Ranger Mine Closure Plan 2023

Appendices

Cover: Sharon Paulka

Issue Date: 1 December 2023

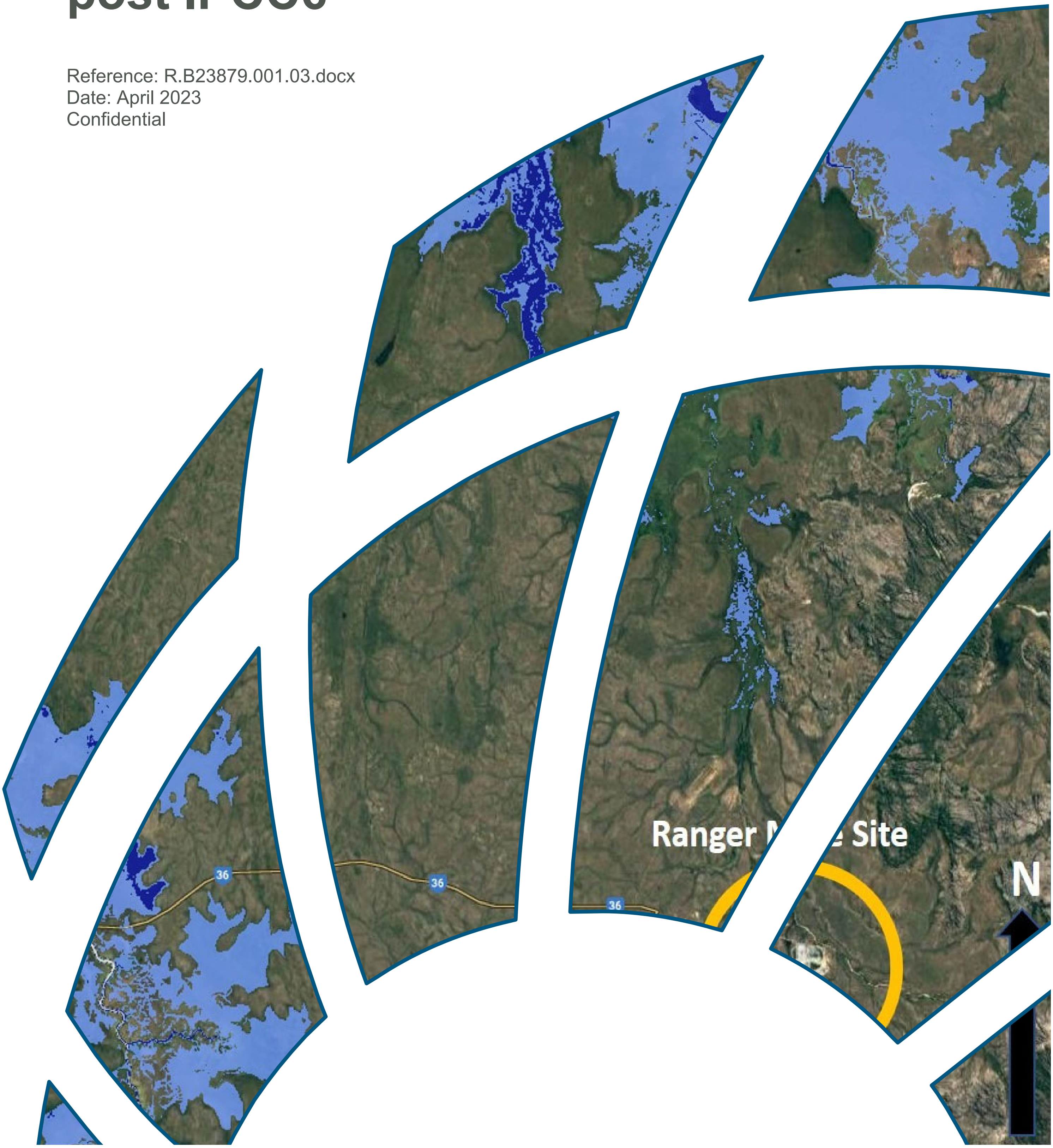
Revision: 1.23.0

APPENDICES

APPENDIX 2.1: RANGER URANIUM MINE CLOSURE CLIMATE CHANGE RISK ASSESSMENT

Ranger Uranium Mine Closure Climate Change Risk Assessment. Updated post IPCC6

Reference: R.B23879.001.03.docx
Date: April 2023
Confidential



Document Control Sheet

BMT Commercial Australia Pty Ltd Level 8, 200 Creek Street Brisbane Qld 4000 Australia PO Box 203, Spring Hill 4004 Tel: +61 7 3831 6744 Fax: + 61 7 3832 3627 ABN 54 010 830 421 www.bmt.org	**Document:**	R.B23879.001.03.docx
	Title:	Ranger Uranium Mine Closure Climate Change Risk Assessment. Updated post IPCC6
	Project Manager:	David Rissik
	Author:	David Rissik and Shelly Iles
	Client:	ERA
	Client Contact:	Alex Ross
	Client Reference:	
Synopsis:		

REVISION/CHECKING HISTORY

Revision Number	Date	Checked by		Issued by	
0	10 July 2020	DR		DR	
1	8 September 2020	DR		DR	
2	22 December 2022				
3	03 April 2023	DR	[signature]	DR	[signature]

DISTRIBUTION

Destination	Revision										
	0	1	2	3	4	5	6	7	8	9	10
ERA	PDF	PDF	PDF								
BMT File	PDF	PDF	PDF								
BMT Library	PDF	PDF	PDF								

Executive Summary

Climate change is a growing concern for organisations, governments and individuals globally. It is an issue that can potentially affect the performance, operational activities and desired outcomes of important management and regulatory requirements such as mine closure activities. Energy Resources of Australia (ERA) is closing its Ranger Uranium Mine and implementing a Mine Closure Plan. Given the long-term nature of the plan and the ultimate objective of handing the area over to a new manager, climate change implications are an important consideration.

This project was initiated to identify how climate change is likely to affect the Mine Closure Plan and to determine any additional investigations or actions that are required to help address any challenges.

The Ranger Mine is located 8 km east of Jabiru and 260 km east of Darwin. It is situated on Aboriginal land, and is surrounded by, but separate from, the Kakadu National Park. The mine is situated in the Magela Creek catchment with Magela Creek being the main creek within the Ranger Mine Project Area.

A stakeholder workshop was held in ERA's Darwin office conference room on 11th March 2020 to undertake a first pass assessment of climate change risk to the closure of the Ranger Uranium Mine. The assessment was based on a process of expert elicitation and included experts from within and outside of ERA. A further on-line workshop was conducted with bushfire experts to gather additional expert input into this critical aspect.

The process included delivery of a briefing on climate projections for the target area, based on available information obtained from reliable resources including the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Bureau of Meteorology (BoM) and the National Climate Change Adaptation Research Facility (NCCARF). Additional information was drawn from published peer reviewed literature.

An overview of the risk assessment process was presented and included discussion on the likelihood and consequence tables to underpin the risk analysis and ensure that all participants were comfortable with the approach. Stakeholders reaffirmed the outcomes from the Inception Workshop for the project including what areas should covered by the assessment and the projected timeframes that should be covered in the assessment. It was agreed that Jabiru and the airport were not to be included in the assessment and that the main timeframes to be considered were 2030 (initial post-closure ecosystem establishment phase), 2050 (planned post-closure monitoring and maintenance end date), and 2100 (best available long-term projections). A mid-range climate change scenario of RCP4.5 was selected and a business as usual climate change scenario of RCP8.5. These are based on scenarios used in IPCC 2014 Reports. Using these two possible futures would help to determine when any major risks were likely to occur. There is little difference between the climate change projections of the two scenarios until after 2050.

In assessing risk, the current management plans and activities relating to the mine closure were discussed, and their role in addressing relevant climate change risks was assessed to enable any residual risk to be identified.

Discussion took place about assessing climate related risks for longer time periods associated with the mine closure including when initial modelling showed peak contaminant loads are likely to be discharged through the groundwater (~270 years) and in 10,000 years to be consistent with regulatory conditions. There are few climate change data available for those periods and the uncertainties associated with them is extreme. Accordingly, it was agreed that there was little merit in including these risks in the risk assessment activity.

The approach was then used to work through risks associated with:

- Heat
- Sea-level rise and salinity
- Rainfall and drought
- Cyclones
- Bushfire.

In December 2022/January 2023, the latest climate change information from IPCC6 was used to review and update the risk assessment. At the same time feedback from the Supervising Scientist Branch (SSB) on version 1 of the report was reviewed and incorporated (a table showing how those comments were addressed is contained in the appendix E). All updates made to the report appear in blue text.

Thirty-five potential risks were identified and assessed in 2020. These were reduced to thirty-three risks in 2023 as three risks were identified (by SSB) as now being redundant. Risks were classified into three key areas.

(1) Revegetation

(2) Onsite and receiving water quantity, quality and ecology

(3) Erosion and sediment.

A changing climate has been a factor in the development of a revegetation plan for the site. Important aspects such as effect of heat on workers, the selection of vegetation and the longer term management, maintenance and monitoring have been considered in the plan. Although this is well thought out it remains an area of importance and it is recommended that the plan is regularly reviewed. The approaches to reduce heat impact on workers should be reassessed as new information or technology becomes available, and as execution planning proceeds to more detailed levels.

The management period following revegetation is an important aspect which reduces short term risk. Vegetation lost or damaged from climate related pressures will be replaced or management procedures will be adjusted, until the site meets the close out conditions (aka closure criteria) with the ecosystem on a trajectory to being self-sustainable, resilient and similar to the surrounding systems (circa 2050). Following this climate related risks are considered to be landscape issues which will affect the whole park and are not related to mine closure activities.

Water quantity and water quality (surface and ground water) may be affected by a changing climate. It is recommended that further modelling is done which accounts for scenarios associated with a changing climate. This entails using different model scenarios to events which have occurred in the past. This will ensure that the models account for non-stationarity in conditions and data which are used to calibrate existing models. It is important that scenarios such as prolonged drought periods are accounted for, including being followed by drier and hotter (more evaporative) wet seasons.

Long dry and highly evaporative periods may dry out billabongs and expose previously unexposed potential acid sulphate soils (PASS) and result in the forming of acid sulphate soils (ASS). This could have impacts on fauna and flora in the area. This has implications if occurring on mine site water bodies, and will be a key area of active management during the closure period. Work on ASS is currently being undertaken.

There are risks associated with impacts of higher temperatures of water bodies which can impact fauna and flora directly but can also affect tolerance of species to contaminants. Reduced water inflow at times and greater rates of evaporation can result in lower flushing rates and loss of connectivity in waterways. This could reduce the ability of certain taxa to move away from areas with poor quality water. These risks were considered more likely in RCP8.5 scenarios beyond 2050 and are outside of the influence of the mine closure. These risks should be re-considered once revised surface and ground water modelling has been completed.

Sea-level rise beyond 2050 is likely to impact low lying areas of the park, reducing the extent of freshwater billabongs and waterways and the associated floral and faunal communities. Upstream sites will become important refugia and includes freshwater bodies on and adjacent to the mine site. This cannot be influenced by the mine closure, although there is potential to consider the opportunity for ensuring additional freshwater bodies remain on the mine site. Sea-level rise beyond 2050 is not a consideration at present and has cost and management implications which have not been considered as part of this assessment.

Other risks associated with sea-level rise were associated with RCP8.5 and are likely to occur beyond 2050. Most of these were landscape risks which will affect the entire park and are not related to the mine closure.

Risks of erosion and runoff of sediment which may occur during cyclones and large storms were identified. Any impacts which occur during the post closure maintenance and management period will be addressed. The risk of gullying causing sedimentation in waterways is considered to be low given the erosion management controls. The risk of gullying exposing buried tailings is also low. Any impacts of erosion on access roads will be addressed during the management period. Longer term risks following handover will be landscape in nature and will be managed through local land management practices.

Risks of bushfire were discussed, and initial discussion indicated that onsite risks will be managed as part of mine closure activities, including replacement of lost or damaged vegetation. In the longer term, mature revegetation shall be resilient to natural disturbance regimes, particularly fire, and any bushfire risk will be managed through local land-management processes. It is essential that this is undertaken in partnership with Traditional Owners and based on Traditional Knowledge.

Summary and recommendations

Climate change is likely to have a significant affect across the Kakadu region. Most impacts are likely to occur beyond 2050. Climate change has implications for the mine closure which will be actively managed. These are predominantly related to the revegetation and soil management on the site and will ensure that the site will be in suitable condition for Mine Close Out Certification to be granted. In the longer term, most climate change risks are landscape in nature and will affect the entire park. Changes to the water bodies and hydrology of the system are likely to occur. These will be park wide, but local receiving waterways may be affected which may influence their susceptibility to discharge of contaminants. Further work to understand this is recommended.

Recommendations are:

- Further water flow and water quality modelling to be undertaken to support a more detailed understanding of risks associated with contaminant discharge into receiving water bodies (note, this occurs when new mine closure scenarios are modelled). Following revised modelling a review of relevant climate related risks should be conducted. Water flow and water quality model runs need to be based on potential future conditions and be appropriately calibrated, or the sensitivity of the model to these should be reviewed. Non-stationarity must be addressed/assessed and long droughts and long wet seasons that have not occurred in the past, but which are likely in the future should be included in any modelling. The sensitivity of model outputs to new climate change information (eg new regional or IPCC data) should be reviewed.
- Risks of climate change be fully embedded into the mine closure plan to ensure worker safety and impacts on revegetation works and monitoring are reassessed as more data and information becomes available.
- Emerging climate change data and information for the Northern Territory and the Kakadu Region should be reviewed and when available the climate change risk assessment should be updated. Alternatively consider having downscaling analysis conducted for the study area.
    - Future climate change risk assessments should consider cascading and compounding risks. For example: higher insolation of surface waters that may be a consequence of any reduction of riparian vegetation that may occur from other drivers such as bushfire or cyclones.
    - Future climate change risk assessment should assess risks of erosion and runoff of sediment that may occur during cyclones and large storms. Floods in Magela Creek may affect the eastern boundary of the rehabilitated mine (see Saynor et al., 2020), and such floods may be larger in future.
- Obtain details of available Lidar data for the region and ensure comprehensive data are available for the area to the north of the mine site. This will support any further sea-level rise modelling that is conducted.
- Analysis of sea-level rise modelling to determine what level of sea-level rise is required for saltwater intrusion to reach the mine. Depending on results the climate change risk assessment may need to be revised.
- Sea-level rise modelling is redone as better LiDAR information becomes available. This will assist to determine the extent of loss of freshwater bodies in the Park and determine whether saline water is likely to encroach further towards the mine site (this is not considered to a mine closure related activity, but can assist to understand the role of mine water bodies as refugia).
- Discussions about the role of water bodies on the mine site as refugia are held with the Traditional Owners and relevant management agencies, including discussion about resourcing and management.
- The monitoring of climate change conducted by CSIRO and BoM should be reviewed to better understand how climate change is tracking. Any rapid on-set of climate change will increase the likelihoods adopted for this risk assessment which will influence the risk assessment. Earlier changes may require additional adaptation action by ERA.
- Results of the current projects on ASS should be reviewed using a climate change lens to assess any implications for closure management.

- Bushfire management will continue to be a risk into the future with implications for managers of the area following close-out and as the mine rehabilitation site vegetation matures and there is less active management of the area. It is essential that fire management approaches are developed and implemented in partnership with the Mirarr People and based on Traditional Knowledge.

Contents

List of Figures

List of Tables

1 Introduction

Ranger Uranium Mine is in the process of closure with transition from open cut mining to full closure between 2012 and 2021. Rehabilitation works are required to be completed by 2026 with monitoring and maintenance planned for a further 25 years. There are several environmental protection conditions outlined in the Environmental Requirements of the Commonwealth of Australia for the Operation of Ranger Uranium Mine (ERs) (Australian Government 1999). These outline environmental objectives which need to be achieved during the life of the mine and following close-out. A Mine Closure Plan (MCP) has been developed to underpin the mine closure activities. Given the timing associated with the closure actions and subsequent monitoring, and the long-term requirements of the mine's regulatory approval, it was considered important that the effect of climate change on mine closure activities was assessed. This enables any risks identified for the close-out period to be managed and longer-term risks to be brought to the attention of the permanent site managers (once these are determined).

The Ranger Mine is located 8 km east of Jabiru and 260 km east of Darwin. It is situated on Aboriginal land, and is surrounded by, but separate from, the Kakadu National Park. The mine is situated in the Magela Creek catchment with Magela Creek being the main creek within the Ranger Mine Project Area.

This report:

- Provides an overview of the future climate for the region;
- Outlines the first pass risk assessment process that was undertaken in 2020 (version 1 of this report, and in the 2023 update (versions 2 and 3 of the report), updates to the report are shown in blue text.
- Provides an overview of the risks identified and current and future management actions that are the responsibility of ERA during the mine closure; and
- Presents a brief discussion and a number of recommendations.

2 Climate Change in Northern Territory

Original (2020, version 1) text is black. Blue text shows changes in version 2 (2023 update).

Climate has been changing in the region in the recent past (Figure 2-1) and it is likely to continue in coming decades and centuries. The amount of change will vary by region throughout the Northern Territory (NT). The extent of climatic changes in the region depends on the amount of greenhouse gases in the atmosphere and whether these continue to increase. The timeframe being considered is also important as impacts of climate change are projected to increase with time. An overview of the future climate outlook for the region is provided in Figure 2-1. These projections are extracted from Climate Change in Australia Website developed by CSIRO and BoM (CSIRO and BoM 2015).

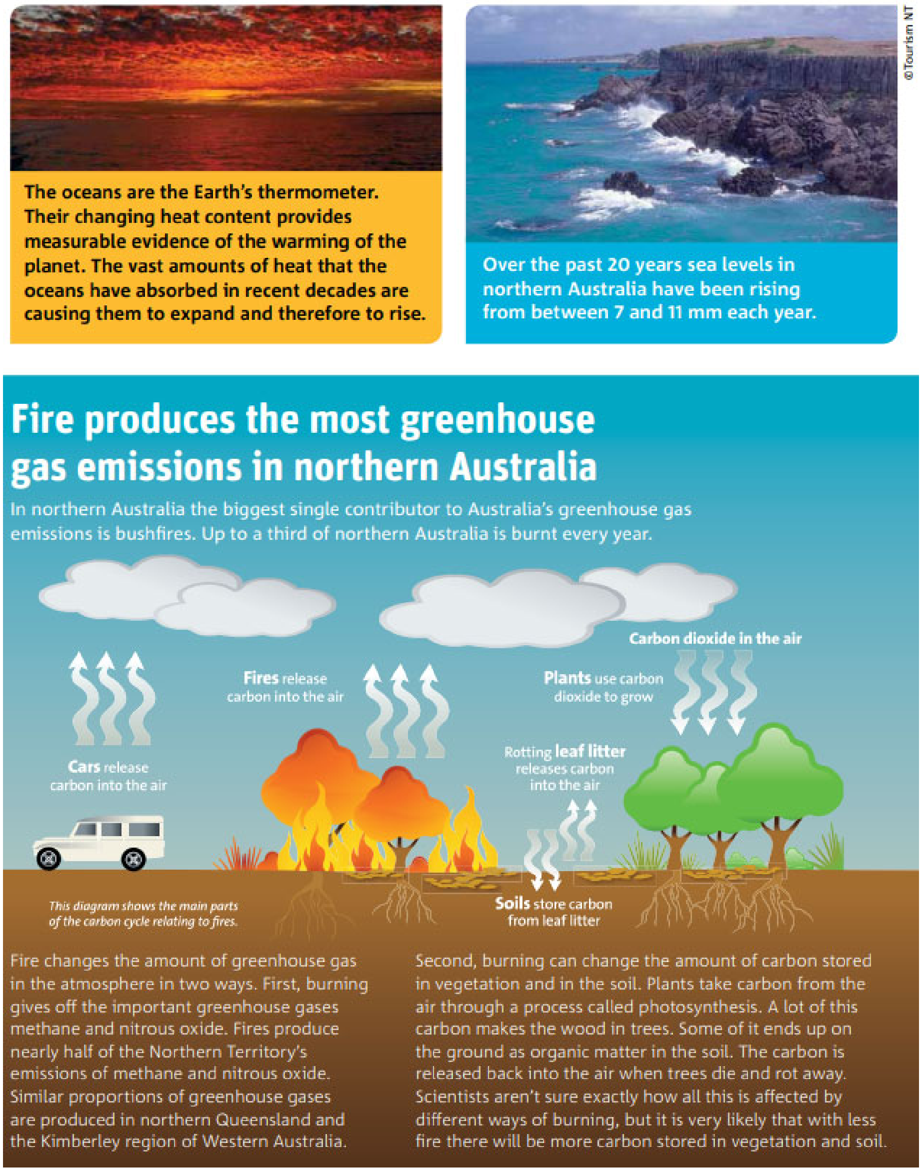


Figure 2-1 Recent climate change in NT. Source Climate Change in Australia's Top End (CSIRO 2014)

With changing climatic conditions, it is important to adapt ecological restoration techniques to make ecosystems more resilient to change. To increase the adaptive capacity of an ecosystem it is necessary to consider the genetic diversity and provenance of populations that are both currently present and being introduced as part of restoration. Climate adjusted provenancing involves enhancing a populations climate resilience by introducing a mix of genotypes from the climatic gradient biasing introduced individuals with adaptations in the predicted direction of climate change (Prober et al. 2015). (Since the 2020 version of this report it has been agreed that climate adjusted provenancing is not acceptable. It does not form part of the revegetation strategy).

