevation model (DEM) of the final constructed landform is captured. The DEM is then rerun with the final land surface topography to ensure tailings are not exposed for at least 10,000 years.	Further Information	Landform Stability: A high-resolution DEM of the constructed landform matches the approved landform design, within applicable construction standards. Modelling of erosion on the constructed landform matches results of erosion modelling conducted on the approved landform design and confirms tailings will not be exposed for 10,000 years.
L5	Modelling predictions of the final conceptual landform confirm long- term denudation rate (averaged over the entire landform) are approaching background rates (0.01–0.04 mm/yr).	Accepted	Landform Stability: Modelling of erosion on the constructed landform predicts that the denudation rate will approach 0.04 mm/yr.
L6	Drainage channels are designed and installed based on the outcomes of LEM model predictions for gully erosion.	Accepted	-
L7	Design of channels will be to blend in with the constructed landform.	Further Information	
L8	Post wet-season observations show drainage channels are in good condition (e.g. remain functional structures).	Further Information	_

RMCP reference	Proposed Landform closure criteria	Assessment outcome	Relevant Rehabilitation Standard
L9	Post wet-season observations show no unplanned gully erosion has occurred.	Accepted	Landform Stability: Annual inspections show that there is no gully formation occurring above the buried tailings.
L10	No bedload coming offsite.	Accepted	Landform Stability: Annual inspections show that no bedload is being transported away from the constructed landform, in the absence of active management.
L11	Event suspended sediment load, evaluated across the wet season, to Magela and Gulungul creeks are approaching background loads.	Further information	Landform Stability: Event-based fine suspended sediment loads, measured in Magela and Gulungul creeks at the downstream boundary of the Ranger Project Area, are approaching background values.
5.8.1. Criteria Terminology

Both closure criteria related to the physical isolation of tailings for 10,000 years (L3 and L4), should be assessed against a probable worst-case scenario, as described in the Landform Rehabilitation Standard.

Clarification is required on the terminology used in closure criterion L7, for drainage channel design. It is not clear how it will be determined that drainage channels *blend in* with the constructed landform, or how comparable they would be to surrounding natural areas.

Further clarification is required on the terminology used in closure criterion L8, for drainage channel condition. It is not clear how it will be determined that drainage channels are in *good condition* and the example provided (i.e. *remain functional structures*) is subjective.

5.8.2. Suspended Sediments

The use of site-specific relationships to convert continuous turbidity data to suspended sediment concentration data is supported. However, there are inconsistencies within the RMCP in describing the preferred method for assessing suspended sediment loads in the surface waters receiving runoff from the final landform. It is recommended that the Moliere and Evans (2010) before-after-control-impact paired (BACIP) method is adopted as described in the Landform Rehabilitation Standard. This method employs event-based regression analyses of stream discharge and suspended sediment concentrations to assess the difference between upstream and downstream sites.

5.9. Rehabilitation Monitoring

The RMCP needs to include further details on monitoring methods to demonstrate how information will be collected to assess landform performance over time, including:

- how gully formation will be measured on the revegetated landform
- details of monitoring data required for ongoing validation of erosion modelling
- water quality monitoring methods to be used for assessing landform erosion (e.g. turbidity as a surrogate for suspended sediment in surface water).

It is stated in the RMCP that the final landform topography will be documented after completion using ground-based LiDAR survey techniques, and that specific details are yet to be determined. The Supervising Scientist is currently developing airborne LiDAR platforms which may be more suited to this task. Methods of monitoring and assessing erosion and landform evolution should be reviewed regularly to ensure that they are optimised and in accordance with current best practice.

These requirements have been identified as KKNs (LAN4 and LAN5).

5.10. Summary of Recommendations and Additional Comments for the Landform

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 9.

Table 9 Summary of recommendations and additional comments pertaining to the Landform

Recommendations Before commencing construction of the final landform (other than over Pit 1) ERA must address the listed KKNs, and demonstrate that the final landform design minimises erosion to the greatest extent possible (LAN3), considering the baseline erosion and sediment transport characteristics (LAN1) and in consideration of landscape-scale process and extreme events (LAN2). *Key Knowledge Needs to be addressed:*

- LAN1 Baseline erosion and sediment transport characteristics in areas surrounding the Ranger Project Area
- LAN2 Landscape-scale processes and extreme events affecting landform stability
- LAN3 Erosion of the rehabilitated landform (excluding LAN3.A and LAN3.D)

In accordance with the previous recommendations of the Supervising Scientist; before the placement of the grade 1s waste rock cap on Pit 1 ERA must address the listed KKNs, and provide a digital elevation model (DEM) of the final landform design that has been demonstrated, using erosion modelling, to minimise erosion to the greatest extent possible (LAN3.A and LAN3.D).

Key Knowledge Needs to be addressed:

- LAN3.A What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?
- LAN3.D What are erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, time frame, groundwater expression and effectiveness of mitigations)?

Landform aspect	Additional comments	Relevant KKN
Detailed Activity Description	 Provide additional information, including: detailed construction plans and timelines engineering designs, construction tolerances and a digital elevation model material movement and balances (including reference to consolidation models) assumed availability rates/capacities of key equipment mapped locations of material grades quality control procedures to be employed during construction a schedule showing material movements as the landform is constructed. 	LAN3
	Update the RMCP to reflect that tailings deposition into Pit 3 has generally been onto either a small beach or down the pit wall and directly into the water.	LAN3

Recommendations						
	Clarify if <i>finished surface level</i> is the surface of the waste rock landform, and therefore much of the infrastructure would remain in situ and simply be buried.	LAN3				
	Include discussion on the placement of contaminated material from RP2 and RP3 in the Exploration Decline, as indicated in Figure 10-14.	LAN3				
	Improve the scheduling for disposal of contaminated material into the pits, including the 4.6 million tonnes of mineralised material from the northern wall of the Tailing Storage Facility that will be placed in Pit 3 in 2025, and the other <i>mineralised</i> material that will be placed in the lower sections of the pits. It should be clarified how this material will be placed below the <i>low-grade 2 rock cap</i> .	LAN3				
	Further detail is required to support the deliberate introduction of weeds on the final landform.	LAN3				
Landform Physical Properties	Provide details on how predicted maximum final landform slopes were calculated.	LAN3				
	Assess the adequacy of existing monitoring data from historical revegetation trials and analogue sites to inform recommendation and future work. If existing data are insufficient or inappropriate, further data should be collected from the trial landform or relevant reference sites.	LAN1, LAN3				
Landform Stability	Develop a water balance for Pit 1 to support the statement that > 99% of the process water expressed by consolidation will be recovered for treatment by January 2026.	LAN3				
	Information on the new tailings deposition strategy in Pit 3 should be included in future versions of the RMCP, including the consolidation time frames, and any differential settlement predicted using the updated Pit 3 consolidation model.	LAN3				
	It should be acknowledged that landform erosion modelling results are dependent on the specific scenario modelled, and are indicative only (e.g. not to be referenced as providing precise locations or depths of potential gully formation on the final landform).	LAN3				

Recommendations				
	Provide the following information on the proposed flow and sediment control structures, including:	LAN3		
	the design			
	a program of maintenance			
	the volume of bedload requiring disposal			
	• potential impacts and planned mitigation measures that the structures are ineffective.			
	Provide information on the background bedload yields, to assess the potential impacts associated with bedload transport to Magela and Gulungul creeks (should this occur).	LAN1		
	Assess the potential risks of extreme events and landscape-scale processes on landform stability.	LAN2		
	Use synthetic rainfall datasets in flood modelling.	LAN2		
Tailings Isolation	The final landform design should be revised to avoid gully formation over tailings for both Pit 1 and Pit 3.	LAN4		
	Given the tailings deposition method is currently under review the control effectiveness rating of C1 for the tailings consolidation risk should be reconsidered.	LAN3		
Infrastructure	Provide a detailed backfill plan for Pit 3 including:	LAN3		
Disposal	 types and volumes of contaminated material that will require disposal (e.g. hydrocarbons, soil, waste from HDS plant) 			
	plans for material segregation (if required)			
	• disposal methods to be used (e.g. mixing with waste rock, layering, cells, etc.)			
	schedule for plant demolition and disposal.			
	Incorporate a summary of the standalone application for rehabilitation of the Ranger 3 Deeps exploration decline into future versions of the RMCP.	LAN3		
Closure Criteria	The <i>probable worst-case scenario</i> should be retained in the closure criteria and clearly defined, in consultation with the Supervising Scientist.	LAN3		
	Quantify closure criteria L7 and L8.	LAN3		
	Use the BACIP method described by Moliere and Evans (2010) to assess suspended sediment loads in closure criteria L11.	LAN3		

Recommendations				
Monitoring	 Provide further details to on monitoring method to demonstrate how relevant information will be collected to assess landform performance over time, including: how gully formation will be measured on the revegetated landform details of monitoring data required for ongoing validation of erosion modelling 	LAN 4, LAN5		
	 water quality monitoring methods to be used for assessing landform erosion (e.g. turbidity as a surrogate for suspended sediment in surface water). 			

6. Closure Theme: Water and Sediment

6.1. Relevant Environmental Requirements

The Water and Sediment closure theme covers the rehabilitation activities undertaken to minimise the release of contaminants (i.e. radiological¹, chemical and physical) and prevent changes to water and/or sediment quality in the receiving environment that might result in impacts to ecosystems and/or human health.

Table 10 provides a summary of the ERs that are relevant to the Water and Sediment closure theme (in addition to the primary ERs presented in Table 1). Table 10 also provides the outcomes of the Supervising Scientist's detailed assessment of the RMCP, indicating whether or not the information provided in relation to the Water and Sediment closure theme is sufficient to demonstrate that each of the relevant ERs can be met.

Water or sediment aspect	Clause	Environmental Requirement	Does RMCP demonstrate ER can be met?
Water/ Sediment Quality	3.1	The company must not allow either surface or ground waters arising or discharged from the Ranger Project Area during its operation, or during or following rehabilitation, to compromise the achievement of the primary environmental objectives.	Further information required
Protection of Ecosystems	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 (b) maintain the health of wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park) (d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes. 	Further information required

Table 10. Ranger Environmental Requirements relevant to the Water and Sediment closure theme

¹ Note that although radiation can be considered as a contaminant in water and/or sediments, this is considered as a specific closure theme in Chapter 7 of this report.

Water or sediment aspect	Clause	Environmental Requirement	Does RMCP demonstrate ER can be met?
	1.2	 In particular, the company must ensure that operations at Ranger do not result in: (a) damage to the attributes for which Kakadu National Park was inscribed on the World Heritage List (b) damage to the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park) (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 (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. 	Further information required
	10.1	 All operations should be managed to minimise, to the maximum extent practicable, and to the satisfaction of the Supervising Authority or the minister with the advice of the Supervising Scientist: (c) the risk to fauna as a result of drinking contaminated water. 	Further information required
	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.	Further information required
Protection of Human Health	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: (c) protect the health of Aboriginals and other members of the regional community.	Further information required

Water or sediment aspect	Clause	Environmental Requirement	Does RMCP demonstrate ER can be met?
	1.2	In particular, the company must ensure that operations at Ranger do not result in:	Further information
		(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.	required

6.2. Activity Summary

The RMCP proposes a number of activities that relate to the management, treatment and disposal of contaminated water and sediment, to minimise environmental impacts on the minesite and to prevent environmental impacts offsite. These activities all relate to the reduction and containment of mine-related contaminants and include:

- management, storage and treatment of contaminated water and sediments
- management and long-term disposal of tailings and brine
- management and remediation of contaminated sites, including contaminated groundwater.

While these proposed activities are broadly in line with the relevant ERs, additional information is required to enable assessment of the activities against the requirement to prevent offsite environmental impacts.

6.3. Detailed Works Description

The RMCP presents the proposed strategy for the management, storage and treatment of contaminated water, and the management, storage and final disposal of brine (the by-product of water treatment). The time for which contaminated water will require active management and treatment to ensure achievement of the ERs will depend on the success of this strategy. The plan currently indicates that all contaminated water can be treated by January 2026 and that all brine generated from the treatment process can be stored effectively in the designated void space in Pit 3.

These management, storage and treatment requirements are based on predictive modelling that estimates annual volumes of contaminated water, and associated volumes of brine produced from water treatment. This modelling includes a number of significant assumptions, including wetseason rainfall, water treatment capacity/efficiency and volume of contaminated water generated by the process of tailings consolidation in Pit 1 and Pit 3. The veracity of these assumptions is still under review and assessment, and further information is required to enable a detailed assessment of likely success of the proposed strategy. Additional information to be provided should include, as relevant:

- detailed plans and timelines for all activities related to water management, storage, treatment and brine disposal
- availability, rates, capacities of key plant and equipment (e.g. water treatment plants, brine injection bores, etc.)
- updated modelling assumptions and modelling uncertainty analyses.

It is expected that a large majority of this information will become available as ERA completes its feasibility-level planning, and it should be detailed in a future version of the RMCP.

The RMCP also presents results of contaminant transport modelling that predicts concentrations of mine-derived contaminants in the offsite environment over 10,000 years. This modelling requires reliable assessment/predictions of contaminant concentrations in key source terms, transport and behaviour of contaminants in groundwater and contaminant concentrations in receiving surface waters. There is still a high degree of uncertainty associated with each of these, and ERA is currently refining the various models to reduce this uncertainty.

Until confidence in the modelling is improved, predicted contaminant concentrations in surface waters surrounding the minesite remain uncertain. As such, assessment of the rehabilitation plan against the requirement to protect the surrounding environment for 10,000 years cannot be undertaken. The section below discusses the additional information that is required to improve the confidence in the modelling.

6.4. Water and Sediment Quality (ER 3.1–3.4)

6.4.1. Water Storage, Management and Treatment

6.4.1.1. Process Water and Brine

To demonstrate that ERA will be able to effectively manage all process water throughout the rehabilitation process, the RMCP should include a detailed schedule that outlines the predicted process water volume and intended storage locations over time. It is understood that the key process water storage locations will be the Tailings Storage Facility, Pit 3 and RP6 (if required).

Further assessment is required to determine if the Tailings Storage Facility can be used as a process water storage post-2020, and relevant contingency options should be considered in the event the Tailings Storage Facility is determined to be unsuitable for water storage.

A schedule should also be included for water treatment, indicating all planned options for process water treatment and demonstrating that these options will be sufficient to treat the predicted process water volumes. It is understood that brine concentration will remain the preferred option for process water treatment during rehabilitation. However, the existing plant will require operational improvements to increase its treatment capacity. Other options for process water treatment plant. The requirement to dispose of the treated water, such as through land application, should also be considered in any assessment of water treatment capacity.

Information is presented in the RMCP on differences in tailings consolidation modelling results between work that was conducted in 2014 and 2016. While most of the results are *essentially the same*, it is unclear why tailings pore water expression during deposition has increased from 14.7 Mm³ to 21.9 Mm³.

Given the uncertainty associated with the predicted process water volumes up to 2025, it is critical that ERA fulfil its commitment to continue water treatment for as long as necessary to treat and

dispose of all process water (including expressed tailings pore water) onsite (section 10.2, pp. 10– 36). This commitment is supported by the Supervising Scientist, along with the intention to increase the capacity of process water treatment over time, which will be necessary to achieve treatment of all process water by 2025. This commitment should be included as a contingency in section 10.9.1.

Further details of the Pit 3 brine injection system should be provided in the RMCP, including:

- the expected lifespan of brine injection bores and factors that may affect this
- time frames and potential issues associated with the construction of additional brine injection bores, should they be required
- any other brine disposal methods that might be used in the case that the brine injection system fails (i.e. failure of all bores, or the underbed drain extraction system).

It is noted that the brine injection system has been offline since late 2016 due to issues with the underdrain water recovery system, and is not likely to recommence operations until later in 2019.

6.4.1.2. Pond Water

It is stated in the RMCP that pond water treatment will continue throughout the rehabilitation process, with treated water discharged to *available* wetland filters and land application areas (LAAs) until 2025. However, as irrigation areas are progressively rehabilitated, only the Corridor Creek wetland filter/irrigation area and Georgetown Creek median bund level-line (GCMBL) will be available after 2021. This could result in potential risks associated with concentrating the disposal over a smaller area (e.g. soil waterlogging, unseasonal surface runoff, raised groundwater levels). Further information needs to be provided to demonstrate that there are sufficient disposal options for treated pond water as irrigation areas are decommissioned, as well as the disposal of the pond water treatment waste stream later in the rehabilitation process.

6.4.1.3. Sediment Control Infrastructure

A concept design for erosion and sediment controls is provided in the RMCP (i.e. surface treatment, drainage channel treatment and sediment basins), which are intended to manage runoff during the early years of landform establishment. While these may be effective in reducing loads of suspended sediments leaving the site, the time frames for which these structures are expected to remain in place should be included (i.e. criteria for removal) along with a schedule for ongoing maintenance (e.g. sediment removal and disposal locations). It is expected that more specific designs and management plans for erosion and sediment controls will be presented in the RMCP before the commencement of major rehabilitation works onsite.

The RMCP proposes the use of *engineering controls* to *minimise the transportation of waste rock solutes to the offsite environment*. Magnesium, the key contaminant of concern, is highly soluble so it is unclear how passive systems can be used to manage magnesium. It is not clear why this control is rated as the highest level of effectiveness in the closure risk assessment.

6.4.2. Site Conceptual Models

The baseline hydrogeological and groundwater quality information presented in the RMCP is largely based on the current Ranger Conceptual Model (INTERA 2016) and assessments of background concentrations of contaminants in groundwater (Esslemont 2015, 2017). Work on defining background concentrations of contaminants in groundwater in the vicinity of Ranger mine, and regionally, is ongoing and should be included in future versions of the RMCP.

The Ranger Conceptual Model (INTERA 2016) was reviewed by SSB and discussed at a groundwater workshop in September 2016. The conceptual model presents a significant amount of information at a range of scales but requires ongoing updates and refinement as further information becomes available. General feedback on the review of the conceptual model included the need for:

- the use of observed data to underpin the conceptualisation rather than using modelling outputs
- further refinement and characterisation of key hydrolithilogical units, aquifers and groundwater flows, particularly in regions in the vicinity of Pit 1, Pit 3 and the Tailing Storage Facility that are high-risk areas for contaminant transport (e.g. the Magela Creek bed, the Djalkmarra sands, and the MBL zone)
- greater detail on surface water and groundwater interactions
- improved characterisation of existing contaminated groundwater (e.g. under the Tailings Storage Facility) and contaminated sites (e.g. LAAs).

The conceptual model must retain sufficient complexity at a relevant scale as it provides the foundation for analytical and numerical models that need to adequately simulate the actual groundwater flow system to the degree necessary to satisfy the objectives of the contaminant transport modelling. The conceptual model must describe key features of hydrogeological and hydrogeochemical regimes during pre-mining, mining and post-closure periods to ensure understanding of the changing nature of the groundwater system during and after decommissioning and post-rehabilitation.

ERA will update the Ranger Conceptual Model with new hydrogeological data and information as required. This is important to ensure confidence in the conceptualisation of the site. The RMCP should detail future hydrogeological work that will be undertaken to refine the Ranger Conceptual Model and explain how this will feed into the contaminant transport modelling and rehabilitation planning.

These information requirements have been identified as a KKN (WS2).

6.4.3. Contaminant Source Terms

Further work is required to quantify contaminant source terms (including radionuclides) and factors that influence their mobilisation on a whole-of-site basis. This includes quantifying existing groundwater contamination and contaminants that are predicted to arise from the waste rock landform, the buried tailings and contaminated soils and sediments disturbed during rehabilitation, including:

- more detailed information on waste rock infiltration rates and vadose zone behaviour, including estimates of pyrite content and oxidation potential
- quantification of the degree and extent of contaminated groundwater under the Tailings Storage Facility, along with its potential for movement through the aquifer into the offsite environment
- tailings consolidation modelling needs to be validated and/or updated in Pit 1 and Pit 3 to improve estimates of the volume and timing of contaminated water expression during tailings consolidation.

For each of these sources, possible remediation options and contingency measures should also be included in the RMCP.

These information requirements have been identified as a KKN (WS1)

6.4.3.1. Waste Rock

The RMCP presents monitoring data from the trial landform (section 7.3.2.3) that show concentrations of contaminants in surface runoff from waste rock are generally low. However, there are few data or little information presented on the contaminant concentrations present in seepage water from the trial landform, which are likely to be higher than those in surface runoff. The rate of rainfall infiltration will drive the seepage process and associated geochemical reactions that lead to the dissolution of contaminants from the waste rock.

Table 7-22 of the RMCP states that infiltration rates will be between 1 and 10 mm per hour, and based on this it has been assumed that 10% of total rainfall will infiltrate the final landform. This value has been used in modelling to predict concentrations of contaminants that could enter shallow groundwater from seepage through the waste rock landform. ERA has recently acknowledged that this rate is too low, and the actual rate is likely to be substantially higher. Work undertaken by the Supervising Scientist also indicates that the actual infiltration rate is likely to be higher than indicated in the plan. ERA plans to investigate infiltration rates in waste rock across the site to ensure that the appropriate rate is used in contaminant transport modelling. Modelling will need to be updated accordingly.

Given the order of magnitude difference in the mean and median values for waste rock sulfur content provided in section 3.2.8 there must have been some significantly higher values detected. Consideration should be given to an improved quantification of sulfide minerals present in the waste rock landform, and assessment of solute release subsequent to the consumption of all the sulfide minerals. The ongoing release from the waste rock could be considered in terms of the acid content of water that will pass through the waste rock as well as from appropriate mineralogical controls if the latter is deemed necessary.

6.4.3.2. Tailings and Pore Water

Current tailings consolidation modelling indicates that by 2026, nearly all tailings pore water (process water) will be removed from the buried tailings in Pit 1 and Pit 3 and treated. This is a key assumption in the current groundwater and contaminant transport modelling. However, it is possible that tailings consolidation may take longer than predicted, and that some tailings pore water may move laterally or downwards into the rock around the edges of the pits, and may not be removed and treated. This could increase the contaminant source associated with pit tailings and require the contaminant transport modelling to be updated accordingly. Additional data are required to update the tailings consolidation modelling and water balance accounting for both pits, considering the heterogeneous nature of the tailings in the pits, and the effect this may have on the quantity of contaminants mobilised from tailings and the timing, direction and rate of solute expression.

ERA's commitment to continue to capture and treat expressed tailings pore water until consolidation is effectively complete is noted and supported.

6.4.3.3. Groundwater

Although it is acknowledged in the RMCP that contaminated groundwater beneath some contaminated sites will require active management during the rehabilitation process, further work is required to characterise existing groundwater contamination onsite. This includes beneath the Tailings Storage Facility, the waste rock stockpiles and the processing plant. Once the nature and extent of groundwater contamination across the site are understood, the Ranger Conceptual Model and contaminant transport models should be updated accordingly to better reflect this important

source term. Where required, specific groundwater management and remediation strategies should be developed and included in the RMCP. This is particularly important for the area beneath the Tailings Storage Facility given the large volume of contaminated groundwater likely to be present.

To support conclusions made in the RMCP that there is negligible groundwater contamination beneath the LAAs, data should be presented from bores representing all aquifers and areas of the Ranger Project Area that could be impacted (i.e. Aquifer 1 and Aquifer 2).

These information requirements have been identified as a KKN (WS1).

6.4.4. Contaminant Transport Modelling

The RMCP provides a modelling plan that illustrates the various models that will be used to predict the transport and fate of contaminants, including groundwater and surface water flow and contaminant transport models. When completed and integrated, these models will provide postrehabilitation surface water contaminant concentrations in the creeks surrounding Ranger mine. These concentrations will then be assessed against the approved water quality closure criteria to demonstrate whether or not mine-derived contaminants are likely to result in impacts to the offsite environment.

All numerical modelling should be based on:

- the data-driven Ranger Conceptual Model, which needs to include sufficient detail and confidence for high-risk areas, particularly the Magela Creek bed, the 'Djalkmarra sands' and the 'MBL zone'
- detailed and reliable quantification of all potential contaminant source terms onsite, including existing groundwater contamination on the minesite
- a calibration period that is sufficient to stress the model to the extent that its behaviour during pre-mining, operational and post-mining conditions can be assessed, including mine-impacted and baseline variability in groundwater levels, stream flow and associated processes
- all available data, including pre-mine data if available, with clear justification for the exclusion of data not used
- surface water and groundwater interactions at an appropriate temporal scale.

The modelling undertaken to date is considered suitable for the intended purpose of estimating the average and peak annual contaminant loads delivered from Pits 1 and 3 to downstream surface waters (i.e. Corridor and Magela creeks) over 10,000 years. However, as indicated above, additional work is required to predict contaminant concentrations in the receiving surface waters to demonstrate that there will not be detrimental impacts to the surrounding environment associated with mine-derived contaminants. This includes:

- undertaking contaminant transport modelling at increased temporal and spatial resolution (particularly around the period of peak solute delivery to the surface water system)
- developing a better understanding of groundwater and surface water interactions that will control the location and timing of delivery of contaminated groundwater to the surface water system
- implications of groundwater recovery as groundwater levels return to a stable state after rehabilitation
- improved understanding of the role of groundwater and surface water interactions in solute migration

• assessment of confidence in modelled outputs using statistical, sensitivity and uncertainty analyses for each model, as well as analysis of cumulative uncertainty where multiple models are interconnected.

The contaminant concentrations presented in the RMCP are not supported by the Supervising Scientist. The concentrations presented are based on modelling that assumes a constant rate of solute delivery from groundwater to surface water throughout the entire period of surface flow. In contrast, water quality data collected throughout mine operations indicate that the expression of groundwater to surface water, and the associated delivery of groundwater contaminants, increases during recessional flow periods, either during intermonsoonal periods or towards the end of the annual wet season. During these periods surface flow is reduced which limits dilution and results in higher contaminant concentrations. Additional work is currently underway by ERA to refine the contaminant transport modelling and provide more realistic predictions of contaminant concentrations in surface waters. A key component of this work is to develop an understanding of the spatial and temporal (seasonal) interactions between groundwater and surface water. This work is required as a priority, particularly in light of the significant concerns related to water quality in Magela Creek raised in Appendix 8.1 of the RMCP (2011–12 ITWC PFS BPT Assessment).

Reactive transport modelling has not been undertaken and all contaminants have been assumed to behave conservatively in groundwater. This assumption is acceptable for all contaminants except calcium, for which reactive transport modelling is required due to its ameliorative effect on magnesium toxicity.

In addition to this, there is no uncertainty associated with the concentrations presented in the RMCP. To ensure that the assessment of potential future environmental impacts is possible, uncertainty in the estimated concentrations must be quantified and understood. This will require a robust analysis of model uncertainty.

Until this work is completed the Supervising Scientist does not accept the statement in section 9.3.2 of the RMCP that contaminants from the landform do not pose a risk to the surrounding environment.

These information requirements have been identified as KKNs (WS2, WS3).

6.4.5. Water and Sediment Quality Risks Not Considered

6.4.5.1. Acid Sulfate Sediments

The potential risks associated with the generation of acid sulfate sediments due to mine-derived sulfate needs to be assessed, particularly in Coonjimba, Georgetown and Gulungul billabongs. This assessment should also consider the potential associated impacts on water quality in Magela Creek. It is stated in the RMCP that *there is a low environmental risk to the billabong system, or to downstream water quality and ecosystems*, and that *acid water does not flow into Magela Creek because there are no natural drains from Coonjimba Billabong in the dry season*. These statements are not considered to be accurate and are not supported by sufficient evidence. Acidic pools have been observed by the Supervising Scientist in Magela Creek downstream of Coonjimba Billabong during the dry season, which indicates there is a subsurface connection between these waterbodies. While it is likely that the predominant source of sulfate in Coonjimba Billabong is from operational releases of mine water, potential inputs of sulfate from groundwater should also be investigated.

These information requirements have been identified as KKNs (WS5, WS7).

6.5. Protection of Ecosystems (ER 1.1, 1.2, 7.1, 11.3) and Protection of Human Health (ER 1.1c, 1.2c)

6.5.1. Baseline Aquatic Biodiversity

There is limited information presented in the RMCP on aquatic biodiversity. There are a large amount of aquatic biodiversity data that have been collected by the Supervising Scientist that should be referenced and included in baseline descriptions in the RMCP. Organism assemblages for all stages of creek flow should be characterised and assessed for their sensitivity to contaminants.

The potential contribution of subterranean fauna in Magela Creek sand beds to ecological processes and the biodiversity of the Alligator Rivers Region (ARR) also needs to be determined and if significant, the potential impact of contaminants on these communities should be determined.

These information requirements have been identified as a KKN (WS4)

6.5.2. Suspended Sediments

While significant consideration is given to contaminants in surface water, more information needs to be provided on concentrations of suspended sediments and the contaminants (including nutrients) bound to suspended sediments, including:

- effects of sediment mobilisation on surface water quality
- physical effects of suspended sediment on aquatic biodiversity
- where, when and to what extent contaminants may accumulate in downstream sediments
- monitoring methods.

These information requirements have been identified as KKNs (WS3, WS8).

6.5.3. Onsite Water Bodies

The potential requirement for remediation of onsite water bodies (i.e. RP1, Coonjimba Billabong, Georgetown Billabong) is not discussed in the RMCP. It is stated that RP1 will be retained temporarily post-closure to manage water quality runoff from the final landform but specific details should be provided for all onsite water bodies on any remediation required and associated timing.

6.5.4. Eutrophication

The potential risk of eutrophication as a result of nutrients emanating from the rehabilitated minesite is acknowledged in the RMCP, and will be assessed when water quality modelling data predicting nutrient concentrations become available.

Further discussion on nutrients in the context of eutrophication risks and closure criteria is provided below.

These information requirements have been identified as a KKN (WS6 — refer Chapter 12).

6.5.5. Protection of Ecosystems and Human Health Risks Not Considered

6.5.5.1. Effects of Contaminants on Riparian and Aquatic Vegetation

While the potential risk to riparian vegetation from contaminants is acknowledged in the RMCP, no investigations to inform the assessment of this risk have been proposed. It is also unclear what concentrations of contaminants aquatic vegetation will be exposed to after rehabilitation and the potential risk of impacts to aquatic vegetation is not discussed in the RMCP. Updated contaminant transport modelling being undertaken by ERA will inform the assessment of this risk.

These information requirements have been identified as KKNs (EE6, WS7).

6.5.5.2. Emerging Contaminants

While not highly likely, it is possible that additional contaminants that have not been previously identified as a risk may need to be considered in future. For example, contaminated site studies that are currently underway could identify 'new' contaminants. Provision should also be made for a periodic review of the contaminants measured in the post-rehabilitation monitoring program outlined in the RMCP, and if required closure criteria developed accordingly.

This information requirement has been identified as a KKN (WS7).

6.5.5.3. Inhibition of Aquatic Organism Movement

The potential risk that a contaminant plume in creek channels could form a barrier that inhibits organism migration and connectivity (e.g. fish migration, invertebrate drift, gene flow) is not considered in the RMCP.

This information requirement has been identified as a KKN (WS7).

6.5.5.4. Additional Key Aquatic Organisms

While current water quality guideline values (and closure criteria) are based on a range of aquatic organism types, it is possible that there may be key groups (e.g. flow-dependent insects, hyporheic biota and stygofauna) that have not been represented in laboratory and field toxicity assessments. This could result in the risk that current guideline values are not sufficiently protective of aquatic ecosystems.

This information requirement has been identified as a KKN (WS7).

6.6. Closure Criteria

Closure criteria proposed in the RMCP pertaining to water and sediment have been assessed and the outcome is described as being either a) Accepted or b) Require Further Information (Table 11). For criteria that require further information (or clarification), comments are provided in the following sections.

Table 11. Supervising Scientist position on proposed Water and Sediment closure criteria

RMCP reference	Water and Sediment criteria	Assessment outcome	Relevant Rehabilitation Standard
W1	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 contaminants to become intolerable.	Further information	
	First-tier screening criteria – drinking water:		
	Drinking water quality in Magela Creek outside the RPA meets the national drinking water health guidelines		
	SO4 ^{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 contaminants 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.		
W2	Water quality in Magela and Gulungul creeks at secondary contact sites is safe for secondary contact.	Further	
	First-tier screening criteria:	mornation	
	Water quality at MG009 and GCH meets these recreational guidelines:		
	NO $_3500$ mg/L, NO $_230$ mg/L, U 170 μ g/L (i.e. drinking water contaminant x 10: NHRMC 2008)		
	SO ₄ ^{2–} 400 mg/L, Mn 100 μ g/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.		