CSIRO produced updated information for the Northern Territory in 2020 after the assessment had occurred. A comparison of the CSIRO data with that used in the 2020 assessment found that the differences would cause no material change to the assessment outcomes. The comparison is provided in Appendix F.

2.1 Air temperature

For the near future (2030), the annually averaged warming is projected to be between 1°C and 3°C above the climate of 1986–2005. Under a high emission scenario, by the year 2090, the projected range of warming is 2.7°C to 4.9°C above the climate of 1990–2009 (Figure 2-2). Summer and autumn will experience the greatest rise in temperature (Figure 2-3).

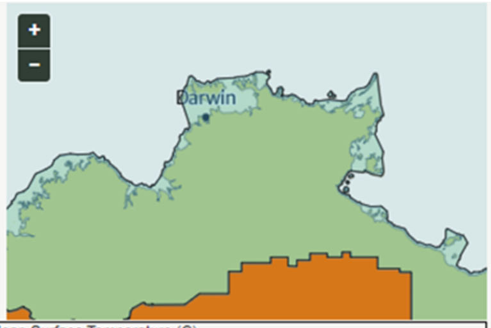
Very hot days will occur more frequently, and warm spells will last longer. Annual average number of days over 30°C will increase from current 343 days to 364 days (Figure 2-4) and average number of days over 35°C will increase from current 11 to 265 days, under a high emission scenario at year 2090 (CSIRO and BoM 2015).

MONSOONAL NORTH
CLIMATE FUTURES

Go back

Change scenario: RCP 8.5

Change time period: 2090



		Annual Mean Surface Temperature (C)			
		Slightly Warmer < 0.50	Warmer 0.50 to 1.50	Hotter 1.50 to 3.00	Much Hotter > 3.00
Annual Rainfall (%)	Much Wetter > 15.00			+ 3 of 48 (6%)	+ 3 of 48 (6%)
	Wetter 5.00 to 15.00			+ 3 of 48 (6%)	+ 6 of 48 (12%)
	Little Change -5.00 to 5.00			+ 3 of 48 (6%)	+ 11 of 48 (23%)
	Drier -15.00 to -5.00				+ 11 of 48 (23%)
	Much Drier < -15.00			+ 1 of 48 (2%)	+ 7 of 48 (15%)

Consensus	Proportion of models
Not projected	No models
Very Low	< 10%
Low	10% - 33%
Moderate	33% - 66%
High	66% - 90%
Very High	> 90%

Figure 2-2 Temperature and rainfall projections for Monsoonal North Climate Sub Cluster for year 2090 (Source Climate change in Australia Website CSIRO and BoM, 2015)

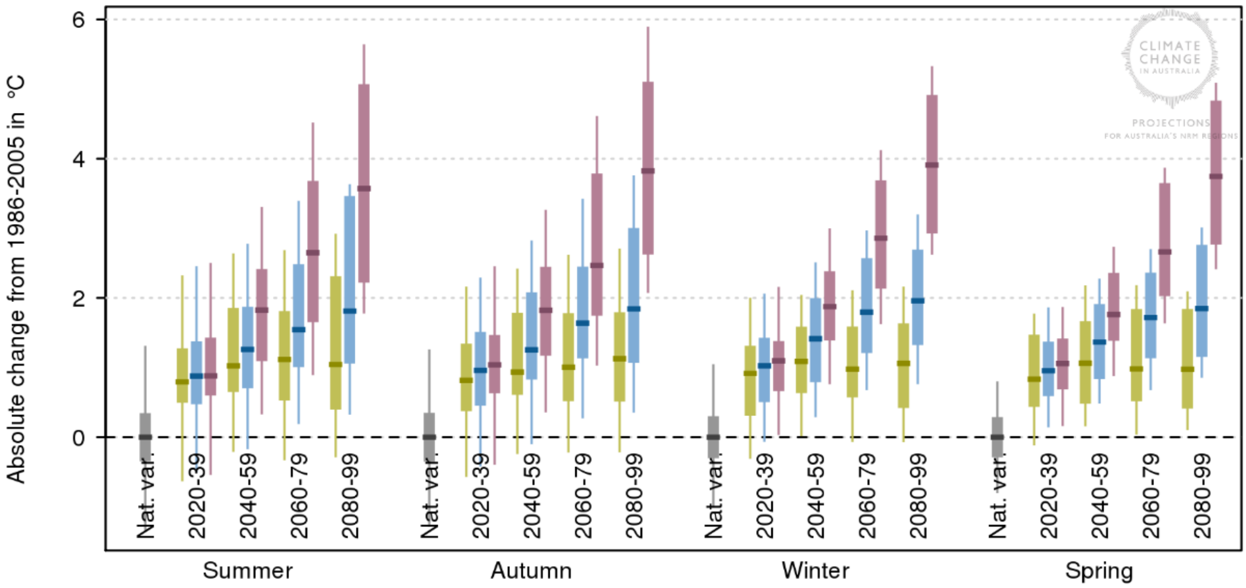


Figure 2-3 Projected change in seasonal maximum surface air temperature for 2090 (2080-99). Graphs show change in (from left) summer (wet season), autumn, winter (dry season) and spring. Anomalies are given in °C relative to 1995(1986-2005) under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. Boxes represent the 10th and 90th percentiles. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source CSIRO and BoM 2015.

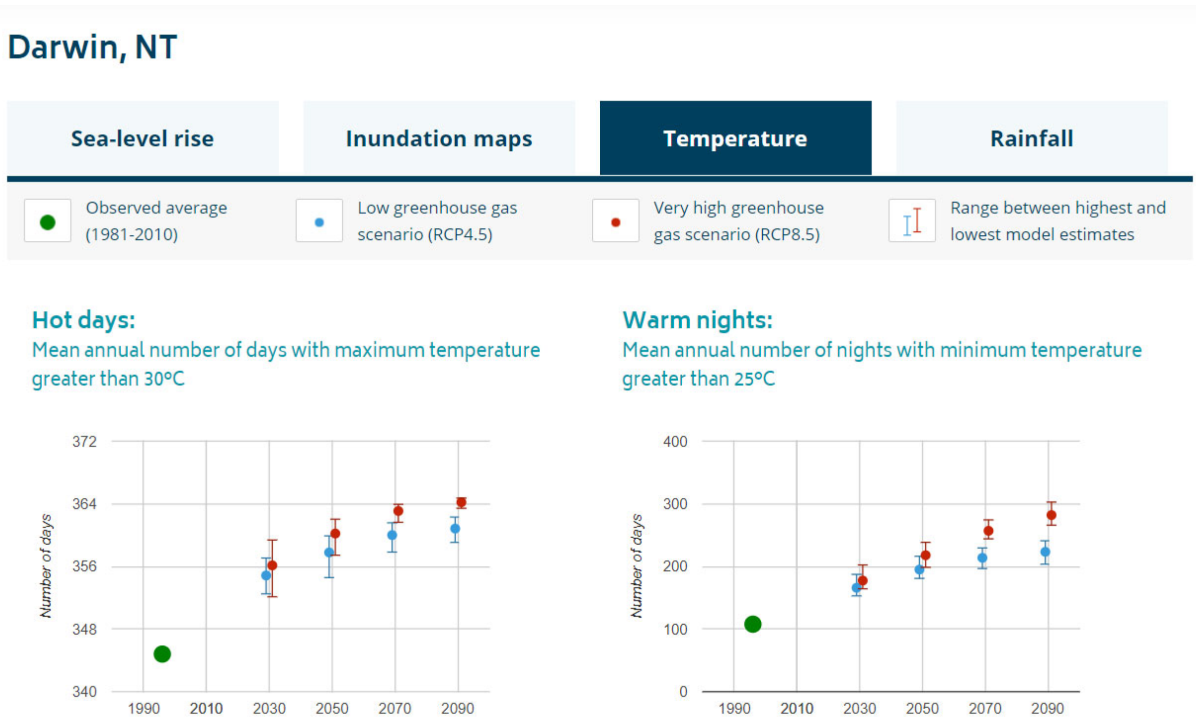


Figure 2-4 Temperature extremes (hot ways and warm nights) in Darwin. Source CoastAdapt (NCCARF 2017)

2.2 Rainfall

The direction of change in rainfall is uncertain for most of Australia. Natural variability is expected to dominate the state's rainfall patterns in the next two decades (Figure 2-5). Drought will continue to be a feature of some part the region's climate, though it is not clear whether or how the intensity or frequency of drought will change in the near term.

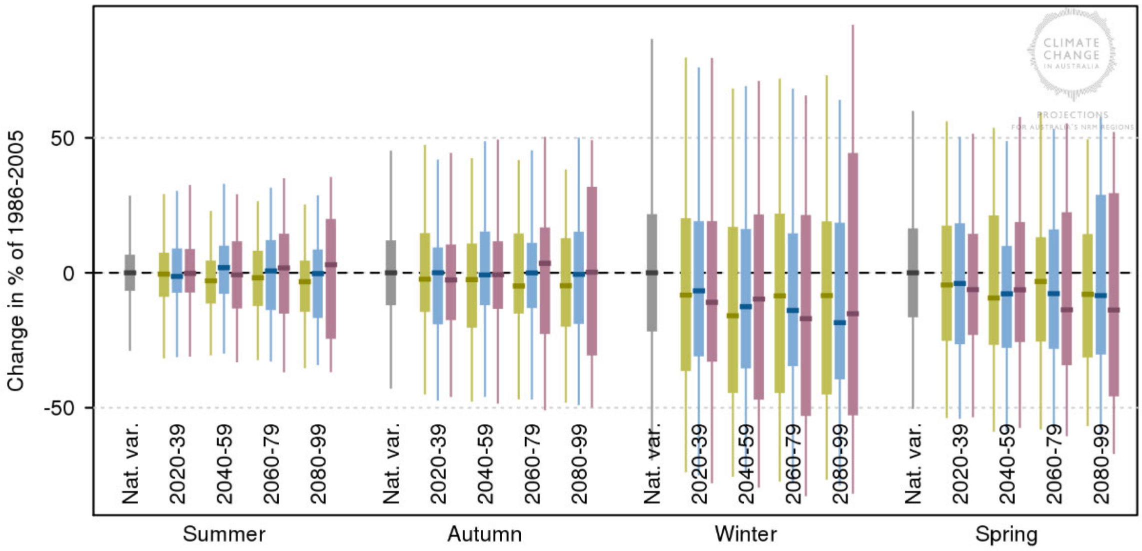


Figure 2-5 Projected change in seasonal precipitation for 2090 (2080-99). Graphs show change in (from left) summer [wet season], autumn, winter [dry season] and spring. Anomalies are given in % relative to 1995(1986-2005) under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. Boxes represent the 10th and 90th percentiles. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source: CSIRO and BoM 2015

SEASON	2030 RCP4.5	2090 RCP2.6	2090 RCP4.5	2090 RCP8.5	MODEL AGREEMENT 2090 RCP8.5 (PERCENTAGES SHOW FRACTION OF MODELS)
RAINFALL CHANGE IN NORTHERN AUSTRALIA (%)					
ANNUAL	0 (-9 to +4)	-4 (-12 to +3)	-1 (-14 to +6)	0 (-26 to +23)	*Low agreement in direction of change* (51% decrease), but substantial decrease (37%) & increase (32%) possible.
DJF	-1 (-8 to +8)	-2 (-16 to +4)	-1 (-18 to +8)	+2 (-24 to +18)	*Low agreement in direction of change* (56% increase), but substantial increase (42%) & decrease (29%) possible.
MAM	0 (-17 to +7)	-4 (-18 to +11)	-2 (-17 to +12)	-2 (-30 to +26)	*Medium agreement in little change* (37% of models), but substantial decrease (33%) and increase (31%) possible.
JJA	-5 (-26 to +16)	-8 (-41 to +16)	-14 (-35 to +20)	-15 (-48 to +46)	*Medium agreement in decrease* (67%).
SON	-4 (-26 to +20)	-7 (-32 to +13)	-7 (-32 to +27)	-13 (-44 to +44)	*Medium agreement in decrease* (64%).

Figure 2-6 Median and 10th to 90th percentile range of projected rainfall change (percent) for northern Australia super-clusters (compared to 1986–2005 baseline). Model agreement on projected changes is shown for 2090 and RCP8.5 (with 'medium' being more than 60 % of models, 'high' more than 75 %, 'very high' more than 90%, and 'substantial' a change outside the 10 to 90 % range of model natural variability). DJF is summer, MAM is Autumn, JJA is Winter, SON is Spring, Source CSIRO and BoM 2015.

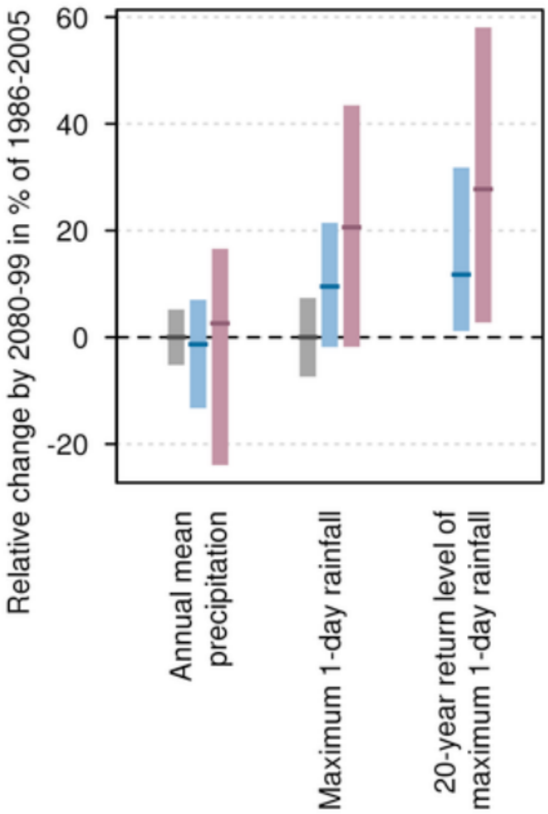


Figure 2-7 Projected changes in mean rainfall, intensity of annual maximum 1-day rainfall and intensity of the 20-year return value for the 1-day rainfall for the monsoonal north cluster. Changes are given in % with respect to the 1986-2005 mean for RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source Moise, Abbs et al. (2015)

2.3 Sea level rise

There is very high confidence that Australian sea levels will continue to rise. The rate will be faster during the 21st century than experienced over the past four decades. Projections for the Australian coastline by 2090 are projected to be as high as between 45-82 cm. However, some recent studies suggested that these projections may be conservative and a 2m sea level rise (global average) is possible towards the end of the century (Bamber, Oppenheimer et al. 2019). Higher sea levels will increase the risks of coastal hazards such as storm tide inundation in the coastal area of the region. It is also important to note that sea level will keep rising beyond 2100 and most recent update from IPCC (2019) provides some indication (see Figure 2-13). The most recent IPCC Report IPCC6 (Arias *et al* 2021) suggests that SLR of about 1.1m are possible by 2100. This figure is compatible with the SLR considered by Bayliss et al. (2018).

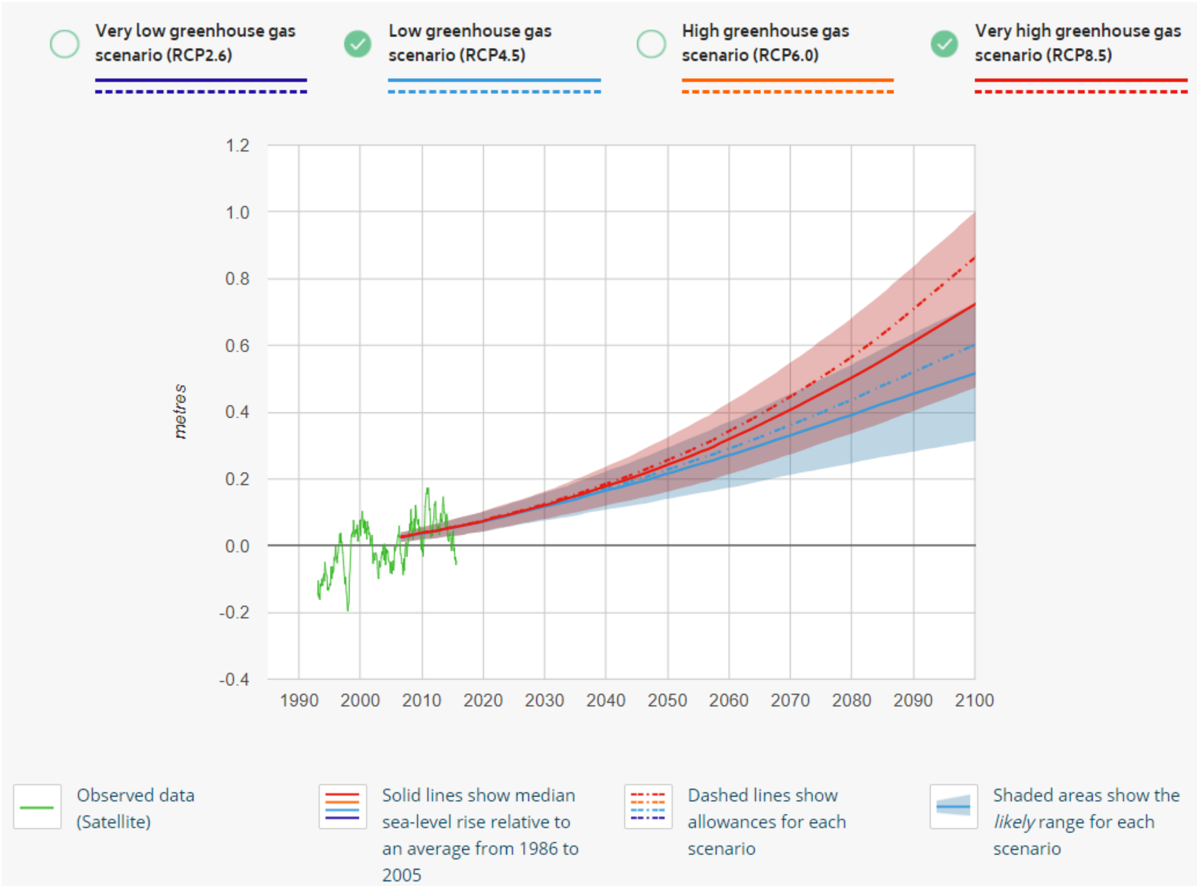


Figure 2-8 Sea Level Rise (SLR) around Darwin. Green line shows observed SLR from satellite observation, different coloured lines show SLR projections in the region under different emission scenarios. Source: CoastAdapt (NCCARF 2017)

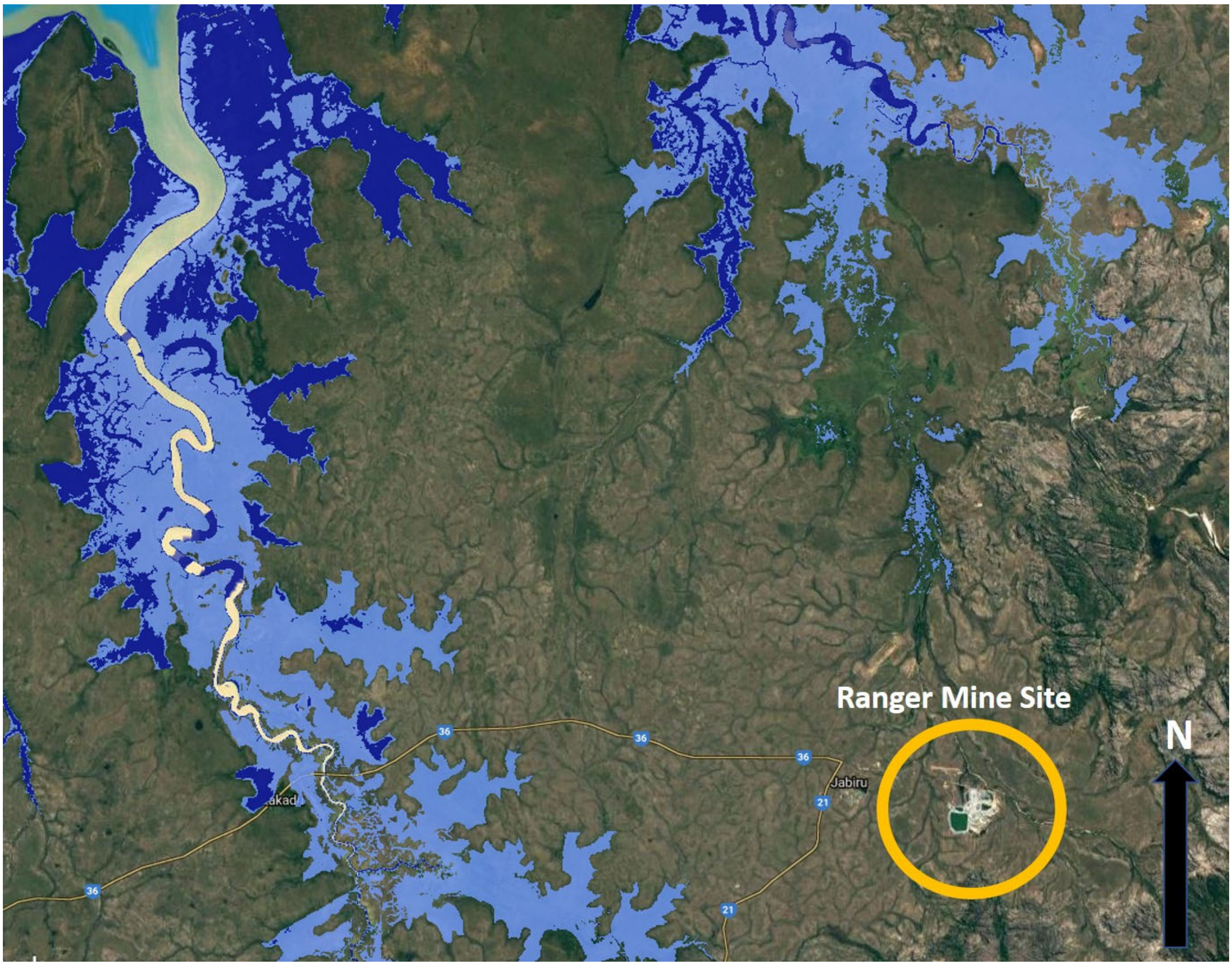


Figure 2-9 SLR inundation map showing high risk areas at year 2100 under a high emission scenario. Dark blue colour shows areas affected by current day high astronomical tide. Light blue colour shows areas affected by 0.74m rise. Source: Coastal Risk Australia Website Spatial Information CRC 2017.

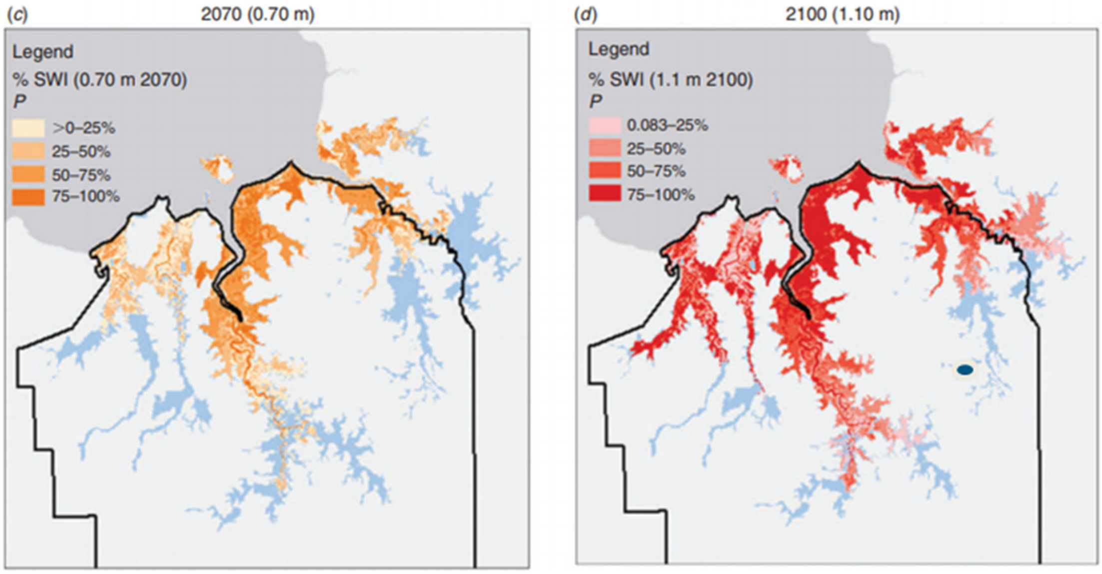


Figure 2-10 The simulated dry season (October tides) maximum extent and frequency of saltwater inundation (SWI) in the Kakadu region for 0.7 m (2070 projection) and 1.10 m (2100). Source Bayliss et al. (2018).

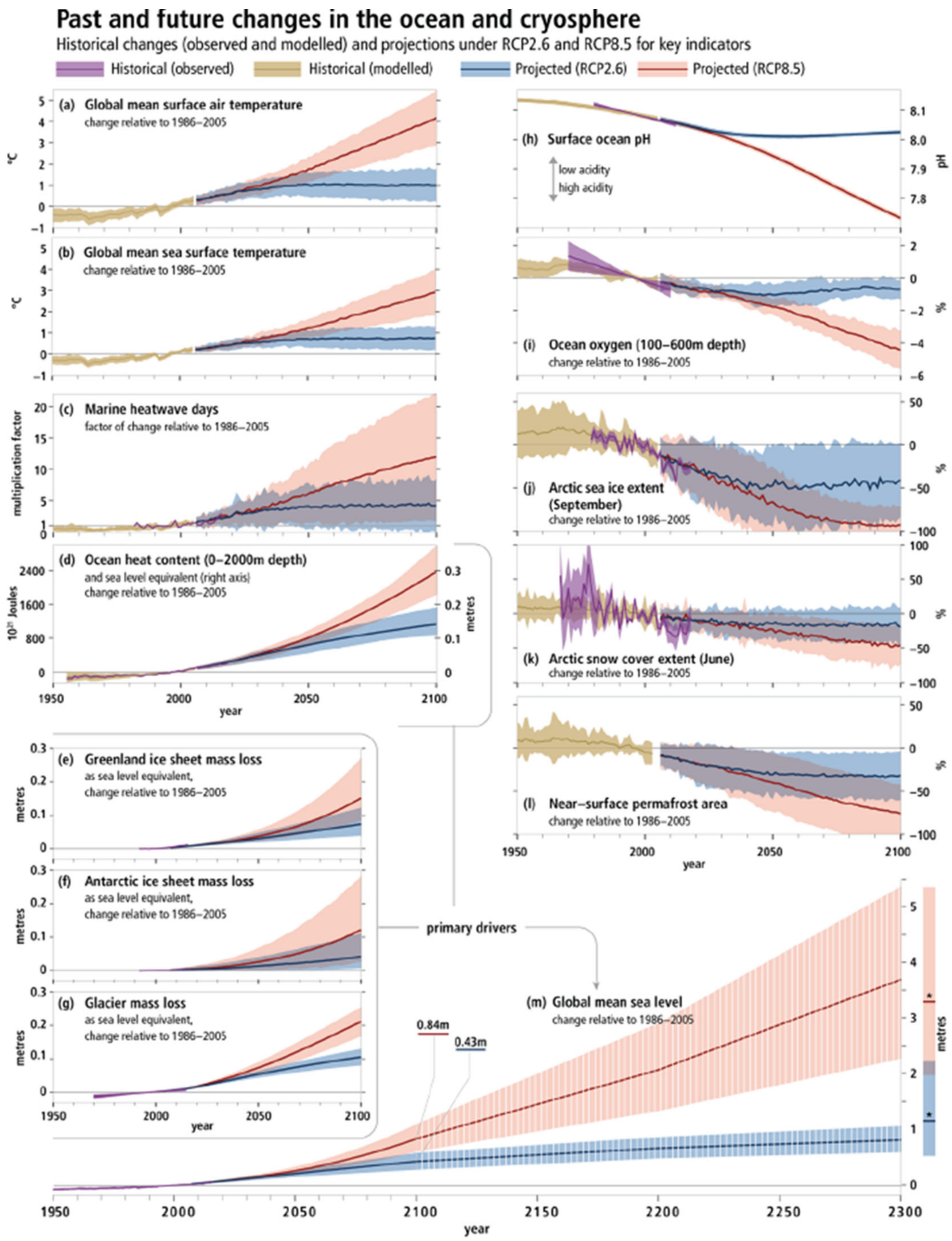


Figure 2-11 Recent update from IPCC indicating sea level rise rate beyond 2100. (IPCC 2019) (cryosphere is not relevant to the NT)

2.4 Ocean temperature and acidification

There is very high confidence that sea surface temperatures around Australia including NT will rise, with near coastal sea surface temperatures around Australia expected to rise by around 0.4-1.0°C by 2030, and by 2-4°C by 2090 under a high emission scenario (RCP8.5) compared to current (1986–2005) (CSIRO and BoM, 2015). In addition, the oceans will become less alkaline (more acidic) due to dissolved carbon dioxide in the ocean water (CSIRO and BoM, 2015).

2.5 Fire weather

Weekly bushfire frequencies in Australia increased by 40% between 2008 and 2013 (Dutta, Das et al. 2016) see Figure 2-12. This trend is likely to continue, and NT is projected to experience an increase in average and severe fire weather in the future. The increases in average and severe fire weather are projected to occur mainly in summer and spring. It is not expected that changes in rainfall will significantly impact the current climate cycle of region and there is high confidence that there will be little change in fire frequency (Moise et al. 2015). When fire does occur, there is high confidence that it will be more extreme (Moise et al. 2015).

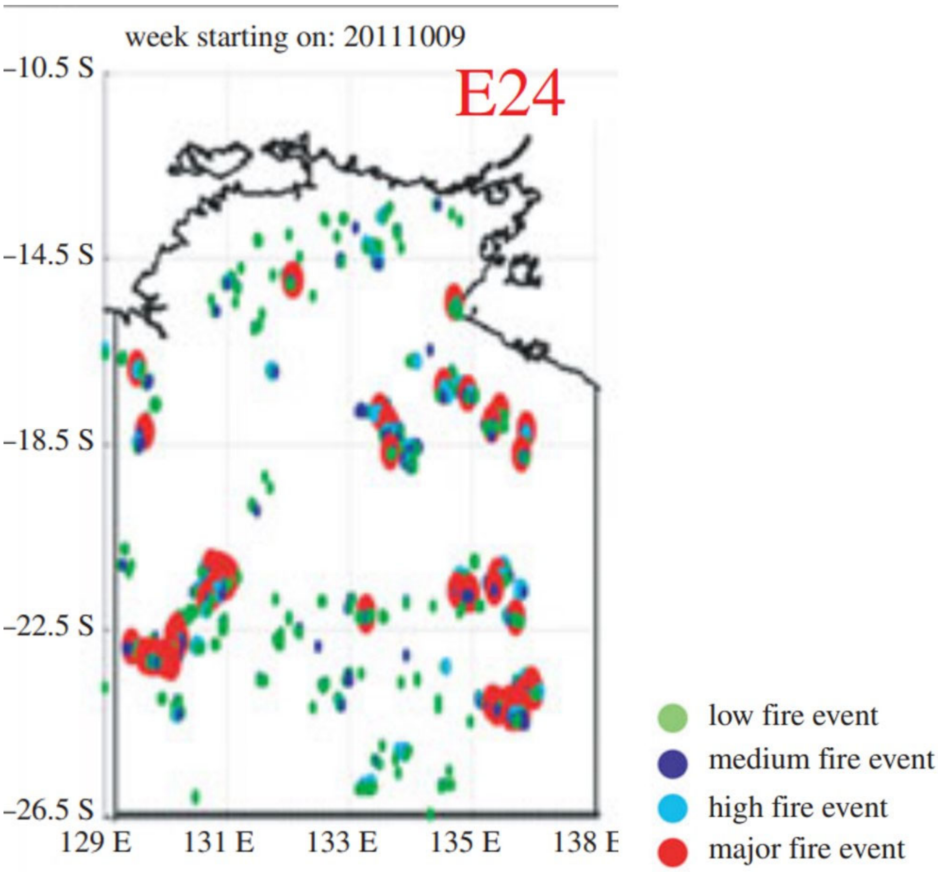


Figure 2-12 Representation of NT average weekly bush-fire intensity derived from NASA MODIS Active Fire data and NASA Burned Area data. E24 is NT bush-fire during September–October 2011 where 9000 km^2 burned in Barkly and Victoria river region. Source (Dutta, Das et al. 2016)

2.6 Evapotranspiration

Rate of evapotranspiration in likely to increase in all seasons with maximum mean increase of 16% in winter compared to 1986-2005 towards the end of the century under a high emission scenario (Figure 2-13). Noticeable uncertainties in the model projections are observed towards the end of century.

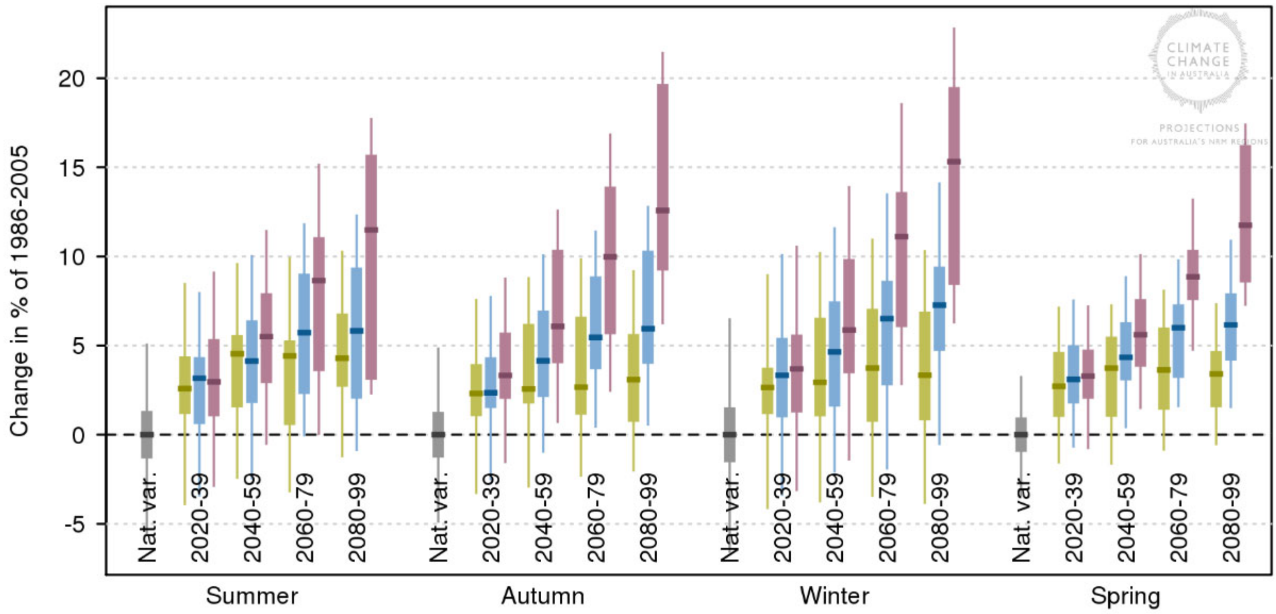


Figure 2-13 Projected change in seasonal evapotranspiration for 2090 (2080-99). Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in % relative to 1995(1986-2005) under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. Boxes represent the 10th and 90th percentiles. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source: CSIRO and BoM 2015

2.7 Humidity

Most of the models are suggesting that humidity will reduce under all climate change scenarios across all seasons with maximum reduction in summer (Figure 2-14).