RMCP reference	Water and Sediment criteria	Assessment outcome	Relevant Rehabilitation Standard
W3	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 \leq 2.8 µg/L; Mn \leq 75 µg/L; NH ₃ -N \leq 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/yr; 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.	Further information	U and Mn in Surfacer Water: U: 2.8 μ g/L Mn: 75 μ g/L Mg in Surface Water: Mg: 2.9 mg/L Mg:Ca: 3.5:1 (mass ratio) Other Metals in Surface Water: Al: 27 μ g/L (seasonal median) Cd: 0.06 μ g/L Cr — total: 0.2 μ g/L (seasonal median) Cr — VI: 0.01 μ g/L Cu: 0.2 μ g/L (seasonal median) Zn: 2.4 μ g/L Pb: 1.0 μ g/L Fe: 82 μ g/L (seasonal median) V: 0.25 μ g/L interim (seasonal median) V: 0.25 μ g/L interim (seasonal median) Prevention of Acid Sulfate Soils: Dissolved sulfate: 10 mg/L (seasonal average) Ammonia in Surface Water: Total ammonia N: 0.40 mg/L
W4	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).	Further information	

RMCP reference	Water and Sediment criteria	Assessment outcome	Relevant Rehabilitation Standard
W5	On the RPA water quality in Magela and Gulungul creeks and sedimentation in the billabongs will be as low as reasonably achievable (ALARA).	Further information	-

6.6.1. Assessment Approach

The use of ALARA terminology within final criteria statements results in closure criteria that are not quantifiable or measurable. It is recommended that ERA update these criteria with quantitative values that reflect ALARA.

There are statements made in the RMCP that misinterpret the Supervising Scientist's view in relation to the proposed tiered approach for Water and Sediment closure criteria. In general, a tiered screening-level approach is undertaken to ensure that the amount of effort placed on environmental protection and impact assessment is commensurate with the level of risk posed by any given contaminant. In this way, a tiered screening-level approach is useful to prevent the requirement to conduct site-specific assessments of biological effects where there is a low risk of effects occurring.

For low-risk contaminants, for which there are no local biological-effects data (aluminium, iron, copper, cadmium, zinc, lead, vanadium and chromium), it is appropriate to base the closure criteria on the first-tier screening level, against which predicted future surface water concentrations could be compared. If the predicted concentrations exceed the first-tier screening level, then further studies will need to be conducted to determine a biological-effect based criteria for that contaminant (e.g. ecotoxicological investigations).

For high-risk contaminants, where site-specific biological-effects based values are already available (magnesium, uranium, ammonia and manganese), there is no need to use a tiered screening-level approach for assessing impact. The closure criteria should be based on the biological-effects values that have been derived by the Supervising Scientist, providing a single numerical value against which predicted future surface water concentrations can be compared. If the predicted concentrations exceed these values there is likely to be some degree of impact on the environment. In this case, the final step of the tiered risk-assessment framework presented in Figure 6-5 may be useful for quantifying and communicating the potential impacts and assessing the appropriate level of mitigation required to minimise these impacts.

It is noted that there has been no agreement reached on an acceptable level of biological effects outside of the Ranger Project Area. The Mirrar Traditional Owners have been clear in stating that they consider any mine-derived change to biodiversity outside of the Ranger Project Area to be detrimental.

Additionally, it is incorrectly asserted in the second outcome of the Water and Sediment Objectives 2 that the ERs require an effect to be regional in nature to be considered detrimental. ER 1.2(d) states that to be considered detrimental a change must be in excess of that observed naturally in the region (i.e. outside the range of natural variability), not that changes must be regional in nature.

Any assessment of water quality criteria must consider uncertainty, both in predicted surface water contaminant concentrations and in the guideline value being applied.

Methods used to derive sediment criteria should be provided in the RMCP.

6.6.2. Locations Where Closure Criteria Apply

The proposal to apply closure criteria in Magela Creek downstream of the Gulungul confluence, within Kakadu National Park, is not supported. In the absence of agreement on an acceptable level of impact outside of the Ranger Project Area, water quality closure criteria should be applied at the Ranger Project Area boundary.

A further rationale should be provided for the locations where the proposed closure criteria apply as this is variable. For example:

- drinking water criteria apply to Magela Creek outside the Ranger Project Area
- recreational contact criteria apply at the sites MG009 and GCH.

6.6.3. Ranger Project Area Human Consumption

The parameters and concentrations proposed in the criterion for drinking water and diet (Criteria W1) are supported. Closure criteria for drinking water are provided for areas outside the Ranger Project Area only. To demonstrate concentrations are ALARA within the Ranger Project Area will require the following information:

- potential levels of exposure of humans associated with drinking water (i.e. consumption rates, locations, concentrations)
- an assessment of the risk to humans.

Depending on the level of risk to humans, drinking water closure criteria may need to be applied to the Ranger Project Area.

This information requirement has been identified as a KKN (WS10).

6.6.4. Water Quality for Ecosystem Protection

The parameters proposed in the closure criterion for protection of ecosystem health (Criterion W3) are generally supported.

Note that for specific concentrations of the parameters:

- turbidity supported
- magnesium generally supported, but the Supervising Scientist's magnesium Rehabilitation Standard is 2.9 mg/L, and also specifies a Mg:Ca (mass) ratio of 3.5:1 that should not be exceeded
- uranium supported
- manganese supported
- ammonia generally supported, but the Supervising Scientist's total ammonia nitrogen (TAN) Rehabilitation Standard is 0.4 mg/L
- nutrients (NOx, NH₃-N, Total-P N) not supported (see section 6.7.8)
- sulfate the Supervising Scientist has developed a Rehabilitation Standard for sulfate of 10 mg/L (seasonal average) in surface water, for prevention of acid sulfate soil formation in sediments
- metals (other than uranium) the Supervising Scientist has developed a Rehabilitation Standard for aluminium, cadmium, chromium, copper, zinc, lead and vanadium.

It is noted in the RMCP that several metals originating from mill tailings/process water have been excluded from the closure criteria list based on a risk analysis comparing previous modelling results to guidelines or limits. This may need to be reconsidered in future, depending on the results of updated modelling that is yet to be completed, as well as any emerging contaminants that are identified during rehabilitation studies.

These information requirements have been identified as KKNs (WS5-WS10).

6.6.5. Effects of Contaminant Mixtures

The RMCP presents a range of closure criteria for individual contaminants, which are based on the effects of those contaminants alone. The contaminants will co-occur in mine waters and receiving surface waters, and synergistic interactions and other modifying factors (e.g. increased pH is known to increase ammonia toxicity) may increase toxicity. It should be demonstrated that the proposed criteria are applicable in all water quality situations.

This information requirement has been identified as a KKN (WS7).

6.6.6. Contaminant Accumulation in Sediments

The second outcome under Water and Sediment Objective 2 refers only to uranium in sediment. This should be expanded to 'contaminants' in sediment.

The sediment monitoring program proposed in the RMCP includes the sampling of uranium in Georgetown Billabong at the end of decommissioning to demonstrate achievement of closure criteria. Work currently underway by the Supervising Scientist indicates that uranium accumulation in sediments will be limited provided the closure criteria for uranium in surface water is met. However, estimates of potential uranium accumulation in sediments post-rehabilitation should be based on the results of surface water contaminant modelling to demonstrate that sediment closure criteria are likely to be met over the long term.

The potential for impacts associated with mobilisation and accumulation of uranium and other contaminants in suspended sediments transported offsite is not detailed in the RMCP, although it is acknowledged that the Supervising Scientist has scheduled research to be undertaken to address this information requirement.

These information requirements have been identified as KKNs (WS3 and WS5)

6.6.7. Nutrients

The closure criteria for nutrients have been derived using default values from ANZECC & ARMCANZ (2000). However, these values are unlikely to be achieved because they are less than the background concentrations for nitrate/nitrite (NO_x) and ammonia (NH₃-N) observed in the surface water systems surrounding the Ranger Project Area. Further work is required to derive closure criteria that are protective of the environment from eutrophication and toxicity, and are also achievable. The risk of eutrophication should be reassessed and placed in the context of both baseline conditions and predicted post-rehabilitation surface water concentrations.

This information requirement has been identified as a KKN (WS6).

6.6.8. Sedimentation in Billabongs

Turbidity closure criteria proposed within the landform theme are considered sufficient to ensure the protection of aquatic ecosystems in the creeks but do not consider the environmental effects of sedimentation in billabongs closer to the mine. It is acknowledged in the RMCP that a closure criterion is to be developed for sedimentation in offsite billabongs in relation to aquatic ecosystem protection.

This information requirement has been identified as a KKN (WS8).

6.6.9. Groundwater

Closure criteria for groundwater are not included in the RMCP. Work underway by the Supervising Scientist to investigate subterranean fauna will assist in determining whether or not groundwater criteria are required.

This information requirement has been identified as a KKN (WS4).

6.7. Rehabilitation Monitoring

6.7.1. Surface Water

The proposal to establish the overall surface water compliance site downstream of the Magela – Gulungul confluence is not supported in the absence of agreement on an acceptable level of effect to the offsite environment (i.e. in the sections of Magela and Gulungul creeks between the lease boundary and the proposed compliance site).

The monitoring section of the RMCP (Chapter 11) includes sulfate as a water quality parameter at the Magela–Gulungul confluence and at GCLB for 'Diet and Recreation' values. Given the risk of acid sulfate soil development on the Ranger Project Area and the Supervising Scientist's rehabilitation standard for this parameter, it should also be monitored at RP1 (and other onsite waterbodies, while they are present) and Georgetown and Gulungul Billabongs.

Grab sampling may need to be conducted more frequently than monthly in the initial period after completion of rehabilitation works. Section 11.3.1 states that only continuous monitoring will be conducted at the upstream sites. It is assumed this includes event-based sampling as shown in Table 11-2.

Ra-226 should be included in the surface water monitoring program.

6.7.2. Groundwater

The groundwater monitoring program presented in the RMCP should be revised to clearly demonstrate that monitoring will be undertaken at an appropriate spatial and temporal scale to:

- observe trends in groundwater level recovery and contaminant transport post-rehabilitation that can be used to validate groundwater models, and recalibrate if necessary
- detect significant increases in contaminant concentrations in aquifers surrounding Pit 1, Pit 3 and the Tailing Storage Facility, to enable downstream mitigation of impacts if required (i.e. groundwater interception or abstraction).

The RMCP incorrectly states that a groundwater monitoring program for Pit 1 was approved in the application of the final tailings level. This is not the case, rather a key recommendation made as part of the approval of the final tailings level in Pit 1 was that the monitoring program approved in the 2005 application to deposit tailings in Pit 1 must be continued until a new, more appropriate monitoring program was developed and approved. This has not yet been done.

6.7.3. Monitoring Program Review

Future reductions in the approved monitoring program should consider the need for ongoing model validation and the predicted time frame for solute migration, as well as observed trends in water quality.

Methods of monitoring and assessing water quality and ecosystem health should be reviewed regularly to ensure that they are optimised and in accordance with current best practice.

This information requirement has been identified as a KKN (WS11).

6.8. Summary of Recommendations and Additional Comments for Water and Sediment

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 12.

Table 12. Summary of recommendations pertaining to Water and Sediment

	Recommendation			
Before commer KKNs, and dem (WS5, WS6, W (WS1, WS2 and Key Knowledge • WS1 — Ch • WS2 — Pri • WS3 — Pri • WS3 — Pri • WS5 — De ecosystem • WS5 — De health • WS8 — De health • WS9 — De	the impact of chemical contaminants in drinking water on terrestri	the listed pacted inesite alth ecosystem osystem		
• WS9 - De	termining the impact of chemical contaminants in drinking water on terrestri	ai wiidilie		
Water and Sediment aspect	Additional comments	Relevant KKN		
Detailed Works Description	 Additional information should be provided to support the site wide water balance model, including: detailed plans and timelines for all activities related to water management, storage and treatment and brine disposal availability, rates, capacities of key plant and equipment (e.g. water treatment plants, brine injection bores, etc.) updated modelling assumptions and modelling uncertainty analyses. 	WS1		
Water Management	Include a detailed schedule that outlines the predicted process water volume and intended storage locations over time.	WS1		
	Demonstrate that the Tailings Storage Facility is able to be used as a process water storage post-2020, and provide relevant contingencies options for the event the Tailings Storage Facility is determined to be unsuitable for water storage.	WS1		
	A schedule should also be included for water treatment, indicating the planned options for process water treatment and demonstrating that these options will be sufficient to treat the predicted process water volumes.	WS1		

	Recommendation	
	Clarify why tailings pore water expression during deposition has increased by more than 30% in consolidation modelling results between 2014 and 2016.	WS1
	It is critical that ERA fulfil its commitment continue water treatment for as long as necessary to treat and dispose of all process water (including expressed tailings pore water) onsite. This commitment is fully supported by the Supervising Scientist, along with the intention to increase the capacity of process water treatment over time, which will be necessary to achieve treatment of all process water by 2025. This commitment should be included as a contingency in section 10.9.1	WS1
	 Further details the Pit 3 brine injection system should be provided in the RMCP, including: the expected lifespan of brine injection bores and factors that may affect this time frames and potential issues associated with the construction of additional brine injection bores, should they be required any other brine disposal methods that might be used in the case that the brine injection system fails (i.e. failure of all bores, or the underbed drain extraction system). 	WS1
	Provide further information to demonstrate that there are sufficient appropriate disposal options for treated water throughout the rehabilitation process, as irrigation areas are decommissioned.	WS1
	Provide further detail on time frames that sediment control infrastructure is expected to remain in place (i.e. criteria for removal) and any ongoing maintenance requirements (e.g. sediment removal and disposal locations).	WS1
Site Conceptual Modes	 The RMCP should detail future hydrogeological work that will be undertaken to refine the Ranger Conceptual Model, and explain how this will further inform rehabilitation planning, particularly with regard to: further refinement and characterisation of key hydrolithilogical units, aquifers and groundwater flows in high-risk areas for contaminant transport (around Pit1, Pit 3 and the Tailings Storage Facility) further information on surface water/groundwater interactions improved characterisation of existing contaminated groundwater (e.g. under the Tailings Storage Facility) and contaminated sites (e.g. LAAs). 	WS2
Contaminant Source Terms	Further work is required to quantify contaminant source terms and factors that influence their mobilisation on a whole-of-site basis, including existing groundwater contamination and contaminants predicted to arise from the waste rock landform, the buried tailings and contaminated soils and sediments disturbed during rehabilitation.	WS1

Recommendation			
	For the waste rock source term:	WS1	
	 ensure that an appropriate infiltration rate is used to understand vadose zone behaviour and to determine the concentrations of contaminants in waste rock seepage, and update contaminant transport modelling accordingly 		
	• improve the estimate of sulfide minerals and associated oxidation potential in the waste rock landform		
	• improved assessment of solute release subsequent to the consumption of all of the sulfide minerals.		
	 For the tailings and pore water source term: additional data are required to update the tailings consolidation modelling and water balance accounting for both pits, taking into account the heterogenous nature of the tailings in the pits, and the effect this may have on the amount of contaminants mobilised from tailings and the direction and rate of solute expression 	WS1	
	 For the groundwater source term: characterisation the existing groundwater contamination onsite, including beneath the Tailings Storage Facility, and update the Ranger Conceptual Model and contaminant transport models accordingly 	WS1, WS2	
	 proposed remediation and active management options for groundwater during and after the rehabilitation of contaminated sites (e.g. the processing area, stockpiles and the Tailings Storage Facility) 		
	• to demonstrate that LAAs will not result in a significant groundwater contamination source, include data from bores representing all aquifers and areas of the Ranger Project Area that could be impacted (i.e. Aquifer 1 and Aquifer 2).		
	The potential risks associated with the generation of acid sulfate sediments due to mine-derived sulfate needs to be assessed, particularly in Coonjimba, Georgetown and Gulungul billabongs.	WS5, WS7	

Recommendation			
Contaminant Transport Modelling	 All numerical modelling should be based on: the data-driven Ranger Conceptual Model, which needs to include sufficient detail and confidence for high-risk areas (e.g. the Magela Creek bed, the Djalkmarra sands and the MBL zone) 	WS2, WS3	
	 detailed and reliable quantification of all potential contaminant source terms onsite, including existing groundwater contamination on the minesite 		
	• a calibration period that is sufficient to stress the model to the extent that its behaviour during pre-mining, operational and post-mining conditions can be assessed, including mine-impacted and baseline variability in groundwater levels, stream flow and associated processes		
	• all available data, including pre-mine data if available, with clear justification for the exclusion of data not used		
	 surface water and groundwater interactions at a temporal scale appropriate for the baseline variation in groundwater levels and surface water flow. 		
	 To enable more reliable predictions of contaminant concentrations in surface water, the contaminant transport modelling, particularly the surface water model, needs to be refined using more relevant and appropriate data and assumptions, including: undertaking contaminant transport modelling at increased temporal and spatial resolution (particularly around the period of peak solute delivery to the surface water system) developing better understanding of groundwater/surface water interactions that will control the location and timing of delivery of contaminated groundwater to the surface water system implications of groundwater recovery as groundwater levels return to a stable state after rehabilitation improved understanding of the role of groundwater/surface water interactions in solute migration assessment of confidence in modelled outputs using statistical, sensitivity and uncertainty analyses for each model, as well as analysis of cumulative uncertainty where multiple models are interconnected. 	WS2, WS3	
	Develop an understanding of the spatial and temporal (seasonal) interactions between groundwater and surface water. This work is	WS2, WS3	
	required as a priority, particularly in light of the significant concerns related to water quality in Magela Creek raised in Appendix 8.1 of the RMCP (2011–12 ITWC PFS BPT Assessment).		
	Reactive transport modelling is required for calcium so that its effect on magnesium toxicity in the receiving surface waters can be understood (calcium has been shown to ameliorate magnesium toxicity).	WS2	
	A robust analysis of model uncertainty will need to be undertaken to	WS2,	
	quantify and understand the level of uncertainty associated with the modelled outputs.	WS3	