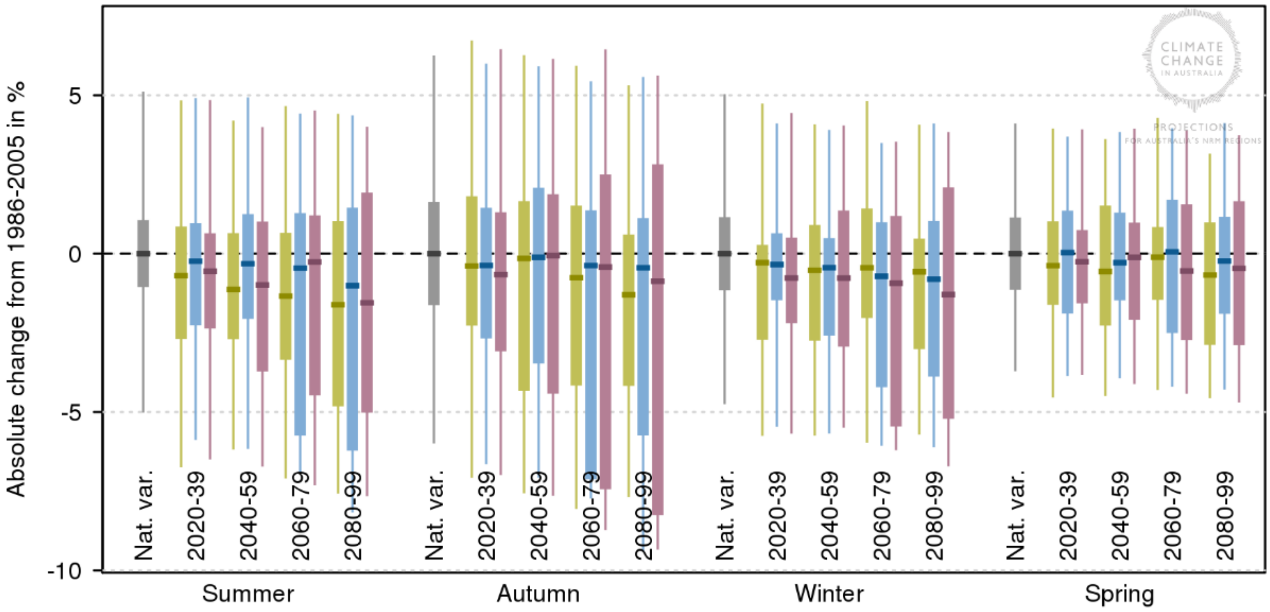


Figure 2-14 Projected change in seasonal humidity for 2090 (2080-99). Graphs show change in (from left) summer [wet season], autumn, winter [dry season] and spring. Anomalies are given in % relative to 1995(1986-2005) under RCP2.6 (green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. Boxes represent the 10th and 90th percentiles. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source: CSIRO and BoM 2015

2.8 Updated climate projections from IPCC6

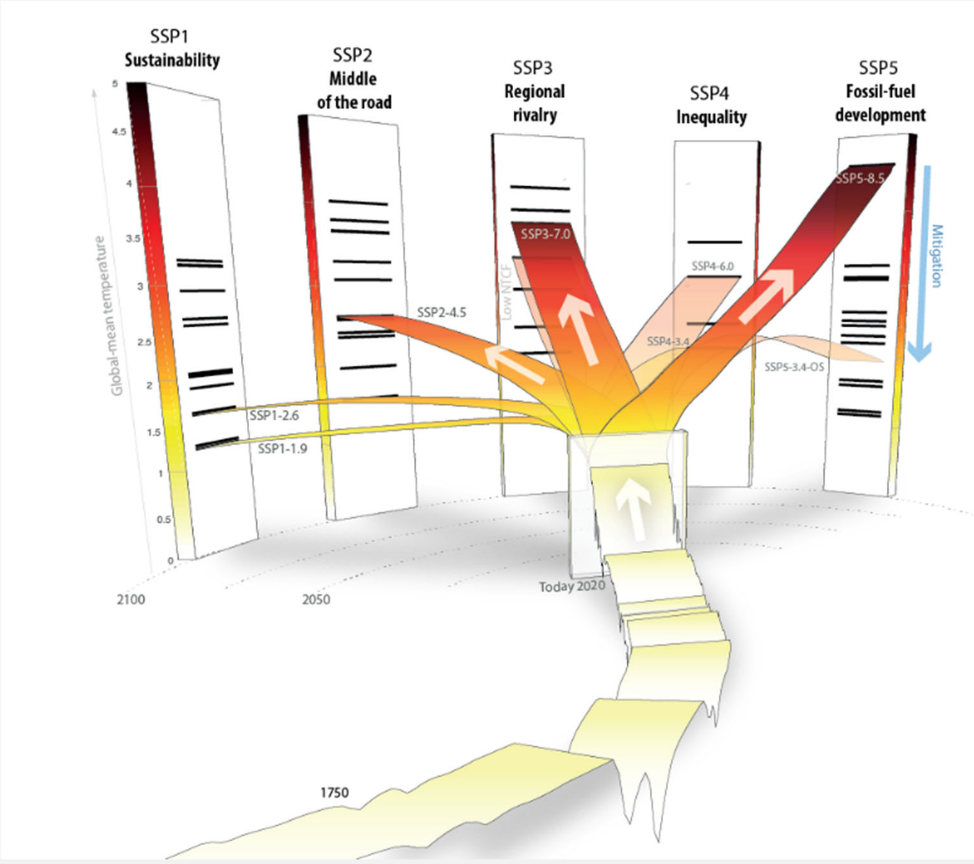
We reviewed the IPCC 6th assessment reports (Arial *et al* 2021; called hereafter IPCC6 or AR6) and the following information was derived for the Northern Territory. As discussed above, downscaled modelling has not yet been completed for Australia, and a broader regional overview was required at this stage. The following key points were determined:

- Human influence on climate change now an established fact
- The last five years 2016-2020 were the hottest on record since at least 1850.
- Climate change has driven detectable changes to the global water cycle. There is high confidence that there is an increase in the variability of the water cycle in most areas of the world.
- It is likely that global temperature change will reach 1.5°C higher between 2030 and 2050

The IPCC6 used a new set of scenarios called Shared Social Economic Pathways (SSPs) in their report. These scenarios use different gas constituents in the modelling than the previously used RCPs and because of this are not directly comparable to RCPs. The SSPs used are (Figure 2-15):

- SSP1 – 1.9
- SSP1 – 2.6
- SSP2 – 4.5

- SSP3 – 7.0
- SSP5 – 8.5



Meinshausen et al. (2020). The SSP scenarios and their five socio-economic SSP families. Shown are illustrative temperature levels relative to pre-industrial levels with historical temperatures (front light yellow band), current (2020) temperatures (white block in the middle), and branching of the respective scenarios over the 21st century along the different socio-economic SSP families.

Figure 2-15 The Shared Socioeconomic Pathways (SSP) used in the ICCP 6 reports (from Meinshausen et al. 2020).

The updated report (Arias *et al* 2021) suggested that the following would occur:

- Increase in % of precipitation in monsoon seasons
- Future: heavy precipitation and pluvial flooding in Northern Australia
- Increased fire weather throughout Australia
- Cyclones – fewer but stronger.

The table below (Table 2-1) compares some of the broader differences between AR5 (used for the IPCC 5th Assessment Report) and AR6 (used for the ICPP 6th assessment report; Arias *et al* 2021).

Table 2-1 Comparison of AR5 and AR6 climate findings

Climate Variable	What it means	AR5	AR6	Change between AR5 and AR6
TXx: annual maximum value of tasmax (°C) (intensity)	How hot it can get on a summer day (maximum temp)	4ºC higher	5.4ºC higher	Maximum temperature towards the end of the century is projected to be 1.4ºC higher in AR6
TNn: annual minimum value of tasmin (°C) (intensity)	How hot it can get on a summer day (minimum temp)	3.7ºC higher	4.7ºC higher	Minimum temperature on a hot day towards the end of the century is projected to be 1ºC higher in AR6
10-year ARI for tasmax average over Australia	What would be the intensity of a 1 in 10-year extreme hot days	45ºC	48.8ºC	8.5% higher intensity of 1- in 10year event is predicted in AR6
wsdi (warm spell duration index): annual count of days with at least six consecutive days when tasmax: >90th percentile (duration)	Heatwave days	132.3 days	166.1 days	Number of days with heatwave conditions towards the end of the century is projected to be 33 days more in AR6 compared to AR5
Rx1day: annual maximum value of daily precipitation (mm) (intensity)	How intensely it can rain	5.1 mm	5.1 mm	Annual Rainfall intensity is similar between AR5 and AR6 projections (towards the end of the century)
R10mm: annual count of days when precipitation ≥ 10 mm (days) (frequency)	How often it can rain heavily	0.8 days	0.5 days	Heavy rainfall frequency is slightly smaller in AR6 compared to AR5 (towards the end of the century)
10-year ARI for precipitation over Australia	What would be the intensity of 10-year ARI rainfall			The 10-year precipitation ARI increases by 15.5%
CDD (maximum length of dry spell): maximum number of consecutive dry days (i.e., with precipitation < 1 mm) (days) (duration)	Dry conditions	12.9 days	13 days	Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century)

3 Risk Assessment Approach

The risk assessment was based on leading practice recommended by the Intergovernmental Panel on Climate Change (IPCC 2014).

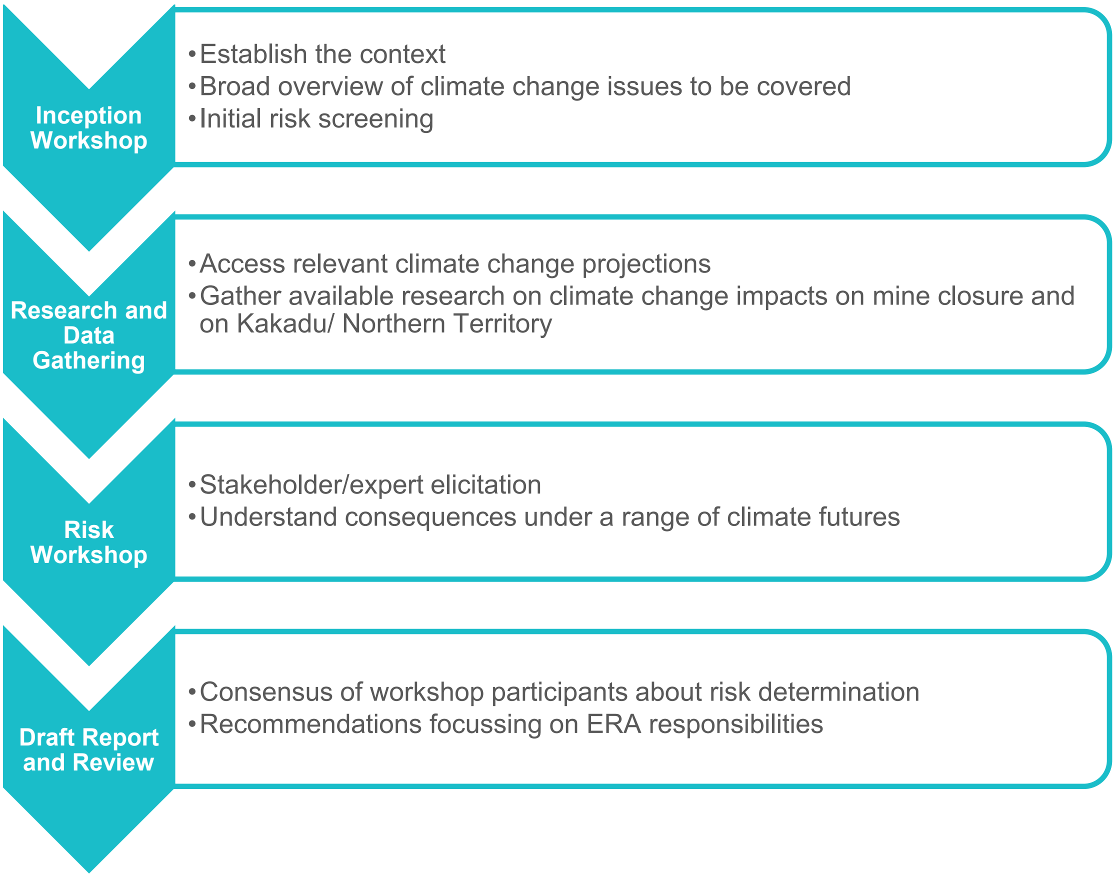


Figure 3-1 Risk Assessment Approach

3.1.1 Inception Workshop

An Inception Workshop was held with a range of stakeholders at the ERA office in Darwin (See Table A-1 for attendees). The workshop was used to confirm organisational objectives, priorities and interests. It also enabled identification of stakeholders to be involved in the first pass risk workshop.

The Inception Meeting was also used to undertake a first pass screening of many of the issues which supported targeted data collection and research to be conducted to support the First Pass Risk Assessment Workshop. Importantly the inception meeting enabled the project to be framed appropriately and for critical planning elements for the project to be determined.

These included:

- Climate change planning horizons;
- The different climate change scenarios that should be considered;
- Risk assessment methodology, scales and criteria;

- Data sources; and
- An initial scan of the impacts of climate change on mine closure activities and on the interaction of the mine with the surrounding park.

3.1.2 Research and Data Gathering

The initial phase had two components:

Climate change description for the Kakadu region. Available climate change information was collated from a range of sources to gain a comprehensive understanding of the best climate science available for the region.

Review of climate change and mine closure relevant to Ranger Mine. We collated relevant information from ERA about the Ranger Mine closure plan and approaches, so that we can focus the breadth of the literature search to relevant information only.

We obtained the risk assessment information and approach that is currently used by ERA to support their mine closure planning and activities. We adapted this for use in the first pass risk screening to ensure consistency in approaches and aid integration of outcomes into corporate risk processes.

A further phase in December 2022 (reported in January 2023) was undertaken following the release of the IPCC's 6th Assessment report (Arias *et al.* 2021), based on a new suite of models. This phase focussed on updating the original assessments by identifying any changes to the risk profile with the new information. We note that downscaled modelling for Australia has not been completed as yet and once this is done and available a further update may be required.

3.1.3 Risk Assessment

A day long risk assessment workshop was held with key stakeholders (internal and/or external) where initial findings were presented and the available expertise used to build on findings and develop appropriate adaptation responses (see Table A-2 for attendees). A further on-line workshop was conducted with bushfire experts to gather additional expert input into this critical aspect (see Table A-3 for attendees).

The climate change synopsis for the region and the results of the literature review was used as the basis for the assessment and planning process. Information generated at the Inception Meeting was also used to support discussions.

Workshop discussion helped to identify the consequences of climate change impacts on the mine site, closure operational activities, and on downstream influences. The likelihood of climate change affecting each attribute at different time steps was also discussed or assessed later based on climate change projections. The workshop enabled collation of any current or planned management actions to address consequences.

The information on likelihood and consequence collected at the workshop was used to populate a risk assessment tool which was used to calculate the risk-based scores (see Table 5.1 and 5.2).

Workshop participants discussed:

- The context of the risk assessment (workshop and project objectives, scale, timeframe, drivers for action, risk assessment methodology).
- The available climate change information (parameters, projections).
- Climate risks that have been identified through the literature review and assessment of the mine closure plan, and any approaches that have been identified to minimise impacts.

For the January 2023 update the risks identified in the initial phase assessment were reviewed by David Rissik and Michelle Iles (BMT) to identify how the risk findings might change in light of the updated information on climate impact drivers reported in AR6 (Arias *et al.* 2021)

4 Climate Change Risk Assessment Considerations

The discussion on the context of the risk assessment agreed the following points to frame the discussion.

4.1 What time frames to consider and why

- **Decommissioning and closure present day while staff on-site - 2026 ~2030**. Decommissioning is in progress. Closure commences at the completion of processing, currently scheduled to end in 2020, and will continue to 2026. Decommissioning, the general works associated with rehabilitating the site to an agreed standard of environmental protection and the re-contouring and re-vegetation of the final landform. The initial phase of the assessment considered this phase to be from 2020 to 2026. There is no longer a regulatory requirement for decommissioning works to be completed by January 2026. For the purposes of the December 2022 climate risk review this phase is assumed to continue to about 2030.
- **Post closure monitoring and maintenance phase 2030-2050**. This phase, previously called the stabilisation and monitoring phase is the period post-closure where additional vegetation infill planting occurs and the site is settling down and progressing towards the development of a long-term viable ecosystem and achievement of closure criteria. This phase may require a lot of initial management as the landform settles down, subsidence and erosion occurs and the vegetation becomes established. There will also be a number of sumps installed as silt and contaminant traps to act as passive water management techniques for the initial settling of the landform. These will require removal once they are no longer required. Post-closure monitoring will continue until it is demonstrated that the closure criteria have been achieved (including through satisfactory achievement of modelling outcomes or the point on the trajectory) and a close-out certificate is issued. At this point the site will be returned to the Traditional Owners who may or may not elect to have it incorporated back into Kakadu National Park. This period spans indefinitely from the time of issue.

  ERA has assumed in its 2020 mine closure plan that this would occur around 2050 and has scheduled monitoring and maintenance until then. The 2022 mine closure plan considers this phase to be 25 years. For the purpose of the December 2022 risk review the end date is still expected to be about 2050. By this time climate related changes are at a landscape scale. By this time climate related changes are at a landscape scale.
- **2100.** Best available projections.
- **Longer term.** There are little data and few projections available. Uncertainties are significant and it achieves little to include these in a risk analysis at this stage.

4.2 What scenarios to consider

The initial 2020 risk assessment considered:

- 8.5RCP: business as usual – worst case, but one the world is tracking at the moment.
- 4.5RCP: an optimistic scenario, but will help to give a view of the differences between a couple of climate futures.

It should be noted that projections do not differ between scenarios until after 2050.

In the January 2023 update we have used SSP5 and SSP2. These are the closest to the projections of 8.5RPC and 4.5RPC that were used in the initial risk assessment.

4.3 Spatial extent

- Keep spatial extent the same as the Mine Closure Plan (ERA, 2019).
- Exclude Jabiru township (although involved in the Inception Workshop).
- Airport not included in Mine Closure Plan.

This January 2023 update has no change to the spatial extent used in the original risk assessment.

5 Likelihood and Consequence Scales

The likelihood and consequence scales used for the ERA Closure Risk Register were considered appropriate for the risk assessment (Tables 5-1 and 5-2). The three most important consequence types considered were on-site environment, off-site environment and compliance. Health and safety consequences were also considered, particularly for the period when staff will still remain on site. Consequences for Community Trust, Stakeholders and Cultural Heritage were not considered in this risk assessment. These are essential aspects of successful mine closure and need to be considered and addressed by ERA through its engagement and outreach processes and programs.

Risks were classified by severity based on the combined likelihood and consequence scales (Table 5-3).

Table 5-1 Table showing likelihood scale used for the risk assessment.

	Likelihood				
	Rare	Unlikely	Possible	Likely	Almost Certain
Frequency Interval (Multiple Events)	<1/100 years	1/10 - 1/100 years	1/year – 1/10 years	2/year – 1/year	>2/year
Probability (Single Events)	< 0.1%	0.1% - 1%	1% - 10%	10% - 25%	> 25%

Table 5-2 Table showing consequence scales used for the risk assessment

Consequence Type	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Health	Reversible health effects of little concern. First aid treatment.	Reversible health effects of concern. Medical treatment.	Severe reversible health effects of concern. Lost time illness.	Single fatality or irreversible health effects or disabling illness.	Multiple fatalities or serious disabling illness to multiple people.
Safety	Low level short term subjective inconvenience or symptoms. First aid treatment.	Reversible injuries requiring treatment but does not lead to restricted duties. Medical treatment.	Reversible injury or moderate irreversible damage or impairment to one or more persons. Lost time injury.	Single fatality and/or severe irreversible damage or severe impairment to one or more persons.	Multiple fatalities or permanent damage to multiple people.
On-site Environment	Near-source confined and promptly reversible impact (typically a shift).	Near-source confined and short-term reversible impact (typically a week).	Near-source confined and medium-term recovery impact (typically a month).	Impact that is unconfined and requiring long-term recovery, leaving residual damage (typically years).	Impact that is widespread unconfined and requiring long-term recovery, leaving major residual damage (typically years).

Consequence Type	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Off-site Environment	Not applicable.	Near-source confined and promptly reversible impact (typically a shift).	Near-source confined and short-term reversible impact (typically a week).	Near-source confined and medium-term recovery impact (typically a month).	Impact that is unconfined and requiring long-term recovery, leaving residual damage (typically years).
Compliance	Non-conformance with internal requirement with very low potential for impact. Non-compliance with community commitment goes unnoticed by external party/parties, requiring minimal effort to correct.	Non-compliance with external or internal requirement with low potential for impact. Formal censure. Non-compliance with community commitment, requiring limited effort to correct.	Non-compliance with internal or external requirement with moderate impact. Moderate penalties for breach of legislation, contract, permit or license. Non-compliance with community commitment reported formally, with significant effort to correct.	Breach of license(s), legislation, regulation-high potential for prosecution. Contract breach-significant penalty. Systemic internal standards breach-high impact. Community commitment breach-high potential business impact-significant effort to fix.	Suspended or severely reduced operations imposed by regulators. Breach of community commitment results in direct loss of established consents with widespread secondary effects.

Table 5-3 Risk Severity Matrix

	Consequence				
Probability	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium
No Risk	No risk	No risk	No risk	No risk	No risk

6 Risk Assessment

The results of the risk assessment have been broken into three main groups. These are:

- Vegetation and associated management;
- Onsite and receiving water (ecosystem, quality and quantity); and
- Erosion and associated impacts.

Risk assessment results presented below show the risk associated with RPC8.5 scenario. The results for RPC4.5 are similar to those from RCP8.5 until 2050 which covers the stabilisation and post-closure monitoring phase. The AR6 modelling shows slightly greater divergence between the SSP scenarios by 2050 (see Figure 6-1 and Figure 6-2), but the differences are marginal at that time and for this report we are using a similar approach as with the RCPs. After 2050 the risks become landscape scale and apply to the broader region. This occurs at a time when it is assumed it is likely that the mine will achieve Close Out and transition to a different manager.

There is currently much discussion in the scientific literature about the levels of emissions that are expected into the future. Many experts suggest that the 8.5RCP is unlikely to occur because of declines in emissions and that 6.0 RCP is more likely. This is something to monitor and account for in any future assessments, but 6 RCP still leads to a temperature increase of 2-3 degrees which is dangerous climate change.

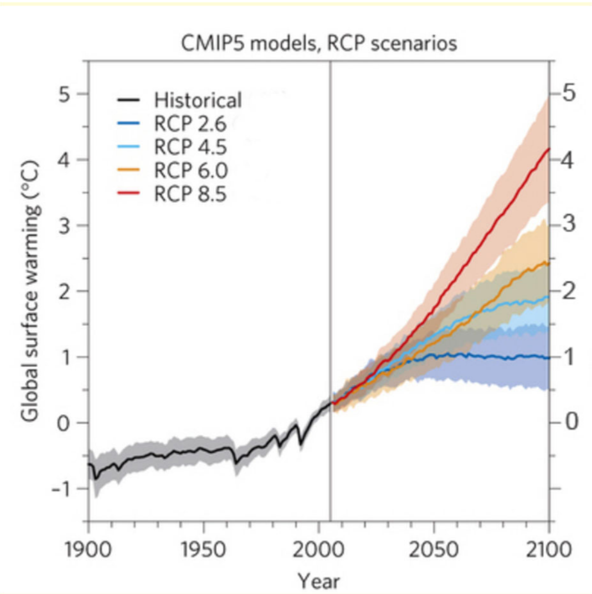
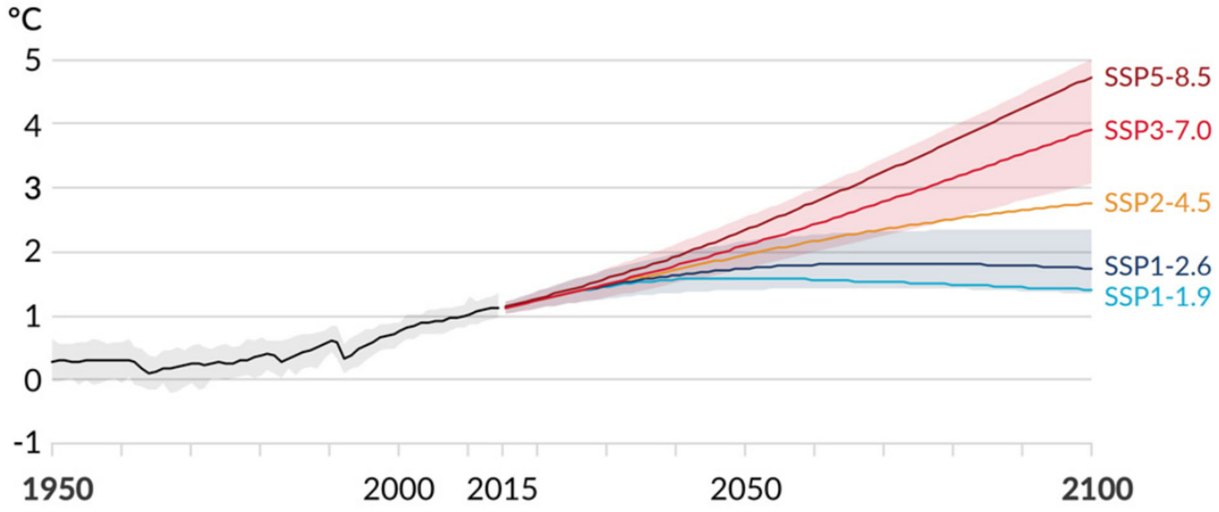


Figure 6-1 RCP scenarios from AR5; RCP4.5 and RCP8.5 were used in the 2020 risk assessment



Global surface temperature changes relative to 1850-1900, degrees C, under the five core emissions scenarios used in AR6. Source: IPCC (2021) Figure SPM.8a.

Figure 6 -2 SSP scenarios from AR6; SSP2 and SSP5 were used for the 2022 risk review

It is important that managers recognise that timeframes associated with identified risks are indicative and that conditions may materialise earlier than the times used in the assessment. If these risks materialise earlier additional management actions may be required. This is particularly important for those risks which are being reduced because of active management onsite Once management ceases and climate continues to change, risks will increase immediately.

6.1 Vegetation and associated management

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	Increased temperatures and heat waves Maximum temperature towards the end of the century is projected to be 1.4ºC higher in AR6 Minimum temperature on a hot day towards the end of the century is projected to be 1ºC higher in AR6 8.5% higher intensity of 1- in 10year event (heat) is predicted in AR6 Number of days with heatwave conditions towards the end of the century is projected to be 33 days more in AR6 compared to AR5					
V1	2020: Risk that increased temperature and long hot and humid conditions will impact health and safety of staff involved in planting, management and maintenance and longer-term monitoring. 2023 update: AR6 forecasts hotter conditions than AR5 and these are already being felt. Increase risk classification for 2030 from low to medium. Stated controls remain relevant and effective. Risk in 2100 not applicable for mine workforce but is real and high for any field workers.	**(2020: Low)** **2023: Medium**	**Medium**	2020: No risk (workforce no longer on mine site) 2022 update: Risk is relevant to any people conducting field work. Inherent risk will be high but can be managed.	Heat impacts are recognised as a risk for the workforce and is being accounted for in the development of revegetation plans. There is the potential for night-time planting to ensure workers operate in safe climatic conditions. Mine workforces are generally adept at, and appropriately structured for, working at night which could help this to be achieved and will be considered if required. There is little long-term risk as by 2100, the period of intense activity has passed. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale.	Staff health specifically focussed on effects of high heat and high humidity should be monitored and the heat management plan should be adjusted as required. PPE may need to be changed overtime to be appropriate for conditions. The potential to use remote sensing, drones and other new technology for monitoring vegetation over time should be considered. This will assist to reduce any potential heat impacts on monitoring and maintenance staff.
V2	2020: Risk that changing climate will result in conditions unfavourable for target revegetation species and that vegetation communities will become unviable. 2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). More hot weather forecast in AR6. Risk managed in 2030. Risk could increase in 2050. Risk already classed as high for 2100. No change to 2020 risk classifications or recommendations.	**Low**	**Medium**	**High**	The current approach entails plant selection based on local species which are naturally resilient to high variation in climate variables and to ensure sufficient temperature tolerant flora are planted. Plant selection has included the plants which are better adapted for low water availability and have more likelihood of successful colonisation on rocky substrate. Includes a selection of hardy and adaptable species.	Maintain current approach. Monitor performance of revegetation actions and make adjustments as required. Monitor climate projections and ensure that new information is accounted for when selecting plant species for revegetation. Depending on performance, plant selection may need to focus on plants which occur in drier area of the NT.
Redundant risk	~~2020: Risk that changes to tree species will have flow on effects to fauna. If deciduous trees dominate, then hollow nesting species may be affected by the lower amount of shade that may eventuate.~~ 2023 update: SSB comment (Climate adaptation point 3b) says risk is redundant now as target ecosystem does not include introduction of new species. Remove risk.	~~**Low**~~	~~**Low**~~	~~**Low**~~	~~A range of taxa are being grown for revegetation, with all of them sourced from Kakadu National Park. This will allow for a mix of species which should help to reduce negative effects on fauna.~~ ~~Trees in the revegetated area will take some time to mature to provide any shelter for fauna.~~ ~~In the long-term the rehabilitated mine site will be managed by a different organisation following close-out. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure~~	~~The use of the revegetated areas by fauna could be monitored as part of the monitoring program, although the lower long-term risk reduces the priority for this substantially.~~

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
Redundant risk	~~2020: Risk that selecting vegetation more tolerant to dry conditions may have flow on consequences e.g. if trees drop leaves to cope with heat stress, ground cover gets impacted by sun and associated heat~~ 2023 update: SSB comment (Climate adaptation point 3c) says risk is redundant now as target ecosystem does not include introduction of new species. Remove risk.	~~Medium~~	~~Medium~~	~~Medium~~	~~A range of taxa are being grown for revegetation with the vast majority native to the area. This makes it unlikely that there will be an increase in impact to ground cover in the revegetated site compared with elsewhere in the surrounding area.~~ ~~In the long-term the rehabilitated mine site will be managed by a different organisation following close-out. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure~~ ~~Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale.~~	~~Ground cover extent and condition should be included as part of the monitoring program.~~ ~~The current active management planned for the site will be sufficient in the short term. Monitoring and associated management responses will ensure that the area is rehabilitating effectively and desired objectives are being achieved.~~
V3	Risks that temperature and excessive dry weather will affect early survival of revegetation. 2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). More hot weather forecast in AR6. Risk managed in 2030. Early survival period for revegetated sites passed in later time periods. Monitoring and maintenance may still occur in 2050. Risk already classed as high for 2100.	Low	2020: Medium 2023: High	High	Irrigation will be implemented to reduce the effects of drought on the revegetation activities. Presently identified that 200+ hectares will require irrigation. This will be done for 3-6 months but must be implemented with caution to reduce the potential for vegetation becoming less tolerant to low water and hotter conditions. Plants will be monitored, and any lost species will be replaced.	Implement currently planned approach and associated monitoring. 2023 update: Consider SSB comment (Future work point 2) “As a priority, SSB supports any modelling sensitivity analyses, including re-analyses based on updated IPCC predictions, for assessing sustainability of ecosystems established on the rehabilitated landform under extreme drought conditions (e.g. plant available water).
V4	Risk of longer, hotter dry periods impacting understorey growth rates and survival. 2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). More hot weather forecast in AR6. Risk managed in 2030 and remains high in later time periods. No change to 2020 risk classifications or recommendations.	Low	High	High	Early understorey growth and survival will be monitored and remediated as required during the management period. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure	Implement currently planned approach and associated monitoring 2023 update: Consider SSB comment (Future work point 2) “As a priority, SSB supports any modelling sensitivity analyses, including re-analyses based on updated IPCC predictions, for assessing sustainability of ecosystems established on the rehabilitated landform under extreme drought conditions (e.g. plant available water).
V5	The risk of weed encroachment from the mine site into Kakadu Park increasing as invasive species have a higher competitive advantage in changing climates. 2023 update: The mine site is not potentially a greater source of propagules than the surrounding environment so change likelihood to unlikely and risk for 2100 to Low (see SSB comment Report findings 1c).	Low	Low	2020: Medium 2023: Low	Weed risks are identified in the ERA risk register. Weeds will be managed on site as part of the active management period and then monitored over time. This reduces potential for spreading into the main park. Successful achievement of the agreed closure criteria will mean that the rehabilitated mine site will be no more susceptible to weeds than the surrounding environment.	Implement currently planned approach and associated monitoring Weed encroachment should be assessed as part of the monitoring program.

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
					The mine site is not potentially a greater source of propagules than the surrounding environment. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure	
V6	Risk of increase in pests or diseases, such as myrtle rust, affecting vegetation on the rehabilitated site. 2023 update: Climate stress is increased under AR6 compared to AR5. Plants will be less resilient so risk of pests and disease impacting vegetation survival could increase. Stated controls are still relevant and expected to be effective. No active controls in 2100 but risk already rated High. No change in 2020 risk classification.	Medium	Medium	High	During the closure period any impacts to vegetation from pests or diseases will be managed through the Revegetation Adaptive Management Plan. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure. In the long term this will be managed by an organisation identified through consultation with key stakeholders.	The Ranger Revegetation Adaptive Management Plan shall include actions that can be implemented to ensure that planted vegetation is resilient until they are properly established.
V7	Risk that higher temperatures coupled with longer drier periods will impact soil biota and affect nutrient cycling. 2023 update: drought conditions similar AR5 and AR6 but temperatures are higher. Increase risk classification to medium in 2100.	Low	Low	2020: Low 2023: Medium	This is a particularly important issue during the planting phase and is specifically addressed as part of the secondary introduction strategy (where sensitive plant species are held back until site conditions are improved such as litter and shade from establishment of initial introduction species) and also the potential litter islands introduction strategy which will introduction local soil biota to further colonise the landform. Unlikely to be an issue in the long term once plants are established.	Implement currently planned approach and associated monitoring.
	Cyclone and intense storms 2023 update: Annual Rainfall intensity is similar between AR5 and AR6 projections (towards the end of the century) Heavy rainfall frequency is slightly smaller in AR6 compared to AR5 (towards the end of the century) The 10-year precipitation ARI increases by 15.5% Heavy precipitation and pluvial (rain related) flooding in Northern Australia Cyclones – fewer but stronger.					
C1	Risk of cyclone damage to vegetation planted as part of mine rehabilitation. 2023 update: Heavy precipitation and stronger cyclones expected under AR6. Likelihood unchanged in 2030 and stated controls remain valid for 2030. Later periods already classified as high risk. No change to 2020 risk classifications	Medium	High	High	Revegetated areas will be monitored and impacts due to cyclones will be remediated as required during the active management period. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale. In the long-term this is a risk for the whole	Implement currently planned management approach and associated monitoring

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
					of Kakadu and is not related to the mine closure	
C2	Risk that leaf litter will increase as a result of intense winds, increasing bushfire risk and potentially leading to water column deoxygenation if washed into waterways. 2023 update: Heavy precipitation and stronger cyclones expected under AR6. Likelihood and consequences unchanged. Risk is landscape scale. Fire and water management in 2030 period effective controls for on the minesite. No change to 2020 risk classifications.	Low	Medium	Medium	This risk is not a mine closure related risk, and any effects would be at a park-wide scale. No specific management plans in place and none proposed.	
	Bushfire 2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century).Increased fire weather throughout Australia in AR6 compared to AR5.					
B1	Risk that climate-driven increased extent of ground cover planted during restoration will increase the fuel load and increase fire risk. 2023 update: Increased fire weather predicted in AR6. Risk is driven by increased fuel loads. Likelihood and consequences unchanged for 2030, later periods already classified as high risk. Controls as noted remain relevant and important. No change to 2020 classifications or recommendations,	Low	High	High	A good level of ground cover in the revegetated areas is an objective of the rehabilitation of the mine and any bushfire activity during the closure and monitoring period will be managed as part of the Revegetation Adaptive Management Plan. Following close out, climate-driven increased risk of bushfire will be a broader landscape management issue Fire risks are already identified in the ERA risk register and management plans for the post-closure period and for the longer-term are being developed in the Revegetation Adaptive Management Plan.	The Ranger Revegetation Adaptive Management Plan shall include monitoring and management actions to manage this risk during the post-closure period. Note that rocky revegetation areas (waste rock sites) will have lower ground cover and a correspondingly lower risk of increased fire intensity.
B2	Risk that exotic grasses will become established following bushfires 2023 update: Increased fire weather predicted in AR6. Controls as noted remain relevant. No change to 2020 classifications or recommendations.	Low	Medium	High	Establishment of exotic grasses after any bushfires will be monitored and managed over the closure period. Following close out, increased risk of weed encroachment and associated management will be a broader landscape management issue	The Ranger Revegetation Adaptive Management Plan shall include monitoring and management actions to manage this risk during the post-closure period.
Redundant risk	~~Risk that vegetation which includes a mix of species better adapted to survival on waste rock sites will be more susceptible to fire.~~ 2023 update: Risk removed based on SSB comment Climate change adaptation 3d; target ecosystem uses local species, this risk is redundant and should be removed.	~~Low~~	~~Low~~	~~Low~~	~~Any climate-adaptable, hardy species shall be selected from the KNP and will be generally subject to a similar overall fire regime. The different taxa will not increase the risk of bush fire, nor be more susceptible than species from agreed reference ecosystems in revegetated areas.~~ ~~Ground cover in rocky dry areas will have slow growth rates and likely not have high fuel loads.~~	~~Any marginal risk will be managed as part of on-site fire management by ERA until handover.~~
B3	Risk that length of the potential burning season will decrease as a result of a changing climate which may increase the risk of inappropriate burning regimes or wildfires.	Low	2020: Medium 2023: High	High	A fire management plan will form an important part of the Ranger Revegetation Adaptive Management Plan for post-closure period.	Fire management plan to be developed and implemented in partnership with the Mirarr People and be based on Traditional Knowledge.

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). Likelihood unchanged in 2030, increased in 2050 increasing risk to High.					After close-out, the fire management regime should continue, but this is outside of the remit of ERA. This risk is landscape in nature and will be similar across the Kakadu area.
B4	Risk that fire severity will increase over time as a result of increased heat and evapotranspiration. This may lead to increased tree mortality. 2023 update: AR6 reports increased fire weather compared to AR5. Likelihood (and risk) unchanged in 2030. Already identified as high risk in 2050 and 2100. Controls remain effective for 2030. No change to 2022 risk classifications.	Low	High	High	A fire management plan will form an important part of the Ranger Revegetation Adaptive Management Plan for post-closure period. Impacts to revegetation will be remediated as required.	Fire management plan to be developed and implemented in partnership with the Mirarr People and be based on Traditional Knowledge. Fire Management Plan should include a focus on wet season burning. This helps to reduce fuel loads without risk of fires getting out of control. Also helps with controlling nuisance species such as spear grass. After hand-over, the fire management regime should continue, but this is outside of the remit of ERA. This risk is landscape in nature and will be similar across Kakadu
B5	Risk that severe fires and associated tree mortality impacts faunal communities. **Note**: Severity will increase as the revegetation matures and develops hollows and other habitat features preferred by fauna, attracting more animals into the area. Also, as the potential for more intense fires increases. 2023 update: AR6 reports increased fire weather compared to AR5. Risk will likely be realised. Consequences (and risk) unchanged in 2030 and 2050. Increased likelihood in 2050 doesn't change risk. Already identified as high risk in 2100. Controls remain effective for 2030.	Low	Medium	High	A fire management plan will form an important part of the Ranger Revegetation Adaptive Management Plan for post-closure period	Fire management plan to be developed and implemented in partnership with the Mirarr People and be based on Traditional Knowledge. After hand-over, the fire management regime should continue. This risk is landscape in nature and will be similar across Kakadu.
B6	Risk that when active mine closure management ceases after close-out, reduced activity on the mine site will result in increased fire potential because of less active on-site management. 2023 update: Risk as stated is caused by reduction in active management rather than change in climate impact driver. Active management still expected in 2030 and 2050. Management not expected to be under ERA control in 2100 and may be reduced if resources are constrained. No change to 2020 risk classifications	Low	Medium	Medium	Resilience of the revegetated ecosystem to a suitable fire regime is one of the closure criteria that must be met prior to close-out. Subsequent implementation of the fire management plan to be developed with the Traditional Owners will be the responsibility of appointed land managers for the area. No planned management by ERA after close-out.	Fire management plan to be developed as described above.
B7	Risk that people living, working or visiting Kakadu will be affected by any increased bushfire. 2023 update: Increased fire weather throughout Australia in AR6 compared to AR5. Unchanged for 2030. Now possible in 2050; risk increases to Medium. Now likely in 2100; risk increases to high.	Low	2020: Low 2023: Medium	2020: Medium 2023: High	Landscape risk that is not increased or influenced/impacted by mine closure	Fire management plan to be developed as described above.