Recommendation			
Protection of	Organism assemblages for all stages of creek flow should be	WS7	
Ecosystems	characterised and assessed for their sensitivity to contaminants		
	Assess the potential contribution of subterranean fauna in Magela	WS4,	
	Creek sand beds to ecological processes and the biodiversity of the	WS7	
	ARR and if significant, then determine the potential impact of		
	contaminants on these communities.		
	Provide information on concentrations of suspended sediments and	WS5,	
	• effects of sediment mobilisation on surface water quality	WS0, WS11	
	 physical effects of suspended sediment on aquatic biodiversity 	Worr	
	• where when and to what extent contaminants may accumulate in		
	 where, when and to what extent contaminants may accumulate in downstream sediments 		
	monitoring methods.		
	Provide additional details on remediation of onsite waterbodies.	—	
	Assess the risk of eutrophication to on and offsite waterbodies when	WS6	
	surface water model results predicting nutrient concentrations become available.		
	Provision should be made for a periodic review of contaminants	WS1	
	measured in the post-rehabilitation monitoring program outlined in the		
	RMCP, and closure criteria developed where required in the future.		
	Assess the risk of contaminated groundwater on riparian and aquatic	WS7,	
	vegetation.	EE6	
	Assess the potential risk of contaminant plumes in creek channels	WS7	
	forming a barrier that inhibits organism migration and connectivity.		
	Assess whether there are additional key aquatic organisms for with	WS7	
	water quality guidelines need to be developed (e.g. flow-dependent insects, hypothetic biota and stygofauna)		
Closure	Define the process for ALARA in the context of closure criteria and	_	
Criteria	provide examples of water and sediment criteria that are ALARA.		
	To enable assessment of the ecological implications of an exceedance	_	
	of a water quality closure criterion, the closure criteria need to be		
	numerical values and should be applied at the boundary of the Ranger		
	Project Area until such time as there is agreement on an acceptable		
	level of detriment for areas outside of the Ranger Project Area.		
	Determine potential levels of exposure of humans to contaminants from	WS10	
	drinking water from onsite waterbodies (i.e. consumption rates,		
	locations, concentrations) and assess the risk to human health.		
	Propose closure criteria for sulfate, specifically in relation to the risk of	WS5,	
		vv3/	
	Acknowledge that there may be a requirement in future to consider the	WS1	
	reintroduction of a closure criterion for pH, depending on the outcome of acid sulfate soil investigations		
	Provide evidence that the proposed closure criteria are applicable to	WS7	
	contaminant mixtures.		

Recommendation			
	Undertake modelling of the potential contaminant accumulation in sediments post-rehabilitation, based on the results of surface water contaminant modelling, to demonstrate that sediment closure criteria are likely to be met.	WS5	
	Assess the potential for offsite impacts associated with mobilisation and accumulation of contaminants via transport of suspended sediments.	WS5	
	Reassess closure criteria for nutrients, as the currently proposed criteria are less than baseline water quality values.	WS6	
	Develop a sedimentation closure criterion for aquatic ecosystem protection in billabongs.	WS8	
	For parameters/locations where criteria are proposed for multiple outcomes (e.g. human health, recreation, ecosystem protection), state that the most conservative criterion across the outcomes applies.	-	
Monitoring	The surface water monitoring program should include:	WS11	
	 acknowledgment that additional contaminants that have not been previously identified as a risk may need to be considered in future (e.g. findings from contaminated site investigations) and include provision in the post-rehabilitation monitoring program for periodic review of contaminants 		
	• key sites on the Ranger Project Area (e.g. Georgetown Billabong, Coonjimba Billabong, RP1 and other onsite waterbodies, while they are present) for demonstration that concentrations of contaminants are as low as reasonably achievable		
	 acknowledgment that grab sampling may need to be conducted more frequently than monthly in the initial period after completion of rehabilitation works 		
	sampling for Ra-226.		
	Revise the proposed groundwater monitoring plan to clearly demonstrate that monitoring will be undertaken at an appropriate spatial and temporal scale to:	WS11	
	• observe trends in groundwater level recovery and contaminant transport post-rehabilitation that can be used to validate groundwater models, and recalibrate if necessary		
	 detect significant increases in contaminant concentrations in aquifers surrounding Pit 1, Pit 3 and the TSF, to enable downstream mitigation of impacts if required (i.e. groundwater interception or abstraction). 		

7. Closure Theme: Radiation

7.1. Relevant Environmental Requirements

The Radiation closure theme covers the radiological aspects of the rehabilitated minesite, and the rehabilitation activities undertaken to understand and minimise the level of radiation exposure and impacts to ecosystems and human health.

Table 12 provides a summary of the ERs that are relevant to the Radiation closure theme (in addition to the primary ERs presented in Table 1) and provides the outcome of the Supervising Scientist's detailed assessment of the RMCP against these ERs. The assessment evaluated whether the information provided in the RMCP was sufficient to demonstrate that each of the relevant ERs can be met.

Radiation aspect		Environmental Requirement	Does RMCP demonstrate ER can be met?
Human health	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: (c) protect the health of Aboriginals and other members of the regional community.	Further information required
	1.2	In particular, 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.	Further information required
	2.2	(b) 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.	Further information required

Table 12. Ranger Environmental Requirements relevant to the Radiation closure theme

Radiation aspect		Environmental Requirement	Does RMCP demonstrate ER can be met?
Ecosystem	1.1	The company must ensure that operations at Ranger are	Further
health		undertaken in such a way as to be consistent with the	information
		following primary environmental objectives:	required
		 (a) maintain the attributes for which Kakadu National Park was inscribed on the World Heritage list (b) maintain the ecosystem health of the wetlands listed under the Ramsar Convention on Wetlands (i.e. the wetlands within Stages I and II of Kakadu National Park) (d) maintain the natural biological diversity of aquatic and terrestrial ecosystems of the Alligator Rivers Region, including ecological processes. 	

7.2. Activity Summary

The RMCP proposes to minimise radiation exposure to both the public and the environment by:

- disposing of tailings in the pit voids and capping with waste rock
- using low-grade waste rock on the surface of the final landform.

While the proposed plan should help to minimise the levels of radiation to which the public and the environment are potentially exposed after rehabilitation, they do not in themselves provide assurance that the closure criteria and ERs relevant to the Radiation closure theme will be met.

7.3. Detailed Activity Description

7.3.1. Tailings Disposal

The RMCP presents the proposed strategy for disposing of radioactive tailings, which is to deposit them in the pit voids and then cover them with waste rock. Radionuclides in the tailings could potentially move through groundwater into surface water systems surrounding the minesite. Elevated radionuclide activity concentrations in surface waters may increase radiation exposure to the public and the environment along various pathways. The need to characterise radionuclide activity concentrations in tailings has been identified as a KKN (RAD1).

To inform the risk to people and the ecosystem from radiation, radionuclide activity concentrations in surface waters will be predicted by multiplying the ratio of (modelled) surface water to (measured) tailings magnesium concentrations by the activity concentration of the radionuclide in tailings. This approach assumes that radionuclides will be transported in an identical manner to magnesium, and is likely to lead to conservative (i.e. over) estimates of surface water radionuclide activity concentrations. Further to this, the approach requires knowledge of radionuclide activity concentrations in tailings, for which no information has been presented in the RMCP. The need to determine radionuclide activity concentrations in surface water has been identified as a KKN (RAD2).

7.3.2. Landform Surface

The RMCP presents the proposed design of the final landform, which indicates that the surface of the final landform will comprise low-grade waste rock. After construction is complete, the waste rock on the surface of the final landform will be the primary source of radiation. The magnitude of exposure along each of the potential exposure pathways will depend on the uranium activity concentration of the waste rock. The plan indicates that the waste rock surface will have an average uranium activity concentration of approximately 0.8 Becquerels per gram. However, the data and analyses through which this value was derived have not been presented.

The RMCP states that the anticipated uranium activity concentration of waste rock (of 0.8 Becquerels per gram) is *below that currently considered to be radioactive according to the Australian Radiation Protection and Nuclear Safety Agency*. While the Australian Radiation Protection and Nuclear Safety Agency's National Directory for Radiation Protection (ARPANSA 2017) provides a regulatory exemption level for small amounts of materials containing uranium of ≤ 1 Bq/g, this does not strictly apply to the large amount of waste rock on the surface of the final landform. Furthermore, the National Directory for Radiation Protection defines radioactive material as being *any material that emits ionising radiation spontaneously*. Therefore, the Supervising Scientist does not support the view that the waste rock is not radioactive.

7.4. Protection of Human Health (ER 1.1, 1.2, 2.2, 5.1–5.3.)

The RMCP outlines the process for assessing radiation doses to the public from the final landform. This includes:

- establishing a baseline (i.e. pre-mining) radiological conditions of the site
- identifying the representative person (i.e. the real or hypothetical individual most at risk of radiation exposure)
- identifying exposure pathways and probable habitation scenarios
- compiling data to parameterise the radiation exposure pathways and habitation scenarios
- developing a radiation dose model to estimate doses.

The RMCP presents information on the baseline radiological conditions of the minesite as determined by Bollhöfer et al. (2014). This includes:

- gamma dose rates
- soil radium-226 activity concentrations
- radon-222 exhalation flux densities.

The RMCP presents information on baseline water radium-226 activity concentrations in Magela Creek, determined from routine water quality monitoring at the Magela Creek upstream location between 2010 and 2013. However, water quality monitoring at this location has occurred over an extended period, and it is unclear why the baseline conditions were derived from a small subset of the monitoring data, rather than from all available data.

The RMCP presents baseline activity concentrations of uranium-238, radium-226 and lead-210 in bush foods, with the information compiled from several studies conducted by the SSB. However, the RMCP does not present baseline activity concentrations for polonium-210, which is the radionuclide with the highest ingestion dose coefficient. Furthermore, a complete compilation of

all SSB bush food radionuclide data were published in 2016 (Doering & Bollhöfer 2016), which has not been used within the RMCP to determine baseline values.

The RMCP identifies the representative person as an Indigenous person using the final landform and surrounding environment for traditional activities including transient camping and the gathering of traditional bush foods for consumption. The probable habitation scenarios have been identified as those documented in Garde (2015) after consultation with the Mirarr traditional owners.

The RMCP identifies the potential radiation exposure pathways to the public from the final landform as:

- external gamma radiation
- ingestion of radionuclides in bush foods
- ingestion of radionuclides in water
- inhalation of radionuclides in dust
- inhalation of radon progeny.

The RMCP does not present a dose assessment which compiles data to parameterise the radiation exposure pathways so that radiation doses received from each pathway can be estimated. The absence of a radiation dose assessment within the RMCP means that there is currently insufficient information to demonstrate that the ERs relevant to radiation protection of the public can be met.

The plan indicates that a dose assessment will be undertaken in the future. The need to compile data for parameterising the various radiation exposure pathways has been identified within several KKNs (RAD3, RAD4, RAD5). The need to assess radiation doses to the public and to undertake a sensitivity analysis of radiation dose modelling has also been identified as a KKN (RAD7).

7.5. Protection of Ecosystem Health (ER 1.1, 5.1)

The RMCP acknowledges the need to assess radiation risks to the environment in line with world's best practice standards for radiation protection and commits to undertake such an assessment using the ERICA Tool. The RMCP should present information on the representative organisms or parameter values (e.g. tissue conversion factors and whole-organism concentration ratios) that will be used in this assessment. The need for this information has been identified as a KKN (RAD6).

The lack of a radiation dose assessment for wildlife within the RMCP means that there is currently insufficient information to demonstrate that the ERs relevant to radiation protection of the environment can be met.

7.6. Closure Criteria

Closure criteria proposed in the RMCP pertaining to radiation have been assessed and all proposed criteria have been accepted (Table 14).

Table 14. Supervising Scientist position on proposed Radiation closure criteria

RMCP reference	Radiation criteria	Assessment outcome	Relevant Rehabilitation Standard
R1	Using the agreed restrictions on land use the total above- baseline radiation dose from external gamma exposure, inhalation of radon decay products (RDP), inhalation of dust and ingestion of bush food (including water), (shall not exceed) 0.3 mSv per year.	Accepted	Public Radiation Projection: Dose constraint: 0.3 mSv in a year — effective dose to members of the public is ALARA below the dose constraint for conditions of agreed future land use.
R2	Should land use restrictions fail the total above-baseline radiation dose from external gamma exposure, inhalation of RDP, inhalation of dust and ingestion of bush food (including water), (shall not exceed) 1 mSv per year.	Accepted	Public Radiation Projection: Dose limit 1.0 mSv in a year — effective dose to members of the public is ALARA below the dose limit for conditions of future land use different to those agreed.
R3	Total above-baseline radiation dose rate to terrestrial plants and animals from internal and external exposures (shall not exceed) 100 μ Gy h ⁻¹ to the most highly exposed terrestrial species.	Accepted	Environmental Radiation Projection: Environmental reference level of 100 μ Gy h ⁻¹ for terrestrial organisms — absorbed dose rates to the most highly exposed individuals are ALARA below the environmental reference level
R4	Total above-baseline radiation dose rate to aquatic plants and animals from internal and external exposures (shall not exceed) 400 μ Gy h ⁻¹ to the most highly exposed aquatic species.	Accepted	Environmental Radiation Projection: Environmental reference level of 400 μ Gy h ⁻¹ for aquatic organisms — absorbed dose rates to the most highly exposed individuals are ALARA below the environmental reference level

7.7. Rehabilitation Monitoring

The RMCP includes a proposed radiation monitoring program after rehabilitation of the minesite. The proposed monitoring program includes:

- atmospheric monitoring of radon progeny and radionuclides in dust at a frequency of 1 week each dry season during the first 5 years after rehabilitation, although no sampling locations have been specified
- surface water radionuclide monitoring in Magela Creek at an initial frequency of monthly but reducing over time to annually, although it is not specified which radionuclides will be monitored
- gamma dose rate monitoring of the final landform by ground-truthing airborne gamma survey results with the results of targeted field surveys for external gamma dose rates and soil radium-226 activity concentrations.

The proposed radiation monitoring program does not include:

- bioaccumulation monitoring of radionuclides in aquatic or terrestrial organisms, including those consumed as bush foods by Indigenous peoples
- soil radionuclide monitoring to assess potential increases in activity concentrations due to the deposition of dust emitted from the final landform
- groundwater radionuclide monitoring.

Methods for monitoring and assessing the radiation risk to the environment and human health should be reviewed regularly to ensure that they are optimised and in accordance with current best practice.

7.8. Summary of Recommendations and Additional Comments for Radiation

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 15

Table 15. Summary of recommendations and additional comments pertaining to Radiation

Recommendation				
Before commencing construction of the final landform ERA must address the listed KKNs, and complete an assessment of radiation dose to wildlife and humans from both tailings and waste rock sources (RAD7 and RAD8), using all relevant data and knowledge on radionuclide activity concentrations (RAD1, RAD2 and RAD3) and relevant exposure pathways (RAD3, RAD4 and RAD5).				
Key Knowledge Needs to be addressed:				
RAD1 — Radionuclides in the rehabilitated site				
RAD2 — Radionuclides in aquatic ecosystems				
RAD3 — Radon progeny in air				
RAD4 — Radionuclides in dust				
RAD5 — Radionuclides in bushfoods				
RAD6 — Radiation dose to wildlife				
RAD7 — Radiation dose to the public				

Recommendation			
Radiation aspect	Additional comments	Relevant KKN(s)	
Baseline conditions	Use monitoring data collected over all years to derive statistical results for baseline water radionuclide concentrations at Magela Creek upstream or otherwise explain why only the data from 2010 to 2013 have been used.	RAD1	
Radiation Sources	Reconsider the view that the waste rock on the surface of the landform (with estimated uranium activity concentration of 0.8 Bq/g) is not radioactive.	RAD1	
	Include data and analyses to demonstrate what the average uranium activity concentration across the landform surface will be.	RAD1	
	Include data and analyses to demonstrate what the radionuclide activity concentration of the tailings will be.	RAD1	
Human health	Provide estimates of radionuclide activity concentrations in surface water surrounding the minesite.	RAD2	
	Provide information on radon and radon progeny concentrations in the air due to the final landform.	RAD3	
	Provide information on the activity concentration of radionuclides in dust due to the final landform.	RAD4	
	Provide information on gamma dose rates on the final landform.	RAD1	
	Provide information on concentration ratios for uranium and actinium decay series radionuclides in bush foods.	RAD5	
	Provide an estimate of radiation doses to the public from the final landform.	RAD7	
Ecosystem health	Identify the representative organisms upon which the radiation dose assessment for wildlife will be based.	RAD6	
	Provide whole-organism concentration ratios for the representative organisms.	RAD6	
	Provide tissue to whole-organism conversion factors for converting tissue-specific activity concentrations to whole-organism activity concentrations.	RAD6	
	Provide an estimate of radiation dose rates to wildlife from the final landform.	RAD6	
Rehabilitation monitoring	Include bioaccumulation monitoring of radionuclides in bush foods within the radiation monitoring program.	RAD8	
	Include soil radionuclide monitoring within the radiation monitoring program.	RAD8	
	Include groundwater radionuclide monitoring within the radiation monitoring program.	RAD8	
8. Closure Theme: Soils

8.1. Relevant Environmental Requirements

The Soils closure theme covers the rehabilitation activities undertaken to minimise the release of contaminated soils, and contaminants from these soils, to prevent changes to water and/or sediment quality in the receiving environment and related impacts to ecosystems and/or human health.

In the RMCP, the only ER listed as being relevant to soils is 1.2 (e), which pertains to environmental impacts within the Ranger Project Area being ALARA. ER 1.2(c) requires that the company prevent 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.... All of the primary ERs should be included in the RMCP as they are all relevant to soils unless it can be demonstrated that contaminated soils within the Ranger Project Area do not pose a risk to the environment outside the Ranger Project Area.

8.2. Activity Summary

Contaminated site assessments will be used to define the extent of soil contamination within the Ranger Project Area. Where remediation is required, the contaminated soil will be recovered and disposed of in Pit 3. This is in line with the relevant ERs.

8.3. Detailed Activity Description

The RMCP identifies the LAAs and processing plant area as the main areas with known or potential soil contamination. For the LAAs, some existing information on soil contamination is presented in the RMCP and it is stated that additional studies are currently underway to confirm whether remediation is required.

It is stated in the RMCP that if soil contaminant concentrations are shown to be below either local background concentrations or the *published investigation levels* (i.e. health investigation level (HIL) and/or ecological investigation level (EIL)), then no further assessment or remediation will be required. Health and/or ecological investigation levels for contaminants that are not currently listed in the published investigation levels, including uranium, need to be developed. Consideration should also be given to guidance provided by the Environmental Health Standing Committee (EnHealth) in assessing the risk of contaminants to human health.

8.4. Delineation of Contaminated Soils

It is stated in the RMCP that the LAAs pose a low risk because contaminated runoff from these areas will be heavily diluted, but it is also acknowledged that there are currently soil assessments being undertaken that will further inform this risk. Additional information is required to assess the potential for mobilisation of contaminants arising from LAAs if soils are disturbed during rehabilitation activities.

Although the RMCP acknowledges that soils in the processing plant area will require remediation, no data indicating the extent (e.g. depth and surface area/volume) of contaminated soil in this area are presented, or referenced. The RMCP needs to indicate the volume of contaminated soil, as well as the proposed method for recovery and placement of this soil into the Pit.

The RMCP indicates that the Tailings Storage Facility is likely to be a source of contamination after rehabilitation. However, there are no details provided on the nature or extent of contamination

(i.e. soils or sediments below the facility or within the walls), or how this area will be rehabilitated to minimise the risk to the environment and human health. ERA is currently undertaking investigations to determine the best method for remediation of the Tailings Storage Facility, and a standalone application will be submitted for assessment.

In addition to the LAAs, the processing plant area and the Tailings Storage Facility, information should be provided on any other areas on the Ranger Project Area where there is or might be contaminated soil. This is discussed in more detail in this assessment report under the Water and Sediments closure theme, in the context of delineation contaminant sources (refer section 6.4.3).

The information presented in the RMCP does not adequately assess the risks of environmental impacts associated with contaminated soils, either on the Ranger Project Area or offsite. To assess whether the rehabilitation activities for contaminated soils will achieve the ERs the RMCP should be updated with a detailed action plan and timeline for undertaking a whole-of-site contaminated site assessment, which includes a direct comparison of soil contaminant concentrations with appropriate standards. Detailed action plans and timelines for remediation of the identified contaminated sites should also be included, including volumes of contaminated material for recovery and disposal.

8.5. Closure Criteria

Closure criteria proposed in the RMCP pertaining to soils have been assessed and the outcome is described as being either a) Accepted or b) Require Further Information (Table 16). For criteria that require further information (or clarification), comments are provided below.

The soil closure criteria were originally based on National Environmental Protection Measure guidelines. The proposed criteria are now aiming to demonstrate that contaminant concentrations in soils are ALARA.

The assessment of ALARA requires a detailed understanding of the potential impacts to human health and the environment such that these can be balanced against the cost and practicality of remediation options. Accordingly, it remains necessary to quantify soil contamination and determine its effects on human health and the environment.

If current investigations indicate that contaminated soils on the Ranger Project Area do pose a risk to the offsite environment, there may be a requirement in future to develop soil closure criteria with specific concentrations for key contaminants.

As discussed above in relation to the ERs relevant to soils (refer Section 8.1), the RMCP does not clearly demonstrate that there is no risk to the offsite environment from contaminated soils within the Ranger Project Area, nor that contamination within the Ranger Project Area will be reduced to levels that are ALARA.

RMCP reference	Soil criteria	Assessment outcome
S1	Contaminated soil assessment for uranium and manganese in LAA: demonstrate risk is ALARA	Further information
S2	Contaminated assessment of identified contaminants for other soils identified as not being part of the larger decommissioning works: demonstrate risk is ALARA	Further information

Table 16. Supervising Scientist position on proposed Soil closure criteria

8.6. Summary of Recommendations and Additional Comments for Soils

A summary of the recommendations and additional comments discussed throughout the Soils chapter is provided in Table 17

Table 17. Summary of recommendations pertaining to soils

Recommendation

Before commencing backfill of Pit 3 ERA must address the listed KKNs, and complete a whole-of-site contaminated site assessment to inform the requirement for soil remediation (WS1 and RAD1), including within the walls of the Tailings Storage Facility.

Key Knowledge Needs to be addressed:

- WS1. Characterising contaminant sources on the Ranger Project Area
- RAD1. Radionuclides in the rehabilitated site

Soils aspect	Additional comments
Closure Criteria	Assess the risk of contaminated soils within the Ranger Project Area impacting the environment outside the Ranger Project Area.
	Develop a site-specific EIL for uranium and any other contaminants that are not covered by National Environmental Protection Measure guidelines.
Risk Assessment	To support the risk assessment that soils in the LAAs pose a low risk as a source of potential contamination, information should be presented on relevant contaminants and suspended sediments (e.g. if soils are disturbed as part of any required remediation).

9. Closure Theme: Ecosystem Restoration

9.1. Relevant Environmental Requirements

The Ecosystem Restoration closure theme covers the restoration of flora and fauna communities on the final landform, aiming to ensure they are sustainable and similar to those in the adjacent areas of Kakadu National Park.

Table 18 provides a summary of the ERs that are relevant to the Ecosystem Restoration closure theme (in addition to the primary ERs presented in Table 1) and whether or not the information provided is sufficient to demonstrate that each of the relevant ERs can be met.

Ecosystem aspect	Clause	Environmental Requirements	Does RMCP demonstrate ER can be met?
Ecosystem Restoration	2.1	Subject to subclauses 2.2 and 2.3, 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.	Further information required
	2.2	The major objectives of rehabilitation are: (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.	Further information required
Ecosystem Protection	10.2	The company must ensure that the operations at Ranger will not result in any adverse impact on Kakadu National Park through the introduction of exotic fauna or flora.	Further information required

Table 18. Ranger Environmental Requirements relevant to the Ecosystem Restoration closure theme

9.2. Activity Summary

The RMCP provides a high-level overview of the proposed ecological restoration process for 950 hectares of disturbed land on the Ranger Project Area, which will be achieved by progressively revegetating the area with local species and undertaking ongoing monitoring and maintenance activities, including irrigation, weed control and infill planting.

These proposed activities are broadly in line with the relevant ERs.

9.3. Detailed Activity Description

The RMCP provides a high-level plan to revegetate the final landform with local species to establish a vegetation community similar to that in surrounding areas of Kakadu National Park. The RMCP assumes that once vegetation has successfully established, the area will be naturally colonised by fauna.

Further information is required to demonstrate the relevant ERs can be achieved. The RMCP states that this will be provided in a standalone application, which should include a detailed description of the works to be undertaken. Additional information to be provided within the application should include:

- detailed action plans and timelines, including methods (i.e. planting, irrigation)
- seed availability and collection plan
- nursery details and propagation studies
- target and planned planting densities and methods (e.g. final target density for each species)
- habitat to be installed (e.g. nesting boxes, rock piles)
- ongoing management activities, including weed control and infill planting
- any other project specific assumptions or information which would be required to conduct a detailed assessment of the activity.

These information requirements have been identified as KKNs (EE2, EE3 and EE4).

9.3.1. Revegetation Strategy

A Revegetation Strategy is presented in Appendix 10.2 of the RMCP but it requires significant revision. It is suggested the Revegetation Strategy be expanded to an 'Ecosystem Restoration Strategy' in recognition of the intention of the ERs, and key linkages between flora and fauna and broader ecosystem processes. These information requirements have been identified as KKNs (EE1, EE2, EE3, EE4).

It is stated in the current strategy that revegetation will be *broadly similar* to adjacent areas of Kakadu. However, this will not satisfy the ERs. Should ERA identify that certain aspects of the ERs cannot be met, a substantial body of evidence must be provided to demonstrate that what is being proposed constitutes BPT.

The Ecosystem Restoration Strategy should be clearly underpinned by data to substantiate the proposed approach. However, it is supported by only three references, one of which is related to the establishment of vegetation. ERA needs to synthesise key findings and knowledge gaps from all revegetation trials. Monitoring on the trial landform to address these gaps and inform the Ecosystem Restoration Strategy should be recommenced as soon as possible.

The following sections provide a detailed assessment of the various factors with the potential to influence the success of ecosystem restoration, and as such should be clearly addressed in the Ecosystem Restoration Strategy.

9.4. Ecosystem Restoration (ER 2.1, 2.2)

9.4.1. Revegetation Trials

In listing various revegetation trials from 1982 to 1999, the RMCP indicates that there has been a substantial body of work conducted in relation to revegetation at Ranger mine over many years. While this is the case, there is no detail or summary provided on the findings or recommendations from each of these studies, or details of how they contribute to the proposed Revegetation Strategy. In the absence of these details, it is difficult to assess the scientific veracity of the studies and whether they are sufficient to demonstrate that revegetation will be successful. Most of the trials have generally been conducted over relatively short time frames and at smaller spatial scales. Therefore, there is limited evidence to support the potential for long-term sustainability of revegetation at Ranger mine.

The RMCP only includes reference to monitoring of the revegetation on the trial landform up until 2015 and states that since 2016 the focus of revegetation monitoring has been on the growth and performance of individual plants. However, much of this work has not been compiled into reports. Any reference to revegetation work on the trial landform is notably absent from section 7.6.1 which lists revegetation trials from 1982 to 1999, but nothing from the past nearly 20 years. The potential success or failure of rehabilitation on the trial landform presented in the RMCP is therefore based on only 6 years of data. Monitoring of revegetation should also include grasses and groundcover species. Section 7.3.3 gives the impression that biannual monitoring has been conducted since 2009. However, it should also state that this monitoring was discontinued around 2014. It is recommended that ERA collate and publish all relevant information from the trial landform, incorporating information from other studies as required, to inform the Ecosystem Restoration Strategy.

It is possible that some species present in the surrounding environment may not be able to establish or persist on the waste rock landform. Information should be presented in the RMCP that demonstrates whether waste rock can maintain long-term species diversity through recruitment and regeneration and whether there are factors that could be manipulated to facilitate this. There is some information presented on natural recruitment on the trial landform, although this is limited to numbers and does not provide an indication of species composition. This information requirement has been identified as a KKN (EE7).

9.4.2. Reference Sites

The SSB is developing techniques to undertake large-scale aerial vegetation surveys, including an extensive ground-truthing program. The information from this program will be provided to ERA as it comes to hand to update measures of vegetation structure and species composition which has historically been obtained from smaller scale ground-based surveys.

It is noted that ERA has commenced a regional vegetation survey program as shown in Figure 7-46. Further information on the survey methods should be provided. While the sites were surveyed in 2016 no data from the survey have been presented in the RMCP. Section 2.3.2.1 of the RMCP states there have been over 90 flora species recorded on the Ranger Project Area. However, a literature survey by SSB showed that 541 flora species have been recorded on the Ranger Project Area.

A KKN related to the scale and temporal variability of terrestrial ecosystems in areas surrounding the Ranger Project Area has been identified (EE1).

9.4.3. Seed Availability and Viability

Further information is required to demonstrate that sufficient seed can be sourced to complete revegetation in the time frame required. Seed availability/collection issues are classified in the RMCP as a Class II risk. This is a key risk given the very large volume of seed required, so it may be more appropriate to be considered a class III risk (as plant propagation success is), or further detail provided on control measures. The amount of seed and resulting tube stock for each species required to reach the desired end state should be documented in the RMCP.

Information should also be provided on which species are currently able to be grown from seed, and which are not able to be successfully propagated. These information requirements have been identified as a KKN (EE3).

9.4.4. Soil Development

Additional information is required to demonstrate that the waste rock substrate will develop into a soil suitable to support a vegetation community similar to the surrounding area.

It has been assumed that rock material will weather rapidly to form rudimentary soil materials but the cited studies were conducted on waste rock from Pit 1, which has different properties to waste rock from Pit 3. Given that the majority of the final landform will comprise waste rock from Pit 3, the information referenced is not applicable across the site. Field observations undertaken by the Supervising Scientist on the trial landform do not support the assumption that rapid weathering will occur.

The soil texture information presented in the RMCP appears to be based on a subset of the substrate (i.e. minus the > 2 mm gravel fraction) rather than the entire substrate. This may have resulted in an incorrect classification of soil properties that could have implications on substrate suitability for plant establishment and survival, such as water-holding capacity.

The RMCP should provide information on soil formation properties for each type of waste rock to be used in landform construction, including:

- weathering rates
- soil texture information for the entire waste rock substrate (i.e. not just < 2 mm fraction).

The trial landform provides the opportunity to assess soil formation over a 9-year period to address some of the above. These information requirements have been identified as a KKN (EE7).

9.4.5. Plant Available Water

The SSB is currently undertaking a detailed review of ERA's work to quantify water usage requirements by the surrounding undisturbed vegetation communities, and to estimate the plant available water within the final landform. Significant additional work is required to demonstrate that the waste rock landform will provide sufficient plant available water to support a mature vegetation community.

The modelling undertaken to predict plant available water in the final landform is unclear and requires more explanation. The modelled plant available water needs to include uncertainty analysis, particularly because the current model simulations predict there may be insufficient plant available water during some years.

The RMCP states that increasing the thickness of the waste rock to 7 m would ensure sufficient plant available water. This requires that plant roots are able to access water down to those depths.

Information should be provided on likely rooting depths in waste rock, including for understory species, to confirm plants will be able to access water at those depths. This should also account for the presence of macropores, which are currently excluded from the textural classification system used to characterise the substrate.

In the RMCP, plant evapotranspiration is used as an indicator to demonstrate that there is sufficient plant available water in the rehabilitated landform, with the assumption that overstorey species are the main component of evapotranspiration during the dry season. However, this assumption is not supported by any data or published studies, with understorey evapotranspiration rates being simulated. A review of available literature on local understorey species should be undertaken, or empirical data provided, to support the assumption that understorey is a minor component of evapotranspiration.

It is proposed in the RMCP that placement of waste rock in the landform will be undertaken via a 'paddock dumping' technique that will create additional compaction layers at 4 m intervals. It is claimed that this may improve the water-holding capacity of the waste rock. However, no evidence is presented to demonstrate this is the case. Nor is there evidence to demonstrate that compaction layers (both within the constructed landform and underlying the original ground surface) won't lead to other issues affecting plant growth such as physically restricting root penetration, the formation of perched water tables or accumulation of metals and salts (Shirtliff 2007).