6.2 Onsite and receiving water (ecosystem, quality and quantity)

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	Increased temperature, reduced rainfall, evapotranspiration 2023 update: Maximum temperature towards the end of the century is projected to be 1.4ºC higher in AR6 Minimum temperature on a hot day towards the end of the century is projected to be 1ºC higher in AR6 8.5% higher intensity of 1- in 10year event (heat) is predicted in AR6 Number of days with heatwave conditions towards the end of the century is projected to be 33 days more in AR6 compared to AR5 Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). Evaporation expected to be higher given increased temperatures Note that although these changes are not caused by the mine, changes to climate impact drivers could act as cumulative stressors in the presence of mine-derived contaminants					
W1	Risk that increased evaporation leads to an increase in contaminants washed into onsite and receiving water during the first flush. A "dry" wet season could mean greater loads into billabongs which do not then flush out. 2023 update: Higher temperatures under AR6 produce higher evaporation. Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). Active water management occurring until 2030. Dry wet season will affect concentrations in billabongs, but billabongs receive backflow before discharging to the creek. This isn't expected to change but should be modelled as recommended. No change to 2020 risk assessment findings.	Low	Medium	High	Current modelling is being done to understand hydrology and associated implications for discharge of contaminants. Water quality monitoring planned to 2050.	Water flow and water quality model runs need to be based on potential future conditions and be appropriately calibrated. Non-stationarity must be addressed and long droughts and long wet seasons that have not occurred in the past should be included in any modelling. 2023 update: This could be *based on the modelling of Cai et al. (2015)* as per SSB comment, Future work point 1a. Including greater consideration of climate change in modelling will help to understand any potential affects that may occur in receiving waters.
W2	Risk that connectivity of water courses will be reduced during longer, drier periods and that solutes will remain in smaller areas for longer. This could increase exposure of fauna and flora in the water courses which are unable to get away during periods of little or no connectivity. 2023 update: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). No change to 2020 risk assessment findings.	Low	Medium	High	Local species are adapted to annual periods of drying and associated evapo-concentration. Current modelling and risk assessments for receiving waters	Assessing the implications and likelihood will help to understand the issues and process. Likelihood will change over time and at present is considered to only increase after close-out. Models include this period.
W3	Risk that toxicity of contaminants will increase in higher temperature water. Guideline values are derived from 30ºC temperatures at present. 2023 update: Greater temperature increases expected under AR6 toward end of century. Changes in AR5 and AR6 minor for 2050. No change to 2020 risk classification.	Low	Medium	High	Review of local ecotoxicity based ammonia guideline values for temperature adjustment. Other contaminant guideline values aren't temperature dependant. Other stressors (dissolved oxygen and algal blooms) that are sensitive to temperature considered more important. Water temperature included in monitoring suite.	Mature, intact riparian vegetation will help mediate water temperatures through shading. Monitor temperatures of waterbodies during the closure period.
W4	Risks that longer hotter dry periods could dry out billabongs and expose previously unexposed acid sulphate soils (ASS) with implications for water quality and release of sediment bound contaminants. 2023 update: Length: Projections of drought conditions are similar between AR5 and AR6 (towards the end of the century). Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and	Low	Medium	High	Occurs naturally in the region so ecosystem has some resilience to occasional acid pulses. Surface water modelling will help to understand billabong water levels. Conceptual model and planned monitoring of current ASS conditions. Identification of post-closure ASS conditions planned based on solute transport models and conceptual model of ASS formation.	Greatest risk is in the longer-term following close-out. Modelling predictions include this timeframe. Drying and exposure cycles can't be controlled. Control of ASS sources already planned. 2023 update: Modelling of billabong behaviour to support future ASS risk assessment should consider information on climate impact drivers

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	AR6 minor for 2050. No change to 2020 risk classifications. (Note updated recommended action.)				Management plans for current ASS conditions to be developed. Mitigation options for current and future ASS to be assessed and management plans developed.	from AR6 or local downscaled predictions if available. 2023 update: Results of the current projects on ASS should be reviewed using a climate change lens to assess any implications for closure management.
W5	Risk that higher temperatures of water bodies may lead to lower levels of dissolved oxygen in the water column which can result in fish kills. 2023 update: Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and AR6 minor for 2050. No change to 2020 risk classifications.	Low	Medium	High	This is a risk for the whole of Kakadu and is not related to the mine closure. 2023: However, the changing climate could be cumulative stressors in the presence of mine-derived contaminants. SSB comment Report findings point 1d.	This should be included as a component of monitoring programs off and on-site. It is important to be able to differentiate between the causes of any fish kills that occur.
W6	Risk of increased algal blooms in water ways due to increased rates of production in higher temperatures. 2023 update: Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and AR6 minor for 2050. Increase risk classification for 2100.	Low	Medium	2020: Medium 2023: High	This is a risk for the whole of Kakadu and is not related to the mine closure. 2023: However, the changing climate could be cumulative stressors in the presence of mine-derived contaminants. SSB comment Report findings point 1d	This should be included as a component of monitoring programs off and on-site. It is important to be able to differentiate between the causes of any fish kills that occur.
W7	Risk that longer periods of increased water temperatures can lead to shifting species complexes, favouring thermophiles which are heat tolerant. 2023 update: Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and AR6 minor for 2050. No change to 2020 risk classifications. This risk is assessed 'in the absence of mine-related sedimentation'; refer to SSB comment Report findings point 1b.	Low	Medium	High	This is a risk for the whole of Kakadu and is not related to the mine closure. 2023: However, the changing climate could be cumulative stressors in the presence of mine-derived contaminants. SSB comment Report findings point 1d	This should be included as a component of monitoring programs off and on-site. It is important to be able to differentiate between the causes of any shift in species complexes
W8	Risk that higher evaporation rates may affect shallow billabongs and result in a loss of refuge habitat for species. 2023 update: Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and AR6 minor for 2050. No change to 2020 risk classifications. This risk is assessed 'in the absence of mine-related sedimentation'; refer to SSB comment Report findings point 1b.	Low	Medium	High	This is a risk for the whole of Kakadu and is not related to the mine closure. 2023: However, the changing climate could be cumulative stressors in the presence of mine-derived contaminants. SSB comment Report findings point 1d	This risk will need to be managed by the body responsible for the longer-term management of the area.
W9	Risk that increased temperatures will influence the sex ratios of reptile species such as crocodiles. 2023 update: Greater temperature increases expected under AR6 toward end of century (risk already classed as high then). Changes in AR5 and AR6 minor for 2050. No change to 2020 risk classifications.	Low	Medium	High	This is a potential climate change impact for the whole of northern Australia and not an issue related to mine closure. Riparian vegetation will provide shading to waterbodies on the rehabilitated mine site. Riparian vegetation is being monitored to inform ecosystem targets and plans. 2023: However, the changing climate could be cumulative stressors in the presence of mine-derived contaminants. SSB comment Report findings point 1d	Mature, intact riparian vegetation will help mediate bank temperatures through shading. This will help to reduce feminisation of crocodile offspring.

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	Sea-level rise 2023 update: The 2020 risk assessment used sea level rise information that are consistent with AR6. No review to 2020 risk classification required on basis of sea level rise data. Any updates reflect comments from SSB or to provide clarification.					
S1	Risk that sea-level rise will reduce the availability of freshwater refugia downstream of the mine site. 2023 update: This risk is assessed 'in the absence of mine-related sedimentation'; refer to SSB comment Report findings point 1b.	Low	Medium	High	Recognised landscape risk not altered by mine closure. Onsite waterbodies may become important freshwater refugia	Obtain details about available Lidar data for Kakadu. Sea-level rise modelling should be updated when new projections are released with IPCC 6 or based on release of intermittent reports such as the IPCC's Oceans and Cryosphere Report 2019. Consider the value of on-site billabongs in the context of reducing refugia sites in the region. Assess opportunity for provision of additional refugia sites on the mine-site (ecological engineering).
S2	Risk of wave action from inundated flood plain causing erosion of the mine site.	Low	Low	Low	Current modelling shows this to be no risk at all. Ruled out as an issue in INTERA and ERA (2017)	Update sea-level rise inundation models to account for updated climate change projections as they are made and reassess. Depending on outcomes, additional management actions may be required.
S3	Risk that sea level rise will cause floral and faunal species complexes to change and they will begin to be dominated by saline tolerant (marine) species which may have flow on effects to other important taxa. For example: Changing vegetation communities as a result of increased salinity may lead to a loss of those species which support nesting geese. Higher salinity waters may result in the loss of freshwater fauna such as freshwater turtles, amphibians.	Low	Medium	High	This is a recognised risk for the whole of Kakadu and is not related to the mine closure	No ERA management activities for the landscape risk necessary. See above action related to potential opportunity for provision of refugia on the rehabilitated site.
S4	Risk that higher sea-levels and more saline water in receiving waters may affect the ways in which surface water models are interpreted. For example: What is the effect of reduced flow into saline waters? At what point will the receiving water bodies no longer be low ionic strength with low solute levels and are current guideline values for ecosystem protection relevant/applicable then?	Low	Low	High		Update sea-level rise inundation models to account for updated climate change projections as they are made and reassess. Depending on outcomes, additional management actions may be required and ecological guideline values reviewed.
S5	Risk that increased cyclone damage to riparian zone degrades water quality. 2023 update: SSB comment Report findings point 1d: *should consider higher insolation of surface waters as a consequence (and hence water temperature interactions from above).* Risks of increasing water temperature are considered in W3, W6, W7 and W9.	Low	Low	Low	Natural resilience in the system. Regrowth rate quick compared to cyclone frequency. No ongoing water quality impacts recorded after previous cyclone. Water quality monitoring occurs during the post closure monitoring and maintenance phase. Risk becomes landscape wide post 2050. No additional ERA management needed.	

6.3 Erosion and associated damage

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
	Storm events 2023 update: Annual Rainfall intensity is similar between AR5 and AR6 projections (towards the end of the century) Heavy rainfall frequency is slightly smaller in AR6 compared to AR5 (towards the end of the century). The 10-year precipitation ARI increases by 15.5% Heavy precipitation and pluvial (rain related) flooding in Northern Australia Cyclones – fewer but stronger.					

Risk number	Risk statement	2030	2050	2100	Current and planned management	Recommended action
E1	Risk of erosion during storm events resulting ~~in minor gullying on land and~~ sedimentation in waterways. 2023 update: Heavy precipitation and stronger cyclones expected under AR6. Changes between AR5 and AR6 occur towards the end of the century. Risk classification is based on risk of sedimentation in waterways. 2030 stated controls remain valid. No change to 2020 risk classifications. Risk of gullying on the landform (without any mitigation) is very likely but unlikely to expose tailings (refer to SSB comment Report Findings point 3 and foot note)	Low	Medium	High	This risk is captured in the ERA closure risk register. The final landform is based on iterative landform design and landform evolution modelling and includes surface treatments and sediment control features. Erosion and gullying which occurs during the management period will be actively managed. ~~There are no steep slopes on the RPA which reduces potential for gullying~~[1]. 2023 update: erosion controls, establishing vegetation cover, monitoring and maintenance mitigate the risk in 2030 and 2050. Following close-out, any erosion management will be undertaken by the designated management authority.	2023 update: Consider SSB comment (Future work point 2) "As a priority, SSB supports any modelling sensitivity analyses, including re-analyses based on updated IPCC predictions, for assessing landform erosion characteristics under extreme wet conditions.
E2	Risk that intense storms will damage road network. 2023 update: Heavy precipitation and stronger cyclones expected under AR6. Changes between AR5 and AR6 occur towards the end of the century. Assumptions for 2100 and stated controls remain valid. No change to 2020 risk classifications.	Medium	Medium	Low	Road networks will be maintained during the closure period. Maintenance can be conducted by ERA during this period if required. Risks become low after close-out as roads will be no longer required. Any vehicular access will be managed by the designated management authority.	
E3	Risk of bushfires destroying riparian vegetation and leading to increased bank erosion when the wet season commences. 2023 update: Increased fire weather throughout Australia in AR6 compared to AR5. Active site management keeps risk low in 2030. Risk classification increased in later time periods.	Low	2020: Low 2023: Medium	2020: Medium 2023: High	This is considered a very low risk during the closure and post-closure monitoring periods. Bushfire control burns planned. Maintenance can be conducted by ERA during this period if required. Risk becomes landscape wide risk after about 2050 and will need to be managed (in consultation with the relevant manager at the time and KNP) at a landscape scale. In the long-term this is a risk for the whole of Kakadu and is not related to the mine closure	No actions recommended. 2023 update: Ensure fire management includes riparian zone fuel control. Undertake monitoring to identify at risk areas.

[1] SSB comment (Report Findings point 3) disputes the now struck out comment saying modelling shows risk of gullying is highly likely but risk of tailings exposure is low and suggests the classification for this risk should be reviewed. The risk classification is unchanged in the 2023 update. The risk is that gullying causes sedimentation of waterways. The risk of this occurring in the absence of management actions (inherent risk) would be higher. The risk classification considers residual risk, ie with the listed mitigation measures considered.

7 Discussion

Thirty-six risks were identified in the risk initial (2020) assessment workshops. These were divided into the following broad categories:

- Vegetation and associated management (19 risks).
  - 2023 update: three identified as redundant and removed, now 16 risks.
- Onsite and receiving water (ecosystem, quality, quantity) (14 risks)
- Erosion and associated impacts (three risks).

Figure 7-1 has been updated to reflect the 2023 updated risk numbers and classification.

In general, most risks were considered low (unlikely, low consequence) for the projected climate for 2030. Noting that this is the climate regime that is expected during the decommissioning and early post-closure period.

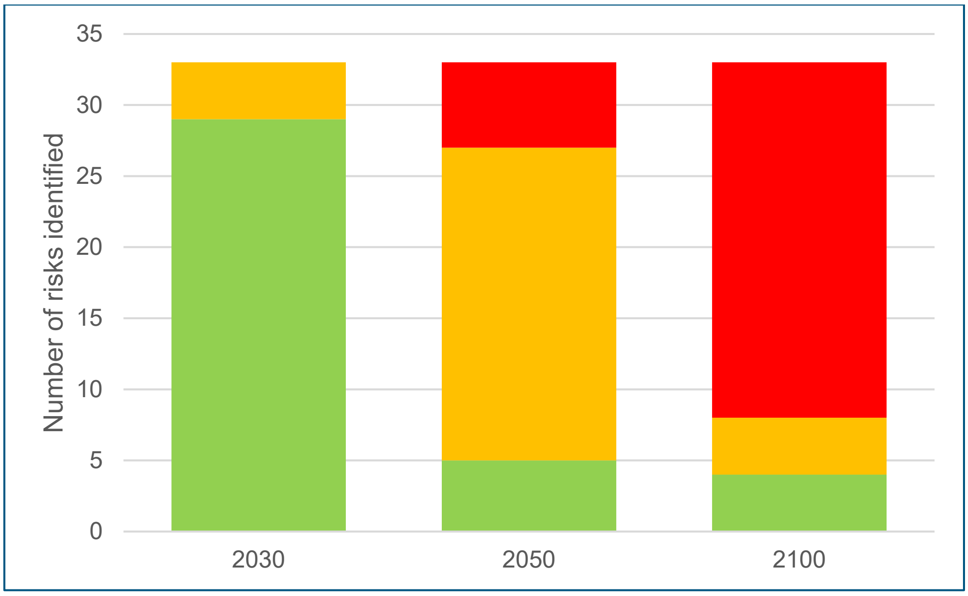


Figure 7-1 Number of high, medium and low risks identified for a RCP8.5 scenario over three time periods

Risks were greater for the climate projected for 2050 with a number of medium and high risks identified. Many of these risks are landscape risks that will be manifest across the broader landscape of Kakadu, but will be actively managed on the mine site as part of the management and monitoring period. This includes weed and fire management onsite and the replacement of vegetation that is lost as a result of drought, fire wind and other pressures. The exact timing of any impacts and the associated management requirements will be identified through monitoring and associated responses. Earlier impacts of climate change will require active management responses which may influence costs of management.

An important and relevant aspect of the process was input from groundwater specialists who undertook an assessment of whether groundwater flows would be likely to be affected by the changing climate. They recommended that as climate change influence on groundwater would be marginal no associated risks that should be included. INTERA 2021 stated *Climate change effects on the Ranger GW UA* [groundwater uncertainty analysis] *were directly addressed and judged to have little to effect on the predictive uncertainty in COPC loads to receptor creeks (Section 7.1). Climate change effects could prove to be more pronounced in the predictive SW modelling of COPC concentrations in creek waters*.

In the longer term between 2050 at the climate projected for 2100 when the effects of climate change are likely to become more extreme, a number of high risks were identified (high likelihood; major or catastrophic consequence). It is highly probable that these risks will be manifest after Close Out of the mine and will be spread across the whole of the Kakadu area, as such any adaptation is outside of the remit of ERA. However, it was agreed that successful implementation of the Ranger Revegetation Plan will result in an ecosystem on the mine site similar to that in the surrounding landscape and which is no more vulnerable to these risks than the natural landscape.

It is important to note that some or all climate change effects may occur earlier than currently projected timeframes and it is important to reassess the risk assessment results as new projections become available. These generally follow releases of information by the IPCC. The IPCC's 6th Assessment Report was released in 2022; the findings have been considered in this report.

The risk table presents risks driven by projections modelled as RCP8.5 and SSP5. Projections for the lower emission scenarios of RCP4.5 and SSP2 are very similar to those of RCP8.5/SSP5 until after 2050 when they diverge substantially (Figures 2.3- 2.7). As risks relevant to the Ranger Mine closure and where adaptation responses are the responsibility of the mine, we report on these above. Following handover, risks on the rehabilitated Ranger project area will be managed by the relevant authority which will be determined in consultation with the Traditional Owners of the area.

The effects of climate change on the broader Kakadu region, particularly from sea-level-rise has implications for the availability of freshwater and associated vegetation on the rehabilitated mine site. As sea-level rises and the characteristics of the water body and floodplain changes, many species will no longer be viable. They are likely to seek out refugia in areas upstream or higher up (such as on the rehabilitated mine site). There is potential that the mine closure could be planned or managed to meet those needs. This is outside of the remit of the current mine closure requirements and plan. It is recommended that this potential is considered together with stakeholders to determine any appetite, and if deemed desirable, to consider possibilities. It is important that monitoring of the rehabilitated area is associated with comparisons of control locations throughout Kakadu National Park. This will help to ensure that changes resulting from climate change that are landscape in nature are identified and reported.

7.1 Risk assessments and risk management

It is important to undertake an assessment of risk with consideration of a full risk management framework. This ensures that the risk assessment alone is not the outcome, and that actions are put in place to enable risks to be addressed. Selected risk management frameworks should be consistent with the international risk management standard ISO31000. Figure 7-2 is a risk management framework designed to underpin climate change adaptation in Australia. The risk screening process is generally undertaken at the outset of adaptation planning, enabling high risk areas to be identified, and determining where additional more detailed assessment may be required using more detailed risk assessment techniques. It is possible, as has been done in this project, to move into step 3 for certain activities and identify suites of actions that can be implemented immediately, while others may still require further detailed investigations before proceeding.

Many of the risks identified in this risk screening process are already captured in the ERA closure risk register. The ERA closure risk register will be updated to capture climate change as a cause for these risks, and to add additional risks and all of the actions identified.