Further information on the internal properties in each area of the final landform (e.g. nature, depth and extent of compacted layers) should be provided, in conjunction with a conceptual model and water balance (under a range of rainfall scenarios) demonstrating that there will be sufficient water available for revegetation (including understorey).

Radon is soluble and soil moisture levels are a significant driver of seasonal fluctuations in radon exhalation rates. It is noted in section 7.3.3 of the RMCP that there was no seasonal trend in radon exhalation rates on the waste rock-only section of the trial landform. This observation should be investigated in the context of the ability of the waste rock substrate to retain water.

The need to gain a better understanding of plant available water in the rehabilitated landform has been identified as a KKN (EE7).

9.4.6. Fire

Although identified as a risk to revegetation success, there is very limited contemporary information presented in the RMCP to demonstrate the resilience of revegetation to fire (i.e. there is a reference from 25 years ago in relation to the impact of fire frequency on tree/grass ratios). Within this limited information, there is no reference to the fire severity and intensity, plant response nor species (other than Eucalypts). It is stated that fire will be introduced to revegetated areas after 5 to 7 years but there is no rationale provided for this, or data presented to support it. There are numerous relevant published studies on fire and plant survivability in the region (e.g. Setterfield 1997; Williams et al. 1999; Setterfield 2002; Russell-Smith et al. 2003; Werner 2005; Werner & Prior 2013) that could be used to strengthen the information presented in the RMCP and provide stronger criteria for vegetation success.

Based on experience in other areas in the region, fire can present a significant risk to revegetation. Further information should be provided to explain why fire was not classified as a class III risk.

The RMCP makes only a brief reference to the effect of fire regimes on fauna (from a protection of wildlife perspective), therefore it is unclear what the most appropriate fire regime may be to allow faunal colonisation and persistence on the rehabilitated minesite.

The requirement to determine the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site has been identified as a KKN (EE8).

9.4.7. Importance of Understorey

Grasses and understorey are critical to savanna structure and function, including creating the conditions required for the colonisation and survival of soil biota (e.g. Scholes & Archer 1997; Hutley et al. 2001; Ludwig et al. 2004; Hutley & Setterfield 2008).

Trials for introducing understory for a limited number of species have recently commenced on the trial landform. The ability for the landform to support understory is critical to the establishment of ecosystem processes and the creation of habitat but remains a key unknown.

There has been very little demonstration of success in establishing understorey species on Ranger mine waste rock. The RMCP states that the revegetation will include understorey, which will be introduced via direct seeding once upper storeys are established. However, only a draft list is provided for species that would be included in the understorey, and does not provide evidence to support that direct seeding will be effective in the establishment of such species. Further detail is also required on how species identified in the reference sites have been selected to be planted on the rehabilitated landform. Faunal requirements, including habitat use and diet, should be a key consideration in the development of the understory species list.

Information requirements pertaining to understorey propagation and establishment on waste rock have been identified as a KKN (EE3).

9.4.8. Fauna

In summarising findings from studies of the trial landform, it is stated in the RMCP that there is evidence of fauna colonisation across the trial landform and other revegetated sites. While there was a study completed nearly 20 years ago (i.e. a single reference is cited), there have not been any recent or ongoing studies to demonstrate that this is the case. Further information is needed to determine what habitats should be provided on the rehabilitated site to ensure the recolonisation of fauna (particularly including threatened species). The creation of this habitat should be a key focus of the Ecosystem Restoration Strategy, both through the plant species introduced and the installation of constructed habitat such as nesting boxes or rock piles.

It is acknowledged in the RMCP that information pertaining to the abundance of feral animals in areas adjacent to the Ranger Project Area is not currently available and it is assumed that this information would be provided in future by Parks Australia North. This assumption may not be appropriate and a commitment should be provided in the RMCP for ERA to obtain the appropriate data if required. Information should be quantitative (i.e. animals per unit area) to allow comparison of densities between the Ranger Project Area and adjacent areas of Kakadu National Park. There should also be an assessment of the risk of feral animals impacting on faunal colonisation of the rehabilitated site.

These information requirements have been identified as KKNs (EE2, EE4 - refer to Chapter 12).

9.4.9. Contingencies for Revegetation Mortality

It is stated in the RMCP that *infill planting* will be required if greater than 65% mortality occurs in revegetation in the first 6 months after planting. However, the rationale for this level of mortality is unclear and it seems simplistic. It does not consider species distribution and does not consider the potential for mortality later in the rehabilitation process. A longer-term strategy is required which is linked to the monitoring program and an ecosystem trajectory model.

9.4.10. Ecosystem Restoration Risks Not Considered

9.4.10.1. Contaminant Impacts on Vegetation

While it has been acknowledged in the RMCP that waste rock in the rehabilitated landform will leach contaminants of potential concern, the risk of potential impacts of contaminants on revegetation and fauna is not assessed. Nor are details provided on how this could be avoided/mitigated if required. For example, areas of the landform overlying contaminated materials may pose a risk of contaminant uptake by plants. These information requirements have been identified as KKNs (EE6, WS9).

Note that radiation is considered as a specific closure theme in Chapter 7 of this report.

9.4.10.2. Landform Stability

As discussed in Chapter 5 of this report there remains the potential for instability in the landform from the differential consolidation of tailings. The Ecosystem Restoration Strategy should include consideration of landform stability, including remedial actions in the event that vegetation is affected during the process of re-contouring the landform surface.

9.4.10.3. Nutrients

There are likely to be substantial differences between waste rock and natural soils in terms of nutrients (e.g. P, N, Mg, exchangeable K and S) and rhizobia/mycorrhizal fungi available to plants.

The potential for nitrogen and other nutrients to be a limiting factor for nutrient cycling on waste rock is not discussed in the RMCP, other than being mentioned in the risk assessment. The need to gain an understanding of nutrient cycling in the rehabilitated landform has been identified as a KKN (EE7).

The Revegetation Strategy should identify the requirements necessary for the commencement of nutrient cycling on the landform, in particular, the colonisation and survival of key soil biota and invertebrates.

9.4.10.4. Weeds

It is stated in the RMCP that ERA has undertaken annual weed surveys and mapping across the Ranger Project Area since 2003. It is understood that initially these annual weed surveys were very detailed and included a large proportion of the Ranger Project Area (i.e. 48 Weed Management Areas') but the extent of areas surveyed annually has decreased over time. Since 2015 the focus has predominately been on areas of the site with known significant weed infestations (ELA 2015). While annual surveys of the entire Ranger Project Area are unlikely to be required for operational weed management programs, it should be acknowledged in the RMCP that comprehensive weed surveys are required on both the Ranger Project Area and in surrounding areas before and during the rehabilitation process. This has been identified as a KKN (EE4).

SSB supports the proposal to establish a weed buffer zone around the rehabilitated site which is listed as a control against risk TB4-01. The rationale for the nominated 200 m buffer should be outlined in the RMCP.

9.4.10.5. Spatial and Temporal Scale of Landscape Factors

Information on spatial and temporal considerations for assessing the influence of landscape-scale factors on revegetation success are only partially addressed in the RMCP (i.e. feral animal monitoring). Mitigations to address integrated landscape risks, such as extreme weather events

(e.g. cyclones, extreme rainfall, prolonged dry season), should be addressed in the Ecosystem Restoration Strategy.

9.5. Closure Criteria

Closure criteria proposed in the RMCP pertaining to ecosystem restoration have been assessed and the outcome is described as being either a) Accepted or b) Require Further Information (Table 19). For criteria that require further information (or clarification), comments are provided in the following sections.

It should be noted that the Supervising Scientist has recently completed a Rehabilitation Standard for ecosystem restoration, which includes recommended indicators of the similarity to surrounding areas of Kakadu National Park and demonstration of long-term ecosystem sustainability.

Table 19.	Supervising	Scientist p	osition on	proposed	Ecosystem	Restoration	closure criteria	a

RMCP reference	Proposed criteria	Assessment outcome	Relevant Rehabilitation Standard
F1	Provenance: Revegetation has used local native species from within Kakadu National Park.	Accepted	-
F2	Species composition (tree and shrubs) and species relative abundance: Bray–Curtis similarity index ≥ 15–30% Total species number over 400 ha ≥ 35.	Further information	Ecosystem Restoration:Assemblages and species abundance are highly similar to, or on a secure trajectory towards, those of the reference ecosystem.Species richness of the restored ecosystem is highly similar to, or on a secure trajectory towards, that of the reference ecosystem.Stems per hectare and percent cover are highly similar to, or on a secure trajectory towards, that of the reference ecosystem.
F3	Canopy architecture: Presence of multistrata canopy. Presence of ground floor shrubs and grasses developed appropriate to the substrate.	Further information	Ecosystem Restoration: Canopy cover, understorey and groundcover are highly similar to, or on a secure trajectory towards, that of the reference ecosystem.
F4	Canopy cover index, groundcover index Comparable to analogue sites, using standard Northern Territory vegetation survey methods.	Further information	Ecosystem Restoration: Percent cover of the dominant and functionally important understorey species is highly similar to, or on a secure trajectory towards, that of the reference ecosystem.
F5	Tree distribution Trees are planted in a manner to appear 'natural'.	Further information	Ecosystem Restoration: Woody plant species size class distribution and the total basal area are highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Patch metrics such as isolation/proximity and dispersion are highly similar to, or on a secure trajectory towards, that of the reference ecosystem.

RMCP reference	Proposed criteria	Assessment outcome	Relevant Rehabilitation Standard
F6	Reproduction (flowering and seeding) Evidence of flowering and fruiting of 80% of framework species or characteristic species (based on species present).	Further information	Ecosystem Restoration: Rates of vegetation recruitment highly similar to, or on a secure trajectory towards, those of the reference ecosystem.
F7	Recruitment / regeneration Presence of seedlings and/or 'suckers' of 80% of framework species or characteristic species (based on species present).	Further information	Phenology of vegetation (including productivity if flowers, seeds and fruit) is highly similar to, or on a secure trajectory towards, that of the reference ecosystem.
F8	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% of the survey plots.	Further information	Ecosystem Restoration:Soil biota (measured by eDNA or other genomic techniques) provide evidence that nutrient cycling could, or is on a secure trajectory towards that which could, indefinitely sustain the species and processes similar to that of the reference ecosystem.Litter decomposition rates that could, or is on a secure trajectory towards that which could, indefinitely support the species and processes similar to that of the reference ecosystem.Abundance and diversity of key invertebrate species (ants, termites) indicative of nutrient cycling that could, or is on a secure trajectory towards that which could, indefinitely sustain the species and processes of the reference ecosystem.
F9	Fire resilience Vegetation demonstrates resilience similar to analogue sites in response to fire.	Further information	Ecosystem Restoration: Fire management is comparable to, and fire impacts no greater than fire regimes in the reference ecosystem. After the reintroduction of a fire regime similar to that in adjacent areas of Kakadu National Park, mortality and recovery of plants and animals are highly similar to that of reference ecosystem.

RMCP reference	Proposed criteria	Assessment outcome	Relevant Rehabilitation Standard
F10	Resilient to wind and drought Woodland ecosystem demonstrates survival under natural condition, similar to analogue.	Further information	Ecosystem Restoration: Ecosystem resilience to disturbances such as high wind and disease is highly similar to that of reference ecosystem.
F11	Plant available water Modelling predicts the store-release waste rock cover layer will provide sufficient plant available water for long-term vegetation growth.	Further information	 Ecosystem Restoration: Plant available water is sufficient to sustain the species and processes similar to that of the reference ecosystem. The growth medium is capable of sustaining the species and processes similar to that of the reference ecosystem. Plant available nutrients (especially nitrogen and phosphorus) can sustain, or are on a secure trajectory towards that which can sustain, vegetation similar to that of the reference ecosystem. Organic matter content can indefinitely sustain, or is on a secure trajectory towards that which can sustain to that of the reference ecosystem.
F12	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.	Accepted	Ecosystem Restoration: Weed composition, abundance and density no greater than that of the reference ecosystem.

RMCP reference	Proposed criteria	Assessment outcome	Relevant Rehabilitation Standard
F13	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.	outcome Further information	Ecosystem Restoration: Assemblages and species relative abundance of fauna (including threatened species) are highly similar to, or on a secure trajectory towards, those of the reference ecosystem. Species richness of overstorey flora and fauna for the restored ecosystem is highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Trophic guilds of fauna are highly similar to, or on a secure trajectory towards, that of
			 the reference ecosystem. Faunal occupation and usage of habitat highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Occurrence and abundance of key habitat features (e.g. hollow logs, tree hollows) are highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Absence of physical barriers (i.e. fences, roads etc.) so the potential for external exchanges is highly similar to, or on a secure trajectory towards, that of the
			reference ecosystem. Evidence of passive regeneration and dispersal, including dispersing fauna (pollinators, frugivores) highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Patch metrics such as connectivity are highly similar to, or on a secure trajectory towards, that of the reference ecosystem. Pest composition, abundance and density no greater than that of the reference ecosystem.

9.5.1. Criteria Terminology

In the Ecosystem Restoration (flora and fauna) closure criteria explanatory text presented in the RMCP, there is a distinction made between *critical standalone* criteria and others that may be assessed *collectively*, or *within the context of meeting the overall closure criteria as a whole*. It is not clear why some criteria would be seen as more critical than others, as all relate to meeting the ERs and if criteria were assessed collectively, the important detail would likely be lost. Clear justification should be provided as to why some criteria would be more important than others.

To ensure that closure criteria for ecosystem restoration are specific and measurable, terminology should be consistent and clearly defined, such as:

- comparable to
- similar to
- to appear
- under natural condition
- *adjacent areas of KNP* and *surrounding KNP*.

There is mention of *framework species* in Chapter 7 of the RMCP but the composition of these species does not appear to be reflected in the information presented in the document, or in the closure criteria.

9.5.2. Revegetation Establishment Trajectories

Trajectories are applicable to any closure criteria that are expected to be reached after a period of time from the initial establishment, which is the case for revegetation establishment. The trajectory approach is based on modelling of a desired and/or expected trajectory pathway, distinguishing the desired pathway from possible undesired states, and selecting points within the desired trajectory that represent milestones for closure criteria.

The information drawn from previous revegetation studies should be used in the development of a revegetation trajectory model. The model should consider scenarios that capture the key aspects of, and influences on, revegetation establishment, and be used to identify and plan for management of risks, and provide the basis for a targeted monitoring program. There is a need to monitor the revegetation against closure criteria until the closure objective has been met, or until milestones within an appropriately modelled trajectory (or trajectories) have been achieved and sufficient confidence is gained that the desired end state will be achieved.

In the Revegetation Strategy presented in the RMCP, it is acknowledged that active management will be required to keep revegetation on a *developmental trajectory that has a predictable long-term result*. However, trajectories of possible change are not documented or presented and management strategies to reach desired end states are not clearly articulated. The trajectory model needs to include the uncertainty associated with the possible end states and management interventions.

The requirement for information in relation to key sustainability indicators and establishment trajectories to measure revegetation success have been identified a KKN (EE5).

9.5.3. Vegetation Composition and Structure

For overstorey species, the RMCP proposes a Bray–Curtis similarity of $\geq 15-30$ % as a closure criterion for revegetation (Criterion F2) together with a proposed total species number criterion of

 \geq 35. SSB does not support the numbers as currently presented noting that both metrics depend upon the spatial scale of measurement. No understorey metrics are provided.

Species number criteria should also incorporate the structural components of vegetation communities (i.e. understorey and overstorey), to ensure that none of these is over or underrepresented. Total species number of combined overstorey and understorey for a 4 km² area is estimated to be 224 from preliminary data in the surrounding environment.

For the closure criterion proposed for canopy architecture (Criterion F3), *presence* alone is not sufficient to demonstrate that revegetation communities are representative of adjacent areas of Kakadu. Criteria should be presented as ranges relative to reference sites and broken down into an appropriate classification of strata. Also, the establishment of understorey species that are *appropriate to substrate* is not consistent with the ERs that state that vegetation should be comparable to surrounding areas.

For the closure criterion proposed for canopy and groundcover (Criterion F4), clarification is required on what is meant by *canopy/groundcover index*. Foliage projective cover would generally be considered as an appropriate measure to assess vegetation cover.

It is suggested in the RMCP that rock is considered as an understorey cover. Although rocks may assist in erosion control, they should not be included in the assessment of whether understorey cover on the rehabilitated site is similar to reference/analogue ecosystems.

A proposed revegetation species list (including both over- and understorey species) should be provided.

The information requirement concerning the development of appropriate structural indicators to measure revegetation success has been identified as a KKN (EE1).

9.5.4. Fauna

Fauna closure criteria presented in the RMCP are qualitative and based largely on one unpublished report/study relating to revegetation, which does not incorporate major advances in fauna sampling technology (e.g. remote cameras) in the last 20 years (Gillespie et al. 2015), and the now well-established application of more systematic fauna sampling in KNP and elsewhere (e.g. Woinarski et al. 2010).

The criteria refer only to major functional groups but should also include standard quantitative biodiversity indices (e.g. species richness and abundance) that allow assessment of whether terrestrial fauna communities on the rehabilitated site are comparable (or on a trajectory to be comparable) with those in adjacent areas of Kakadu National Park. There is also a lack of evidence to support the assumption that fauna will colonise the rehabilitated site once suitable habitat has established. The requirement for information to assess the suitability of habitats on the rehabilitated site (and inform its design) for fauna colonisation has been identified as a KKN (EE2) and should be a key aspect of the Revegetation Strategy.

Criterion F13 should be reworded to; feral animal densities 'not greater than' those in surrounding areas, as opposed to *similar* to those in surrounding areas.

9.5.5. Sustainability

The exclusion of 20% of plant species from the plant reproduction closure criterion (Criterion F6) should be justified. To demonstrate that the revegetated site is comparable to adjacent areas, there should be some consideration of the amount and periodicity of flower, fruit and seed resources

provided in the revegetated site, rather than simply whether there is any evidence of any flowering or fruiting.

The closure criterion for recruitment and regeneration (Criterion F7) does not adequately capture the process of vegetation recruitment. A seedling may be present but not survive the dry season and hence is not recruited into the population (i.e. recruitment has not occurred). This criterion should capture seedling germination/sucker emergence, survivorship and growth. While understood as a general term, *framework species* should be clearly defined to avoid confusion.

Issues identified with the closure criterion for nutrient cycling (Criterion F8):

- Relatively broad assessments are proposed for measuring nutrient cycling that only require evidence of build-up of organic matter and decomposition, which are essentially opposite processes.
- There are no measures of uptake of nutrients and there is no assessment of what nutrients are being cycled, which would demonstrate a functioning ecosystem.
- Closure criteria should include measures of actual nutrients that are being cycled and identify preferable organisms for nutrient cycling.
- For soil biota, presence alone is not appropriate and should be relative to the abundance of functional groups and similar to adjacent areas of Kakadu.
- The requirement for the proposed criteria to be met in 90% of the survey plots is subject to the number and location of plots and may not represent the spatial scale of the entire minesite.
- *Infill planting* is identified as a contingency for an absence of nutrient cycling but it is unclear how this would address such an issue.

In relation to the closure criterion proposed for fire resilience (Criterion F9), it is not clear how *resilience* would be assessed, or what an acceptable value for resilience is. It is also important to assess how the restored vegetation community responds to fire regimes that are characteristic of the surrounding area, rather than how it may respond to a single fire.

In addition to *long-term vegetation growth*, the proposed criterion for plant available water (Criterion F11) should incorporate sustainability of a mature plant community, which would need to be confirmed by monitoring.

9.6. Rehabilitation Monitoring

It is stated in the RMCP that a long-term vegetation and fauna monitoring program has commenced at 17 sites, to document the condition and seasonal variation of reference sites in adjacent areas of Kakadu and undisturbed areas of the Ranger Project Area. It is intended that information collected from these reference site will be used to assess future rehabilitation success. The RMCP should provide detailed information about:

- justification for site selection
- survey methods (including plot size) and quantitative metrics being used to assess *condition* and *natural variability*
- how the data from these surveys are being used to derive or update closure criteria.

Monitoring techniques described in the RMCP are unlikely to be sufficient to provide comprehensive surveillance of weeds, fire and revegetation establishment on the Ranger Project Area. Further research is required to investigate efficient and cost-effective methods that can be used to measure and monitor these aspects at a landscape scale. SSB does not support the monitoring frequency proposed in section 11.5, which suggests that after the first 5 years of annual monitoring, the monitoring frequency should be reduced to 5-yearly intervals and weed monitoring ceased altogether. Five-yearly monitoring will be too infrequent to detect and correct deviations from the desired restoration trajectory in a timely manner. The monitoring program should be developed based upon the risks and mitigations identified through a trajectory model, and include monitoring of the progressive rehabilitation activities which have already commenced. Weed monitoring and weed control, at some frequency, will need to continue until closure.

The overall monitoring time frame of 25 years proposed in the RMCP is reasonable but should be extended if required. Methods for monitoring the success of ecosystem restoration should be reviewed regularly to ensure that they are optimised and in accordance with current best practice.

The above information requirements have been identified as a KKN (EE9).

9.7. Summary of Recommendations and Additional Comments for Ecosystem Restoration

A summary of the recommendations and additional comments discussed in this chapter is provided in Table 20.

Table 20 Summary of recommendations and additional comments pertaining to Ecosystem Restoration

	Recommendation
Before KKNs, fauna	commencement of revegetation activities on the final landform ERA must address the listed and develop an ecosystem restoration strategy which includes consideration of both flora and (EE1, EE2, EE3 and EE4), and is based upon an appropriate trajectory model (EE5) that
accoun	nts for key influences on revegetation establishment (EE6, EE7 and EE8).
Key Kr	nowledge Needs to be addressed:
• EE Are	E1 — Determining the characteristics of ecosystems in the areas surrounding the Ranger Project rea.
• EE	E2 — Determining the requirements to support a faunal community similar to areas surrounding e Ranger Project Area.
• EE	E3 — Understanding how to establish native vegetation, including understory species.
• EE	E4 — Determine the density of introduced species in areas surrounding the Ranger Project Area.
• EE	E5. Develop a revegetation trajectory for Ranger mine.
• EE	E6 — Understanding the impact of contaminants on vegetation establishment and sustainability.
• EE	E7 — Understanding the effect of physical and geochemical properties of waste rock on egetation establishment and sustainability (excluding EE7.B).
• EE	E8 — Understanding fire resilience and management in revegetation.
In acco of the g waste r commu	brdance with the previous recommendations of the Supervising Scientist; before the placement grade 1s waste rock cap on Pit 1 ERA must address the listed KKNs, and demonstrate that the rock landform will provide sufficient plant available water to support a mature vegetation unity (EE7.B).
Key Kr	nowledge Needs to be addressed:
• EE	E7.B — Will sufficient plant available water be available in the final landform to support a mature equatation community?

Ecosystem Restoration aspect	Additional comments	Relevant KKN
Detailed Activity Description	Additional information on the works proposed in the revegetation application should include:	EE2, EE3, EE4
	• detailed action plans and timelines, including methods (i.e. planting, irrigation)	
	seed availability and collection plan	
	nursery details and propagation studies	
	• target and planned planting densities and methods (e.g. final target density for each species)	
	habitat to be installed (e.g. nesting boxes, rock piles)	
	 ongoing management activities, including weed control and infill planting 	
	 any other project specific assumptions or information which would be required to conduct a detailed assessment of the activity. 	
	Expand the Revegetation Strategy to an ecosystem restoration strategy.	EE1, EE2, EE3, EE4
	Key findings and knowledge gaps should by synthesised from all previous work, and based on this a monitoring program should commence on the trial landform to inform the Ecosystem Restoration Strategy.	EE2, EE3
Revegetation Trials	Information and data from previous revegetation studies need to be collated and incorporated into the Ecosystem Restoration Strategy, including:	EE2, EE3, EE4
	• up-to-date monitoring results for the trial landform, including monitoring of grasses and groundcover species	
	• findings and recommendations from revegetation studies conducted at Ranger that pre-date the trial landform	
	• a synthesis of key findings and knowledge gaps.	
	Provide information demonstrating that waste rock can maintain long-term species diversity through recruitment and regeneration and whether there are factors that could be manipulated to facilitate this.	EE7
Reference Sites	Provide the survey methods used for the regional vegetation survey program.	EE1

Ecosystem Restoration	Provide further information to demonstrate that sufficient seed can be sourced to complete revegetation in the time frame required and reach the desired end state (including the amount of seed and resulting tube stock for each species), and consider classifying seed availability as a Class 3 risk.	EE3
	Provide information on which species are currently able to be grown from seed, and which are not able to be successfully propagated.	EE3
	 Provide information on soil formation properties for each type of waste rock to be used in landform construction, including: weathering rates soil texture information for the entire waste rock substrate (i.e. not just < 2mm fraction). 	EE7
	Provide uncertainty analysis for all modelling undertaken in relation to demonstrating that there will be sufficient plant available water in the final landform.	EE7
	Provide information to demonstrate that plant roots will be able to penetrate a waste rock substrate to a sufficient depth to address plant available water requirements, including understory species and accounting for macropores.	EE7
	Provide further evidence to support the assumption that understorey is a minor component of evapotranspiration.	EE7
	 Provide evidence to demonstrate that compaction layers: will improve the water-holding capacity of the waste rock will not lead to other issues affecting plant growth (e.g. physical restriction of roots, formation of perched water tables) 	EE7
	Provide further information on the internal properties of the final landform (e.g. nature, depth and extent of compacted layers), in conjunction with a conceptual model and water balance (under a range of rainfall scenarios) to demonstrate that there will be sufficient water available for revegetation.	EE7
	The lack of a seasonal trend in radon exhalation rates on the waste rock-only section of the trial landform should be investigated in the context of the ability of the waste rock substrate to retain water.	EE7
	Include more relevant information on fire and plant survivability in the region, including reference to fire severity and intensity, and survivability of specific species.	EE8
	Determine the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site, including reference to faunal colonisation.	EE8
	Further information should be provided to explain why fire was not classified as a class III risk.	EE8

	Provide details on which species would be included in the understorey (in consideration of requirements for faunal colonisation), and evidence to support the assumption that direct seeding is the best option for the establishment of such species.	EE3
	Provide evidence to demonstrate that appropriate measures will be taken to ensure fauna colonisation of the rehabilitated site.	EE2
	Quantify the magnitude of potential sources of feral animals (i.e. no. of animals per unit area), to allow comparison of densities between areas inside the Ranger Project Area and adjacent areas of Kakadu National Park.	EE2
	Assess the risk of feral animals impacting on faunal colonisation of the rehabilitated site.	EE2
	Refine the vegetation mortality contingencies to consider mortality beyond the first 6 months and the potential for mortality to vary between species and locations.	EE3
Ecosystem Restoration Risks Not Assessed	Assess the risk of potential impacts of contaminants leached from waste rock on revegetation and fauna, including details on how this would be avoided or mitigated.	EE6, WS9
	Provide information to assess how vegetation community development may be affected by landform stability, including recontouring the landform surface.	EE7
	Provide information on nitrogen dynamics in the rehabilitated landform, including an assessment of the potential for nitrogen to be a limiting factor for nutrient cycling, and nutrient availability and presence of soil biota to assist in plant growth.	EE7
	Acknowledge that comprehensive surveys to inform the status of weeds and feral animals will be required before and during the rehabilitation process, including the entire Ranger Project Area and surrounding areas.	EE4
	Provide the rationale for the nominated 200 m weed buffer zone.	EE4
	Mitigations to address integrated landscape risks, such as weather, should be addressed in the Ecosystem Restoration Strategy.	EE3
Closure Criteria	Clearly justify why some closure criteria would be more important than others, in relation to the Environmental Requirements.	_
	Ensure that the closure criteria for ecosystem restoration use consistent and clearly defined terminology.	-
	Include a defined trajectory (or trajectories) in relation to vegetation community establishment, using site-specific indicators relating to ecosystem composition, structure and function.	EE5
	Provide information to justify the \geq 15–30 % similarity as the closure criterion for species composition and relative abundance.	EE1

Provide information to justify the proposed total species number closure criterion of \geq 35.	EE1		
The canopy architecture criterion (F3) should not be expressed as presence/absence, rather should be presented as ranges and broken down into an appropriate classification of strata.			
Clarify what is meant by <i>canopy/groundcover index</i> in relation to criterion F4 and do not include rocks in the assessment of understorey cover.	EE1		
A proposed revegetation species list (including both over- and understorey species) should be provided.	EE1		
Update terrestrial fauna closure criteria using data gathered with contemporary fauna sampling methodologies.	EE2		
Include standard quantitative biodiversity indices (e.g. species richness and abundance) for fauna that allow assessment of whether terrestrial fauna communities on the rehabilitated site are comparable (or on a trajectory to be comparable) with those in adjacent areas of Kakadu National Park.	EE2		
Provide evidence to support the assumption that fauna will colonise the rehabilitated site, once suitable habitat has established.	EE2		
Provide information to justify the proposed plant reproduction closure criterion of evidence of flowering and fruiting in 80% of species, including consideration of the amount and periodicity of flower, fruit and seed resources provided in the revegetated site.	EE1		
Criterion F7 should capture seedling germination/sucker emergence, survivorship and growth, and the term <i>framework</i> <i>species</i> should be clearly defined.	EE1		
Criterion F13 should be reworded to; feral animal densities 'not greater than' those in surrounding areas, as opposed to <i>similar</i> to those in surrounding areas.	EE1		
Criteria for recruitment/regeneration should capture seedling germination/sucker emergence, survivorship and growth.	EE5		
Criteria for nutrient cycling (F8) should be expanded to include a more detailed assessment of nutrient cycling, including:	EE7		
quantification of nutrients present			
relative abundance for soil biota			
appropriate spatial scales.			

	The criterion proposed for fire resilience should clearly detail how <i>resilience</i> would be assessed and what an acceptable value for resilience is. Consideration should also be given to how the restored vegetation community responds to fire regimes that are characteristic of the surrounding area, rather than how it may respond to a single fire.		
	Criterion F11 (plant available water) should incorporate sustainability of a mature plant community.		
Rehabilitation Monitoring	 The vegetation and fauna monitoring program should include detailed information about: justification for site selection survey methods and quantitative metrics being to assess <i>condition</i> and <i>natural variability</i> how the data from these surveys are being used to derive or update closure criteria. 	EE9	
	Revise the proposed monitoring methods and frequency based upon the risks and mitigations identified through a trajectory model.	EE9	
	Weed monitoring and weed control, at some frequency, will need to continue until closure.	EE9	

10. Monitoring

10.1. Relevant Environmental Requirements

Under the ERs monitoring is required until site closure (Table 21). Monitoring programs must be implemented

- while undertaking rehabilitation activities to ensure continued protection of the offsite environment and to inform the progressive rehabilitation process
- after the completion of rehabilitation activities to assess and demonstrate achievement of the rehabilitation objectives.

Monitoring related to specific themes has been discussed in more detail in the relevant rehabilitation theme chapters.

Monitoring aspect	Clause	Environmental Requirement	Does RMCP demonstrate ER can be met?
Monitoring for Environment Protection	13.3	The company must carry out a monitoring program approved by the Supervising Authority or the minister with the advice of the Supervising Scientist following cessation of operations until such time as a relevant close-out certificate is issued under clause 9.3.	Further information required

Table 21. Ranger Environmental Requirements relevant to Monitoring

10.2. Activity Summary

The RMCP provides a chapter on closure monitoring and maintenance which covers the period post-2026 after the completion of rehabilitation, defined as the stabilisation and monitoring phase. During this phase, monitoring will be used for ongoing assessment of the success of the rehabilitation activities and enable effective implementation of an adaptive management approach to ensure the successful transition of the site from its rehabilitation through to final closure.

These proposed activities are broadly in line with the relevant ERs. However, there is very little discussion on monitoring to be carried out to assess potential environmental impacts of rehabilitation activities undertaken from now until 2026, nor to monitor the success of progressive rehabilitation works currently underway.

10.3. Detailed Works Description

The RMCP summarises the proposed post-rehabilitation monitoring programs at a high level.

Further information is required to ensure the ongoing protection of the offsite environment during and immediately after rehabilitation and to determine whether or not the proposed monitoring is appropriate for assessing the success of the rehabilitation objectives. It is acknowledged that ERA is close to completing feasibility-level planning for rehabilitation and this additional detail should be provided once available.

Additional information to be provided should include, as relevant:

• detailed monitoring plans that cover and distinguish between all the necessary types and periods of monitoring, including:

- 'operational' monitoring to detect potential impacts during the implementation phase of rehabilitation
- progressive rehabilitation monitoring to confirm that rehabilitated areas are performing as expected and if necessary, inform future rehabilitation activities
- monitoring to verify surface and groundwater modelling predictions
- post-2026 stabilisation and maintenance phase monitoring
- resources required to fulfil monitoring requirements
- any other project specific assumptions or information which would be required to conduct a detailed assessment of the appropriateness of the monitoring programs.