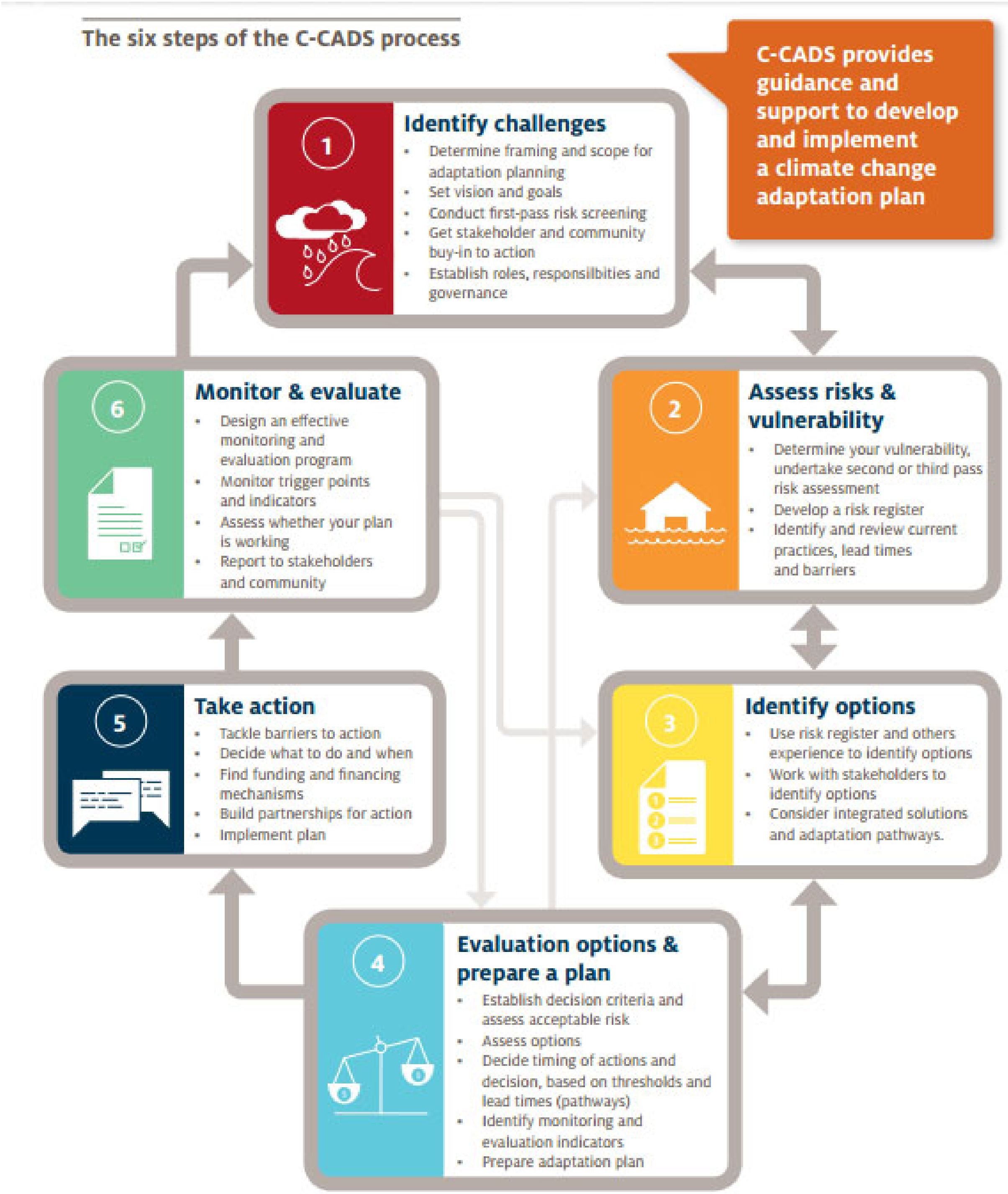


Figure 7-2 Adaptation risk management framework, identifying a process for identifying and managing climate related risk. Note: Risk screening is a component of an early stage of risk management planning (C-CADS is a framework produced by the National Climate Change Adaptation Research Facility (NCCARF)).

7.2 Conclusions and recommendations

Climate change is likely to have a significant affect across the Kakadu Park. Most impacts are likely to occur beyond 2050. Climate change has implications for the mine closure which will be actively managed. These are predominantly related to the revegetation and soil management on the site and will ensure that the site will be in a suitable condition for Mine Close Out Certification to be granted. In the longer term, most climate change risks are landscape in nature and will affect the entire park. Changes to the water bodies and hydrology of the system are likely to occur. These will be park wide, but local receiving waterways may be affected which may influence their susceptibility to discharge of contaminants. Further work to understand this is recommended.

Recommendations are made in Table 7.1 below (recommendations arising from the 2023 review are shown in blue text).

Table 7-1 Recommendations of climate change risk actions for Ranger closure. Note priorities are high (6 months – 12 months), medium (1-2 years) and low (2-4 years)

Recommendation	Priority (high, medium, low)	Estimated cost
Further water flow and water quality modelling to be undertaken to support a more detailed understanding of risks associated with contaminant discharge into receiving water bodies (note, this occurs when new mine closure scenarios are modelled). Following revised modelling a review of relevant climate related risks should be conducted, or the sensitivity of the model to these should be reviewed. Water flow and water quality model runs need to be based on potential future conditions and be appropriately calibrated. Non-stationarity must be addressed/assessed and long droughts and long wet seasons that have not occurred in the past, but which are likely in the future should be included in any modelling. This could be based on the modelling of Cai et al. (2015). The sensitivity of model outputs to new climate change information (eg new regional or IPCC data) should be reviewed.	High	Medium
Risks of climate change be fully embedded into the mine closure plan to ensure worker safety and impacts on revegetation works and monitoring are reassessed as more data and information becomes available	High	Low
Emerging climate change data and information for the Northern Territory and the Kakadu Region should be	Medium	Low/medium

reviewed and when available the climate change risk assessment should be updated.		
Alternatively consider having downscaling analysis conducted for the study area. • Future climate change risk assessments should consider cascading and compounding risks. For example: higher insolation of surface waters that may be a consequence	Medium	Low
of any reduction of riparian vegetation that may occur from other drivers such as bushfire or cyclones. • Future climate change risk assessment should assess risks of erosion and runoff of sediment that may occur during cyclones and large storms. Floods in Magela Creek may affect the eastern boundary of the rehabilitated mine (see Saynor et al., 2020), and such floods may be larger in future.	Medium	Low
Obtain details of available Lidar data for the region and ensure comprehensive data are available for the area to the north of the mine site. This will support any further sea-level rise modelling that is conducted.	Medium	Medium
Analysis of sea-level rise modelling to determine what level of sea-level rise is required for saltwater intrusion to reach the mine. Depending on results the climate change risk assessment may need to be revised.	Medium	Low
Sea-level rise modelling is redone as better LiDAR information becomes available. This will assist to determine the extent of loss of freshwater bodies in the Park and determine whether saline water is likely to encroach further towards the mine site (this is not considered to a mine closure related activity, but can assist to understand the role of mine water bodies as refugia).	Medium	Medium
Discussions about the role of water bodies on the mine site as refugia are held with the Traditional Owners and relevant management agencies, including discussion about resourcing and management.	High	Low
The monitoring of climate change conducted by CSIRO and BoM should be reviewed to better understand how climate change is tracking. Any rapid on-set of climate change will increase the likelihoods adopted for this risk assessment	High and ongoing	Low

which will influence the risk assessment. Earlier changes may require additional adaptation action by ERA.		
Results of the current projects on ASS should be reviewed using a climate change lens to assess any implications for closure management.	High	Low
Bushfire management will continue to be a risk into the future with implications for managers of the area following close-out and as the mine rehabilitation site vegetation matures and there is less active management of the area. It is essential that fire management approaches are developed and implemented in partnership with the Mirarr People and based on Traditional Knowledge.	High	Medium

8 References

Arias, P.A., N. Bellouin, E. Coppola, R.G. Jones, G. Krinner, J. Marotzke, V. Naik, M.D. Palmer, G.-K. Plattner, J. Rogelj, M. Rojas, J. Sillmann, T. Storelvmo, P.W. Thorne, B. Trewin, K. Achuta Rao, B. Adhikary, R.P. Allan, K. Armour, G. Bala, R. Barimalala, S. Berger, J.G. Canadell, C. Cassou, A. Cherchi, W. Collins, W.D. Collins, S.L. Connors, S. Corti, F. Cruz, F.J. Dentener, C. Dereczynski, A. Di Luca, A. Diongue Niang, F.J. Doblas-Reyes, A. Dosio, H. Douville, F. Engelbrecht, V. Eyring, E. Fischer, P. Forster, B. Fox-Kemper, J.S. Fuglestvedt, J.C. Fyfe, N.P. Gillett, L. Goldfarb, I. Gorodetskaya, J.M. Gutierrez, R. Hamdi, E. Hawkins, H.T. Hewitt, P. Hope, A.S. Islam, C. Jones, D.S. Kaufman, R.E. Kopp, Y. Kosaka, J. Kossin, S. Krakovska, J.-Y. Lee, J. Li, T. Mauritsen, T.K. Maycock, M. Meinshausen, S.-K. Min, P.M.S. Monteiro, T. Ngo-Duc, F. Otto, I. Pinto, A. Pirani, K. Raghavan, R. Ranasinghe, A.C. Ruane, L. Ruiz, J.-B. Sallée, B.H. Samset, S. Sathyendranath, S.I. Seneviratne, A.A. Sörensson, S. Szopa, I. Takayabu, A.-M. Tréguier, B. van den Hurk, R. Vautard, K. von Schuckmann, S. Zaehle, X. Zhang, and K. Zickfeld, (2021): Technical Summary. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 33−144. doi:10.1017/9781009157896.002.

Bamber, JL, Oppenheimer, M, Kopp, R, Aspinall, WP and Cooke, RM (2019). Ice sheet contributions to future sea-level rise from structured expert judgment, Proceedings of the National Academy of Sciences of the United States of America, 116, p. 11195-11200

Bayliss P., Finlayson C. M., Innes J., Norman-López A., Bartolo R., Harford A., Pettit N. E., Humphrey C. L., van Dam R., Dutra L. X. C., Woodward E., Ligtermoet E., Steven A., Chariton A., Williams D. K. (2017) An integrated risk-assessment framework for multiple threats to floodplain values in the Kakadu Region, Australia, under a changing climate. Marine and Freshwater Research 69, 1159-1185.

Cai, W., Santoso, A., Wang, G., Yeh, S-W., An, S-I., Cobb, K.M., Collins, M., Guilyardi, E., Jin, F-F., Lengaigne, M., McPhaden, M.J., Takashi, K., Timmermann, A., Vecchi, G., Watanabe, M., Wu, L. (2015). ENSO and greenhouse warming. Nature Climate Change, 5, 849-859.

Climate change in Australia Website CSIRO and BoM (2015). Accessed 10 January 2020.

CSIRO (2014) Climate Change in Australia's Top End. CSIRO.

CSIRO and Bureau of Meteorology (2015), Climate Change in Australia Information for Australia's Natural Resource Management Regions: Technical Report, CSIRO and Bureau of Meteorology, Australia

CRC, S. I. (2017). "Coastal Risk Australia Website (http://coastalrisk.com.au/viewer). Accessed 25 September 2019.

Dutta, R, Das, A and Aryal, J (2016). Australian bush-fire frequency is increasing significantly, Royal Society Open Science, 3, p. 1-11.

INTERA and ERA (2017). Final: Evaluation of Features, Events, and Processes and Safety Functions for The Ranger Uranium Mine. Energy resources of Australia Ltd and INTERA Geoscience and Engineering Solutions. October 2017.

INTERA (2021). Final Report: Groundwater Uncertainty Analysis for Ranger Mine Closure, report for Energy Resources of Australia Ltd.

IPCC (2014). 'Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.' (Eds R.K. Pachauri and L.A.Meyer). (IPCC: Geneva, Switzerland.)

IPCC, 2019: Technical Summary [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, E. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.- O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)].In press.

Meinshausen et al. (2020). The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500. Geoscientific Model Development, 13(8), 3571–3605. https://doi.org/10.5194/gmd-13-3571-2020.

Moise, A, Abbs, D, Bhend, J, Chiew, F, Church, J, Ekstrom, M, Kirono, D, Lenton, A, Lucas, C, McInnes, K, Monselesan, D, Mpelasoka, F, Webb, L and Whetton, P (2015). Monsoonal North Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports. eds Ekstron M, Whetton P, Cerbing C, Grose M, Webb L and Risbey J. CSIRO and Bureau of Meteorology, Australia.

NCCARF (2017). "CoastAdapt: Climate change and sea-level rise based on observed data. National Climate Change Adaptation Research Facility, Gold Coast. Available from: https://coastadapt.com.au/climate-change-and-sea-level-rise-based-observed-data. Accessed 25 September 2019."

Prober, SM, Bryne, M, McLean, EH, Steane, DA, Potts, BM, Vaillancourt, RE and Stock, WD (2015). Climate-adjusted provenancing: a strategy for climate-resilient ecological restoration, Frontiers in Ecological Ecology and Evolution, 3, p. 1-5.

Saynor, M., Wasson, R., Erskine, W., Lam, D. 2020. Holocene palaeohydrology of the East Alligator River, northern Australia, with application to mine site rehabilitation. Quaternary Science Reviews, 249, Article 106552.

Appendix A Stakeholders

Table A-1 Inception Workshop Attendees (1st of October 2019)

Company	Attendees
BMT	David Rissik
ERA	Michelle Iles, Ping Lu, Dave Staggs, Sarah Reid, Sarah Joyce, Stephanie Howden and Peter Anderson
KNP	Feach Moyle
NLC	Chris Brady
SSB	Chris Humphrey, Mike Saynor and Andrew Harford

Table A-2 Risk Assessment Workshop Attendees

Company	Attendees
BMT	David Rissik and Darren Richardson
ERA	Michelle Iles, Ping Lu, Dave Staggs, Sarah Reid, Chris New, Ingrid Meek, Elmarie Fagan and Andrew Nelson
ERM	Tamie Weaver and Wijnand Gemson
GAC	Mark Taylor
KNP	Stephen Balharrie
NLC	Chris Brady
Norther Territory Government	Max Smith
Rio Tinto	David Parry
SSB	Chris Humphrey, Mike Saynor, Andrew Harford, Mike Welch and Renee Bartollo
Water Solutions	John Macintosh

Table A-3 Fire Meeting Attendees

Company	Attendees
Charles Darwin University's Darwin Centre for Bushfire Research	Andrew Edwards and Cameron Yates
ERA	Ingrid Meek, Ping Lu, Michelle Iles and Peter Lander

Appendix B Risk Tables

Risk assessment template

Organization	**Name of the organization**	ERA
Project	**Project**	Climate Risks to Ranger Mine Closure
Date	**Date**	January 2023 update of 2020 assessment

Scope your assessment	**Objective**	Risks of current and future climate on mine closure including on receiving water		
	Select the future time frame of the assessment	Short term (2030, medium term (2050) and Long-term (2100)	**Briefly document the reason behind this selection of timeframe**	Looked at 2030 (reasonable planning timeframes) and 2050 aligns with timing associated with expected end of monitoring and maintenance phase, and long term gives an indication of what is likely to occur post closure
	Select future climate change scenario for which the risk assessment will be conducted	**2020 assessment: Medium emission scenario-RCP 4.5** **2023 update: Middle of the road SSP2**	**Briefly document the reason behind this selection of scenario/s**	greenhouse gas emissions are reduced. January 2023 risks were updated based on AR6 SSP2. The closest projections To AR5 RCP4.5.

List your systems	**List the hazards that are affecting your system**	**Future projections**	**How change in climate and sea level may affect your system (description of future risk)**	***Future* Risk** **2030** **Consequences**	**Likelihood**	**Risk at 2030**	**2050** **Consequences**	**Likelihood**	**Risk at 2050**	**2100** **Consequences**	**Likelihood**	**Risk at 2030**
Risk that changing climate will result in conditions unfavourable for target revegetation species and that vegetation communities will become unviable.	High temperatures and extreme hot days 35+		higher temperatures and a drier environment will influence viability of species	**Minor**	**Unlikely**	**Low**	**Minor**	**Likely**	**Medium**	**Moderate**	**Likely**	**High**
Risk that increased temperature and long hot and humid conditions will impact health and safety of staff involved in planting, management and maintenance and longer-term monitoring	High temperatures and extreme hot days 35+		higher temperatures and a drier environment will influence viability of species	**Minor**	**Likely**	**Medium**	**Minor**	**Almost certain**	**Medium**	**No risk**	**Rare**	**No Risk**
risks that temp and excessive dry weather will affect early survival of vegetation				**Insignificant**	**Likely**	**Low**	**Moderate**	**Likely**	**High**	**Moderate**	**Likely**	**High**
Risk of longer, hotter dry periods impacting understorey growth rates and survival	High temperatures and extreme hot days 35+		understory growth is limited as a result of high temperatures	**Insignificant**	**Likely**	**Low**	**Moderate**	**Likely**	**High**	**Moderate**	**Likely**	**High**
The risk of weed encroachment from the mine site into Kakadu Park increasing as invasive species have a higher competitive advantage in changing climates			Rehabilitation site is colonised by weeds (native and non-native)as a result of the changing	**Insignificant**	**Unlikely**	**Low**	**Insignificant**	**Unlikely**	**Low**	**Insignificant**	**Unlikely**	**Low**
Risk of increase in pests or diseases, such as myrtle rust, affecting vegetation on the rehabilitated site			Younger assemblage of species more at risk	**Moderate**	**Unlikely**	**Medium**	**Moderate**	**Possible**	**Medium**	**Moderate**	**Likely**	**High**
Risk that higher temperatures coupled with longer drier periods will impact soil biota and affect nutrient cycling			Lack of information and knowledge	Minor	Unlikely	**Low**	Minor	Unlikely	**Low**	Minor	Possible	**Medium**

Risk that connectivity of water courses will be reduced during longer, drier periods and that solutes will remain in smaller areas for longer. This could increase exposure of fauna and flora in the water courses which are unable to get away during periods of little or no connectivity.	Dryer wet seasons and high evapotranspiration rates			Major	Rare	**Low**	Major	Unlikely	**Medium**	Major	Possible	**High**
Risk that toxicity of contaminants will increase in higher temperature water. Guideline values are derived from 30oC temperatures at present.				Major	Rare	**Low**	Major	Unlikely	**Medium**	Major	Possible	**High**
Risk that sea-level rise will reduce the availability of freshwater refugia downstream of the mine site.				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk that higher temperatures of water bodies may lead to lower levels of dissolved oxygen in the water column which can result in fish kills.				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk of increased algal blooms in water ways due to increased rates of production in higher temperatures.				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	likely	**High**
Risk that longer periods of increased water temperatures can lead to shifting species complexes, favouring thermophiles which are heat tolerant				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk that higher evaporation rates may affect shallow billabongs and result in a loss of refuge habitat for species.			Loss of water through evaporation would result in lower billabong depths and lead to higher water temperatures	Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk that increased temperatures will influence the sex ratios of reptile species such as crocodiles				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk that sea level rise will cause floral and faunal species complexes to change and they will begin to be dominated by saline tolerant (marine) species which may have flow on effects to other important taxa. For example: Changing vegetation communities as a result of increased salinity may lead to a loss of those species which support nesting geese. Higher salinity waters may result in the loss of freshwater fauna such as freshwater turtles, amphibians.				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Likely	**High**
Risk that higher sea-levels and more saline water in receiving waters may affect the ways in which surface water models are interpreted. For example: What is the effect of reduced flow into saline waters? At what point will the receiving water bodies no longer be low ionic strength with low solute levels and are current guideline values for ecosystem protection relevant/applicable then?				Minor	Unlikely	**Low**	Minor	Unlikely	**Low**	Minor	Likely	**High**