10.4. Monitoring for Environment Protection (ER 13.1–13.3)

Two different types of monitoring are required as part of the rehabilitation and closure process, listed here with the applicable criteria:

- 1. during rehabilitation (including progressive rehabilitation) to demonstrate that site works do not result in environmental impacts, to inform requirements for maintenance and to inform future rehabilitation activities operational criteria
- 2. after rehabilitation to validate modelling predictions and/or verify that the rehabilitation objectives have been met closure criteria.

The intent of the monitoring will dictate the type of monitoring required and it is recommended that the monitoring programs be presented separately for each. Each monitoring program should also include additional information on reporting of monitoring results. Agreement on appropriate reporting frequencies will need to be reached, noting that annual reporting of surface water quality monitoring results post-rehabilitation is not likely to be frequent enough.

It is accepted that monitoring effort will be reduced over time in line with reducing environmental risk. However, any future reduction in monitoring effort should be justified with data which demonstrate a reduction in environmental risk, rather than being based on a predetermined time frame. The overall monitoring time frame of 25 years proposed in the RMCP is a reasonable estimation, but in accordance with ER 13.3 it will need to continue until closure should this take longer than 25 years.

The Supervising Scientist supports the use of the 'trigger action response plan' (TARP) methodology for implementing adaptive management activities. It is noted that this approach will only be useful in situations where effects are likely to be observed within a relatively short time frame, as opposed to effects which may appear after hundreds or thousands of years. This approach could be improved by:

- ensuring that triggers are specific, measurable and readily linked to management actions
- ensuring that actions are specific and avoid the use of generic responses such as *monitor trends and develop site-specific action plans as required*
- using a 'tiered' risk approach.

Examples of the tiered approach include:

• 'first tier' triggers that identify opportunities for closer monitoring or early intervention that may mitigate potential impacts before significant impact to rehabilitation success, or the environment, occurs

• 'second tier' triggers that identify when indicators have reached a threshold that requires more substantive or widespread remedial actions to prevent rehabilitation failure or mitigate environmental impacts.

10.5. Summary of Recommendations and Additional Comments for Monitoring

A summary of the recommendations and additional comments discussed throughout the Monitoring chapter is provided in Table 22. The need to develop and periodically review/update monitoring methods for each of the rehabilitation themes has been identified as KKNs under each of the closure themes (WS11, LAN4, LAN5, EE9, RAD8).

Table 22. Summary of recommendations and additional comments pertaining to monitoring

Recommendations					
Develop detail	Develop detailed monitoring plans that cover and distinguish between all the necessary types and				
periods of mor	itoring, including:				
detaile period	 detailed monitoring plans that cover and distinguish between all the necessary types and periods of monitoring, including: 				
o'(r	 'operational' monitoring to detect potential impacts during the implementation phase of rehabilitation 				
0 P	rogressive rehabilitation monitoring to confirm that rehabilitated areas are performing as				
e	xpected and if necessary, inform future rehabilitation activities				
 monitoring to verify surface and groundwater modelling predictions 					
 post-2026 stabilisation and maintenance phase monitoring. 					
resources required to fulfil monitoring requirements					
any other project specific assumptions or information which would be required to conduct a					
detailed assessment of the appropriateness of the monitoring programs.					
Monitoring aspect	Additional comments				
Monitoring	Update the TARP.				
for					
Environment					
Protection					

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Appendix 1 — List of Acronyms

AALL	annual additional load limits		
Ac	actinium		
ALARA	as low as reasonably achievable		
APR	Annual Plan of Rehabilitation		
ARR	Alligator Rivers Region		
ARRTC	Alligator Rivers Region Technical Committee		
BPT	best practicable technology		
EIL	ecological investigation level		
ER	Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine, attached to the Ranger Authority issued under s 41 of the Atomic Energy Act 1953		
ERA	Energy Resources of Australia Ltd		
GCH	Gulungul Creek at Arnhem Highway		
GCMBL	Georgetown Creek median bund level-line		
GCT2	Gulungul Creek Tributary 2		
KKN	Key Knowledge Need		
LAA	land application area		
NTU	nephelometric turbidity unit		
Ramsar	The Ramsar Convention on Wetlands, an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources		
RMCP	Ranger Mine Closure Plan		
RP1/RP2/RP3	Retention Pond 1/Retention Pond 2/Retention Pond 3		
RPA	Ranger Project Area		
SSB	Supervising Scientist Branch		
TARP	trigger action response plan		
Tailings Storage Facility	Tailings Storage Facility (dam)		
U	uranium		

Appendix 2 – The Supervising Scientist's Key Knowledge Needs

Landform

KKN No.	ER Link	Category	Title	Questions
LAN1	Erosion	Baseline	LAN1. Determining baseline erosion and sediment transport	LAN1A. What is the baseline rate of gully formation for areas surrounding the Ranger Project Area?
			characteristics in areas surrounding the Ranger Project Area	LAN1B. What is the baseline rate of bedload movement and deposition in creeks and billabongs?
LAN2	Erosion	Baseline	LAN2. Understanding the landscape-scale processes and extreme events affecting landform stability	LAN2A. What major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate)?
				LAN2B. How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?
LAN3	LAN3 Erosion Predict	Predicting	edicting LAN3. Predicting erosion of the rehabilitated landform	LAN3A. What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?
				LAN3B. Where and how much consolidation will occur on the landform?
				LAN3C. How can we optimise the landform evolution model to predict the erosion characteristics of the final landform (e.g. refining parameters, validation using bedload, suspended sediment and erosion measurements, quantification of uncertainty and modelling scenarios)?
				LAN3D. What are erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, time frame, groundwater expression and effectiveness of mitigations)?
				LAN3E. How much suspended sediment will be transported from the rehabilitated site (including LAAs) by surface water?
LAN4	Erosion	ion Monitoring	g LAN4. Development of remote sensing methods for monitoring erosion	LAN4A. How do we optimise methods to measure gully formation on the rehabilitated landform?
				LAN4B. What monitoring data are required for ongoing LEM validation?
LAN5	Erosion	Monitoring	LAN5. Development of water quality monitoring methods for assessing landform erosion	LAN5A. How can we use suspended sediment in surface water (or turbidity as a surrogate) as an indicator for erosion on the final landform?

Water and Sediment

KKN No.	ER Link	Category	Title	Questions	
WS1	Biodiversity and ecosystem	Source	WS1. Characterising contaminant sources on the Ranger Project	WS1A. What contaminants (including nutrients) are present on the rehabilitated site (e.g. LAAs, contaminated soils and groundwater, tailings and waste rock)?	
	health		Area	WS1B. What are the factors that influence the mobilisation of contaminants?	
	Biodiversity and			WS2A. What is the nature and extent of groundwater movement, now and over the long term?	
WS2	ecosystem	Pathway	WS2. Predicting transport of contaminants in groundwater	WS2B. What are the factors that influence contaminant (including nutrients) transport and toxicity in groundwater?	
	health			WS2C. What are predicted contaminant (including nutrients) concentrations in groundwater over time?	
WS3	Biodiversity and	Pathway	WS3. Predicting transport of	WS3A. What is the nature and extent of surface water movement, now and over the long term?	
	ecosystem		contaminants in surface water	WS3B. What are the factors that influence contaminant (including nutrients) transport and toxicity in surface water?	
	nealth			WS3C. Where and when does groundwater discharge to surface water?	
				WS3D. What influences the movement of contaminants (including nutrients) between groundwater and surface water?	
				WS3E. What are predicted contaminant (including nutrients and contaminants bound to sediment) and suspended sediment concentrations in surface waters over time?	
				WS3F. To what extent will the mobilisation of contaminants from sediment influence surface water quality?	
				WS3G. Where, when and to what extent will contaminants accumulate in downstream sediments?	
WS4	Biodiversity and ecosystem health	Receptor	WS4. Characterising baseline aquatic biodiversity and ecosystem health	WS4A. What are the nature and extent of baseline surface water, hyporheic and stygofauna communities, as well as other groundwater dependent ecosystems, and their associated environmental conditions?	
WS5	Biodiversity and ecosystem	Receptor	WS5. Determining the impact of contaminated sediments on aquatic biodiversity and ecosystem	WS5A. To what extent will contaminants accumulate in sediments over time, including the development of acid sulfate sediments?	
	health			WS5B. What are the factors that influence the toxicity of contaminants in sediment?	
			health	WS5C. What is the impact of contaminated sediments to aquatic ecosystems?	
WS6	Biodiversity and ecosystem	sity and Receptor stem lth	iodiversity and Receptor WS6. Determining the impact of nutrients on aquatic biodiversity	WS6. Determining the impact of nutrients on aquatic biodiversity	WS6A. What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?
	health		and ecosystem health	WS6B. Can annual additional load limits (AALL) be used to inform ammonia closure criteria?	
				WS6C. Will the total loads of nutrients (N and P) to surface waters represent a eutrophication risk?	
WS7	Biodiversity and ecosystem	Receptor	WS7. Determining the impact of chemical contaminants on aquatic	WS7A. Are current guideline values appropriate given the potential for variability in toxicity due to mixtures and modifying factors?	
	health		biodiversity and ecosystem health	WS7B. Are there any emerging contaminants that have not yet been identified as a risk?	

KKN No.	ER Link	Category	Title	Questions
				WS7C. Are current guideline values appropriate to protect the key groups of aquatic organisms (e.g. flow-dependent insects, hyporheic biota and stygofauna) that have not been represented in laboratory and field toxicity assessments?
				WS7D. How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota?
				WS7E. How will Mg:Ca ratios influence Mg toxicity?
				WS7F. Can a contaminant plume in creek channels form a barrier that inhibits organism migration and connectivity
				(e.g. fish migration, invertebrate drift, gene flow)?
				WS7G. What concentrations of contaminants from the rehabilitated site will aquatic vegetation be exposed to?
				WS7H. What concentrations of contaminants will be detrimental to the health of aquatic vegetation?
WS8	Biodiversity and	Receptor	WS8. Determining the impact of	WS8A. What are the physical effects of suspended sediment on aquatic biodiversity, including impacts from
	ecosystem		suspended sediment on aquatic	sedimentation and variation in sediment characteristics (e.g. particle size and shape)?
	health		biodiversity and ecosystem health	WS8B. To what extent does salinity affect suspended particulates, and what are the ecological impacts of this?
WS9	Biodiversity and	Receptor	WS9. Determining the impact of	WS9A. Will surface water quality on the rehabilitated site pose a risk to terrestrial wildlife (e.g. both chronic and acute
	ecosystem		chemical contaminants in drinking	impacts)?
	health		water on terrestrial wildlife	
WS10	Human health	Receptor	WS10. Determining the impact of	WS10A. What are the chemical pollutants of potential concern to human health?
			chemical contaminants on human health	WS10B. What are the concentration ratios for chemical pollutants in bush foods?
				WS10C. What are the concentrations of chemical pollutants in drinking water sources?
				WS10D. What is the dietary exposure of a member of the public to chemical pollutants?
				WS10E. Does public exposure to chemical pollutants conform with relevant Australian and/or international guidelines?
WS11	Biodiversity and	Monitoring	WS11. Optimisation of water	WS11A. How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?
	ecosystem		quality monitoring programs and	
	health		assessment methods	

Radiation

KKN No.	ER Link	Category	Title	Questions
RAD1	Human and ecosystem health	Source	RAD1. Radionuclides in the rehabilitated site	RAD1A. What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and LAAs?
RAD2	Human and ecosystem health	Pathway	RAD2. Radionuclides in aquatic ecosystems	RAD2A. What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?
RAD3	Human and ecosystem health	Pathway	RAD3. Radon progeny in air	RAD3A. What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?
				RAD3B. What is the equilibrium factor between radon progeny and radon in air?
				RAD3C. What is the unattached fraction of radon progeny in air?
RAD4	Human and ecosystem health	Pathway	RAD4. Radionuclides in dust	RAD4A. What is the resuspension factor (or emission rate) of dust emitted from the final landform?RAD4B. What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?
				RAD4C. What is the activity median aerodynamic diameter of long-lived alpha-emitting radionuclides in dust emitted from the final landform?
RAD5	Human and ecosystem health	Pathway	RAD5. Radionuclides in bushfoods	RAD5A. What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?
RAD6	Human and ecosystem health	Receptor	RAD6. Radiation dose to wildlife	RAD6A. What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?
				RAD6B. What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?
				RAD6C. What are the tissue to whole-organism conversion factors for uranium and actinium series radionuclides for wildlife represented by the representative organism groups?
				RAD6D. What are the dose–effect relationships for wildlife represented by the representative organism groups?
				RAD6E. What is the sensitivity of model paramaters on the assessed radiation doses to wildlife?
RAD7	Human and ecosystem health	Receptor	RAD7. Radiation dose to the public	RAD7A. What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?
				RAD7B. What is the sensitivity of model paramaters on the assessed doses to the public?
RAD8	Human and ecosystem health	Monitoring	RAD8. Optimisation of radionuclide monitoring and assessment methods	RAD8A. How do we optimise methods to monitor and assess radionuclides?
Ecosystem Restoration

KKN No.	ER Link	Category	Title	Questions
EE1	Ecosystem similarity	Ecosystem similarity	EE1. Determining the characteristics of ecosystems in the areas surrounding the Ranger	EE1A. What are the key characteristics of the terrestrial ecosystems (including riparian) surrounding the Ranger Project Area, and how do they vary spatio-temporally?
			Project Area.	EE1B. Which structural indicators should be used to measure revegetation success?
EE2	Ecosystem similarity	systemEcosystemEE2. Determining the requirements to support anilaritysimilarityfaunal community similar to areas surrounding		EE2A. What faunal community structure (composition and relative abundance) is present in the areas surrounding the Ranger Project Area?
			the Ranger Project Area.	EE2B. What habitat should be provided on the rehabilitated site to ensure the recolonisation of fauna, including threatened species?
				EE2C. What is the risk of feral animals (e.g. cats and dogs) to faunal colonisation?
EE3	Ecosystem similarity	Ecosystem similarity	EE3. Understanding how to establish native vegetation, including understory species.	EE3A. How do we successfully propagate and establish native vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?
EE4	Ecosystem similarity	Ecosystem similarity	EE4. Determine density of introduced species in areas surrounding the Ranger Project Area.	EE4A. What is the composition and abundance of feral animals and weeds in areas surrounding the Ranger Project Area?
EE5	Long-term	Ecosystem	EE5. Develop a revegetation trajectory for	EE5A. What are the key sustainability indicators to be used to measure revegetation success?
	viability	Sustainability	Ranger mine.	EE5B. How can we develop vegetation community trajectories to predict when the rehabilitated site will move to a sustainable vegetation community without further management intervention (including different fire and weed scenarios)?
EE6	Long-term viability	Ecosystem Sustainability	EE6. Understanding the impact of contaminants on vegetation establishment and sustainability.	EE6A. What concentrations of contaminants from the rehabilitated site will plants be exposed to, including riparian vegetation?
				EE6B. What concentrations of contaminants will be detrimental to plant health?
				EE6C. Have contaminants impacted the structure of vegetation on the LAAs?
EE7	Long-term	Ecosystem	EE7. Understanding the effect of physical and	EE7A. What is the potential for plant available nutrients (e.g. nitrogen and phosphorus) to be a limiting
	viability	sustainability	geochemical properties of waste rock on	factor for sustainable nutrient cycling in waste rock?
			vegetation establishment and sustainability.	vegetation community?
				EE7C. Will ecological processes required for vegetation sustainability (e.g. soil formation, reproduction
				and nutrient cycling) occur on the rehabilitated landform?
EE8	Long-term	Ecosystem	EE8. Understanding fire resilience and	EE8A. What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the
	viability	Sustainability	management in revegetation.	rehabilitated site?

KKN No.	ER Link	Category	Title	Questions
EE9	Ecosystem similarity and sustainability	Monitoring	EE9. Developing monitoring methods for revegetation.	EE9A. How do we optimise methods to measure revegetation structure and sustainability on the rehabilitated site, at a range of spatio-temporal scales and relative to the areas surrounding the Ranger Project Area?

Cross Theme

KKN No.	ER Link	Category	Title	Questions
CT1	Biodiversity and	Risk	CT1. Assessing the cumulative risks to the success of	CT1A. What are the cumulative risks to the success of rehabilitation and to the offsite
	Ecosystem Health		rehabilitation and to the protection of the offsite	environment?
			environment.	
CT2	World Heritage	Heritage	CT2. Characterising World Heritage values of the Ranger	CT2A. What World Heritage Values are found on the Ranger Project Area, and how might
	values	Values	Project Area.	these influence the incorporation of the site into Kakadu National Park and World
				Heritage Area?