Risks that longer hotter dry periods could dry out billabongs and expose previously unexposed acid sulphate soils (ASS) with implications for water quality and release of sediment bound contaminants.				Minor	Unlikely	**Low**	Major	Unlikely	**Medium**	Major	Possible	**High**
Risk of cyclone damage to vegetation planted as part of mine rehabilitation.				Major	Unlikely	**Medium**	Major	Possible	**High**	Major	Possible	**High**
Risk that leaf litter will increase as a result of intense winds, increasing bushfire risk and potentially leading to water column deoxygenation if washed into waterways.				Moderate	Rare	**Low**	Moderate	Unlikely	**Medium**	Moderate	Unlikely	**Medium**
Risk of erosion during storm events resulting in minor gullying on land and sedimentation in waterways.				Moderate	Rare	**Low**	Moderate	Unlikely	**Medium**	Moderate	Likely	**High**
Risk that intense storms will damage road network				Minor	Possible	**Medium**	Minor	Possible	**Medium**	Insignificant	Possible	**Low**
Risk that climate-driven increased extent of ground cover planted during restoration will increase the fuel load and increase fire risk.				Moderate	Rare	**Low**	Catastrophic	Possible	**High**	Catastrophic	Possible	**High**
Risk that increased evaporation leads to an increase in contaminants washed into onsite and receiving water during the first flush. A "dry" wet season could mean greater loads into billabongs which do not then flush out to the ocean.				Insignificant	Likely	**Low**	Minor	Likely	**Medium**	Moderate	Likely	**High**
Risk that fire severity will increase over time as a result of increased heat and evapotranspiration. This may lead to increased tree mortality.				Minor	Unlikely	**Low**	Major	Possible	**High**	Major	Likely	**High**
Risk that length of the potential burning season will decrease as a result of a changing climate which may increase the risk of inappropriate burning regimes or wildfires				Insignificant	Possible	**Low**	Moderate	Likely	**High**	Moderate	Likely	**High**
Risk that people living, working or visiting Kakadu will be affected by any increased bushfire.				Minor	Rare	**Low**	Minor	Possible	**Medium**	Moderate	Likely	**High**
Risk that when active mine closure management ceases after close-out, reduced activity on the mine site will result in increased fire potential because of less active on site management.				Minor	Rare	**Low**	Minor	Possible	**Medium**	Moderate	Possible	**Medium**
Risk that exotic grasses will become established following bushfires				Minor	Unlikely	**Low**	Moderate	Unlikely	**Medium**	Major	Likely	**High**
Risk that severe fires and associated tree mortality impacts faunal communities. Note: Severity will increase as the revegetation matures and develops hollows and other habitat features preferred by fauna, attracting more animals into the area. Also as the potential for more intense fires increases.				Minor	Unlikely	**low**	Minor	Likely	**Medium**	Moderate	Likely	**High**

Risk of wave action from inundated flood plain causing erosion of the mine site. Risk of bushfires destroying riparian vegetation and leading to increased bank erosion when the wet season commences.				Minor	Unlikely	**Low**	Minor	Unlikely	**Low**	Minor	Unlikely	**Low**
Risk of bushfires destroying riparian vegetation and leading to increased bank erosion when the wet season commences.				Minor	Unlikely	**low**	Minor	Likely	**Medium**	Moderate	Likely	**High**
Risk that cyclone damage to riparian zone degrades water quality				Minor	Unlikely	**Low**	Minor	Unlikely	**Low**	Minor	Unlikely	**Low**

Appendix C Workshop 1 Notes

C.1 Climate Change Risk Assessment Considerations

C.1.1 What time frames to consider and why

(1) Operational present day while staff on-site - 2026

(2) Stabilisation monitoring 2026-2050

(3) 2100 (best available projections)

(4) Longer term, there are little data and few projections available. Uncertainties are significant and it achieves little to include these in a risk analysis at this stage.

C.1.2 What scenarios to consider

- 8.5RCP (business as usual – worst case, but one the world is tracking at the moment).
- 4.5RCP an optimistic scenario, but will help to give a view of the differences between a couple of climate futures.
- Noting that projections do not differ between scenarios until after 2050.

C.1.3 Spatial extent

- Keep spatial extent the same as the Mine Closure Plan
- Exclude jabiru township (although invite them to workshop)
- Airport not included in Mine Closure Plan.

C.2 Climate Change in the location and initial scan of issues and risks for Ranger Uranium Mine closure

C.2.1 Heatwaves and heat

Affected Activity/process	Impact
Vegetation planting, management and monitoring	Plant selection to ensure sufficient temperature tolerant flora are planted. Plant selection is focussing on identifying plants which are adapted for low water availability. This includes species which are found in dryer climate than the mine site (e.g. Katherine) Need to understand the projected time line for revegetation and the challenges of uncertainty both in the climate but also in the ways in which vegetation species respond to changing conditions. ERA Contingency Strategy already considering a number of species from different climates. Challenges in existing conditions such as landform rock which is dryer than surrounds. Also to increase the mix of different species to

Affected Activity/process	Impact
	increase resilience of vegetation community to change. Climate change contingency planning underway. Some trees adapt naturally to dryer conditions by dropping leaves and reducing evapotranspiration. Potentially a greater proportion of deciduous species in the revegetation communities could reduce exposure. Presently 2 vegetation species from a dryer part of the park are being cultivated and included in the mix. Changes to tree species will have flow on effects to fauna. If deciduous trees dominate then hollow nesting species may be affected by the lower amount of shade that may eventuate. Irrigation can be implemented to reduce the effects of drought on the revegetation activities. Presently identified that 200+ hectares will require irrigation. This would be done for 3-6 months, but must be implemented with caution to reduce the potential for vegetation becoming less tolerant to low water and hotter conditions.
	Revegetation execution – 2025 temperatures important as is the peak planting year. Requires planting vegetation on waste rock in all forms of weather. Implications for labour management. People doing vegetation work are exposed to heat and humidity which has implications for their health. Important to mechanise the process as much as possible to reduce any risk to human health, and also possibly reduce costs
	From 2025 onwards – monitoring will be required and people will be in the field for approximately 5 years. Will need to consider how to reduce requirements for people days in the full sun/heat. Already altered productivity assumptions and considered the need for people hours to be reduced. Can we reduce human exposure to excessive heat by using drones? This can include monitoring, fertiliser and herbicide application. There is the potential for night-time planting to ensure workers operate in safe climatic conditions. Mine workforces are generally adept at and appropriately structured for working at night which could help this to be achieved.
	Are assessing how mango producers are adapting to climate change and learning lessons, but the lessons may not be applicable to the species used for revegetation
	Challenges with weed encroachment and fires which may be exacerbated as a result of climate change...Fires are likely to be more intense which may mean that vegetation is cleared for longer periods of time, making them more susceptible to erosion.
Increasing water temperatures	Increased air temperatures are highly likely to result in increased water temperatures in creeks and billabongs with a variety of biological, physical and chemical implications. These include: • Increased water temperatures have the potential for contaminants to be more toxic (Hooper et al. 2013 Environmental Toxicology and Chemistry, Vol. 32, No. 1, pp. 32–48. • Higher temperatures can lead to lower levels of dissolved oxygen in the water column which can result in fish kills.

Affected Activity/process	Impact
	• Algal blooms are more likely due to increased rates of production in higher temperatures. • Longer periods of increased water temperatures can lead to shifting species complexes, favouring thermophiles which are heat tolerant. • Higher evaporation rates may affect shallow land billabongs. Loss of water through evaporation would result in lower billabong depths and lead to higher water temperatures and a resulting loss of refuge habitat for species. This would be made worse by any increases in sedimentation. • Increased temperatures have the potential to influence the sex ratios of certain species. For example, crocodile sex is often determined by the temperature of the soil/eggs. Higher temperatures increase in male crocodiles.
	Temperatures and radiation – high moisture conditions - less radon emitted Dryer conditions more radon Pronounced annual patterns of radon emanation have been measured at Nabarlek and Ranger mines. Bollhoeffer et al 2004 report that radon flux was strongly influenced by soil moisture conditions with the flux from wet soils being lower than from dry soils. Bollhöfer A, Martin P, Tims S & Ryan B 2004. High sensitivity airborne radon concentration measurements in the Alligator River Region: rehabilitated Nabarlek uranium mine. Internal Report 469, January, Supervising Scientist, Darwin. Unpublished paper.
	Increased heat and associated inhospitable conditions increase the challenge of accessing sites for maintenance and monitoring.

C.2.1.1 Relevant literature

Temperature can also influence distribution of threatened species (look at NCCARF reports from Steve Williams, Steven Garnet and others)

Chris Humphrey study on temperature tolerance of freshwater mussels.

C.2.2 Sea level rise

Affected Activity/process	Impact
	As sea-levels rise, there is a potential that species complexes will change and begin to be dominated by saline tolerant (marine) species. Changing vegetation communities as a result of increased salinity may lead to a loss of those species which support nesting geese. Higher saline waters may result in the loss of freshwater fauna such as freshwater turtles, amphibians.
	Higher sea-levels and more saline water in receiving waters may affect the ways in which surface water models are interpreted. For example, what is the effect of reduced flow into saline waters.

Affected Activity/process	Impact
	Higher sea levels will result in a higher hydraulic gradient between the receiving water and the groundwater, reducing the amount of groundwater likely to discharge. It is possible that reduced rates of groundwater discharge as a result of higher head gradient, will lead to magnesium being more concentrated in the groundwater.
	Higher sea-levels will substantially reduce the availability of freshwater refugia. There are very few lowland refugia apart from at the mine site which is more elevated that downstream areas within the Kakadu Wetlands. Even though the mine site offers a potential refugium, it is possible that not all species are able to make use of the refugium over time because of different soil constituents which make it impossible for some species to grow there. Changes to downstream ecosystems and resulting reduced availability of culturally important taxa may mean that TO communities have a greater reliance on mine water bodies for hunting of species such as geese and turtles. The potential importance of the mine site as a refugium has implications for the application and interpretation of ALARA. Without climate change some changes to the mine site may be acceptable. However, with climate change and the increasing importance of the mine site as a refugium, ALARA may become a more important consideration with different interpretations required to ensure the refugia are in the best condition possible to enable them to function more effectively.
	Challenges with aquatic weeds. It is not known whether aquatic weeds will increase of be eliminated because of salt. Other invasive organisms such as rusts and fungi may also be influenced by higher temperatures and changes in salinity.
	A dryer climate may result in loss of water from the soil in the park, exposing acid sulphate soils. Alternatively, salt-water cover as a result of sea-level rise may buffer acid water entering billabongs.
	Implications for exposing waste rock were identified. There is potential for wave erosion adjacent to waste rock but this was considered to be a minor issue with little likelihood of having an effect on the rehabilitated mine. Lack of access and changes to locations of traditionally important species as a result of sea-level rise may create challenges for TO groups who may need to change hunting and fishing locations, potentially moving into locations traditionally used by other groups.

C.2.3 Storms and Cyclones

Affected Activity/process	Impact
Vegetation planting	Changes to storms and cyclones are only likely to be an issue in the first three years of vegetation growth while plants become established and still have poorly developed root systems. It is important to manage the use of irrigation following planting which will help to ensure that plants do not develop shallow root systems which would make them less resilient to cyclones and storms.
	The plants being trialled as part of the mine closure plan are proving to be quite robust to cyclone (wind) damage. It was considered that the rocky nature of the mine site increases robustness of vegetation to cyclones as a result of better anchorage of root systems in rock matrix compared to earth that can become sodden.
	The increased rainfall and associated runoff during cyclones or more intense storms, increases the potential for landslips on steep slopes. This can impact vegetation in those areas and also increase runoff of turbid water.
	Cyclones and associated winds can cause substantial damage to trees and vegetation, which can increase the fuel load in the area. Ultimately this can influence fire regimes and the intensity of any fires.
	Melaleuca trees are very susceptible to cyclone damage. Loss of large trees can reduce the rates of uptake and loss of groundwater by evapotranspiration and result in increased water levels in the soil. Loss of Melaleuca trees also reduces shade around water bodies and leads to increased water temperatures. Additionally, there is potential for more stream bank erosion if riparian vegetation is lost.
	Roads may be more prone to impacts during extreme weather events and may erode during cyclones or storms, making them more difficult to use, but also increasing maintenance costs. It is important to consider whether there will be maintenance crews for fire tracks, and the likelihood of any emergency evacuation routes being compromised?
	There were questions about whether the flood design for sediment traps on the mine site be sufficient given future climate projections. Sediment control points may need to be managed more regularly which has implications for maintenance costs on the rehabilitated mine site.
	Rainfall events associated with storms may last for shorter periods but be but more intense with greater volumes of rain. This could influence infiltration rates.

BMT

Appendix D Workshop 2 Notes

APPENDIX D: CLIMATE CHANGE HAND WRITTEN NOTES

WORKSHOP 2

It was noted that fire on the RPA will be managed by ERA & the traditional owners. Different aspirations from KNP.

Current state of fire management more broadly (NT):

- 20% cured grass – can manage,
- ~April/May increase in wind → decrease in humidity drives period for active management
- Available active management window getting shorter.
- It was noted that there is a need to manage fire currently, so no different under climate change.

Fire strategy for 5-10 years is the exclusion of fire from the rehabilitated landform, weed control & manage the understorey (reduce grasses)

2100 – hotter & drier conditions (increased evaporation)

- Not all fire is bad
- Severity will increase
- Improved fire management Mirrar savannah burning

25 year old trees are not very old. Won't behave the same as old savannah:

- Mortality will be greater
- Litter will be less as less canopy
- Managed by TO burning
- Might need different management plan for wast rock?

Wet season burn – annual grass reduction but can open up & be prone to erosion if done too often (refer to Kate Duggan paper)

Anticipate higher mortality, plant higher than target, recruitment.

- Plant more saplings to compensate for mortality

More cyclones → vegetation damage → increased fuel load.

Humidity, changing fuel loads & types – are we expecting a shift in the ecology e.g. more grassy?

Anthropogenic influence versus natural occurrence - is the increased natural occurrence as a result of climate change simply noise when compared to human impacts?

It was noted that by the time fire becomes a risk, it will be due to climate change as it is a landscape issue, not a new revegetation issue → need to assess against surrounding landscape.

Risk is when rain is delayed. Need climate change predictions on delayed onset of wet season.

Timeframe/impact

- Decreased understorey in young rehabilitated area, so decreased fire impact
- Low risk in active management phase.
- Fire risk on natural surface (Koolpinya surface) (e.g. LAAs) will always be higher than on waste rock rehabilitation → different risk profiles.

Risk of dislocating people as a result of altered fire regimes throughout KNP.

Grassy weed establishment as a result of erosion and fire → ongoing fire cycle → increased weed establishment again

Direct & indirect impact of fauna especially decreasing understorey → landscape scale impacts.

Appendix E Response to SSB comments

Annex E Response to SSB comments on Rissik and Iles (2020).

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
• Report format, structure and interpretation of information sources		
1	The time frames and scenarios to be considered are introduced late in the report – at Section 4. These need to be described in the report's introductory sections.	Report structure retained for the 2023 update. Restructuring will be considered for future reports.
2	There is heavy reliance on cut-and-paste figures and tables from various CSIRO, BoM and other reports which are either not explained or for which a local context is not provided. We note the following examples: a. In Section 2.1, Air temperature, the text commences: "There is very high confidence that maximum, minimum and average temperatures will continue to rise in the coming years". The only supporting evidence provided in terms of 'confidence' is Figure 2-2 which indicates very low to low consensus on this outcome using as its basis, proportion of models in agreement. b. Reference to "fewer frosts" in Section 2.1 (Air temperature), a cut and paste, also undermines the readers' confidence in the authors' information sources or ability to adapt the source text to a local context. c. Section 2.2 Rainfall, Figures 2-5 and 2-6. The most obvious changes to median rainfall are those projected for "Winter" and "Spring", yet consequences/implications of reduced rainfall in these seasons – when rainfall totals for the region are historically either negligible or very low – are not discussed. Further, the statement, "By 2070, rainfall is projected to decrease in all seasons (Figure 2-5)" is not the case for all Representative Concentration Pathways (RCP) scenarios based on Figure2-5.	a. Statement about high confidence removed from text in Section 2.1. b. Reference to fewer frosts removed. c. Statement about 2070 decrease in all seasons removed. Assessment of new implications is out of the scope of the 2023 update report. The implications for winter and spring rainfall changes can be addressed in future climate change assessments. d. The data shown in Figure 2.7 was incorrectly labelled "Southern slopes cluster" in the source report. A comparison of the reports for the Southern Slopes Cluster and the Northern Monsoonal Cluster from the source documents shows the figures are not the same for both clusters leading to the conclusion that the information in Figure 2.7 is correct but was incorrectly labelled in the source document. The Figure caption has been changed in the 2023 update report. e. Figure captions updated to include "wet season" and "dry season".

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
	d. Figure 2-7 figure caption indicates a different climate region – “southern slopes cluster”. The authors need to clarify this. e. In general, the representation of modelled data for parameters such as air temperature and rainfall (e.g. Fig 2-3 and 2-5) could be contextualised to wet and dry season rather than the traditional temperate seasons to provide a clearer understanding of what these projections mean for the Top End. f. The relevance and implications of Section 2.5 (Fire weather) to the region are not apparent. Given that a separate, on-line workshop was conducted with bushfire experts to gather additional expert input into this critical aspect, the section is notably short on outcomes. The statement “The increases in average and severe fire weather are projected to occur mainly in summer [= northern wet season] and spring [= northern late dry season]” seems at odds with the actual fire weather for the region where the summer wet season would be unlikely to give rise to such increased risks. Figure 2-12 is also not fit for purpose in terms of conveying fire history over the Ranger site and surrounds (i.e. “low fire events” in the late dry season of 2011). More can be gained for the region around Ranger from fire intensity data SSB have acquired for various purposes.	f. The initial release of Rissik and Iles 2020 (September 2020) did not contain notes from the workshops. The report was reissued in 2021 with notes from the workshop contained in Annexes. With the guidance of the bushfire subject matter experts, information additional to that captured in the report was considered. Reviewing information on fire weather from the AR6 report led to a change in risk ranking for some of the fire related risks in the 2023 update report. More detail on fire weather, including any Ranger specific information, will be considered in future assessments. The inception workshop stage of an assessment project aims to identify such information with the input of stakeholders.
Report findings		
1	The framing of the BMT study is set out on p. 15 to consist of planning horizons, climate change scenarios, risk assessment methods, data sources, and ‘An initial scan of the impacts of climate change on mine closure activities and on the interaction of the mine with the surrounding park’. While a number of climate-change-related risks are landscape in nature and “will affect the entire park and are not related to the mine closure”, a number of risks are either incorrectly assigned to that category, or require some further explanation or qualification, including:	Changes to the 2023 update report include: a. Recommendation to consider the information from Saynor et al. 2020 in future climate assessments. b. The qualifying statements recommended by SSB. c. The qualifying statements recommended by SSB. d. Statements acknowledging the issues in

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
	a. Risks of erosion and runoff of sediment that may occur during cyclones and large storms. Floods in Magela Creek may affect the eastern boundary of the rehabilitated mine (see Saynor et al., 2020), and such floods may be larger in future. b. A number of such risks should be qualified with, 'in the absence of mine-related sedimentation' i.e. flood deposition of sand (and mud) in billabongs from Magela Creek (a natural process, Nanson et al., 1993) could increase under future climate change scenarios, exacerbating any mine-related infilling; from Section 6.2, "Risk that longer periods of increased water temperatures can lead to shifting species complexes, favouring thermophiles which are heat tolerant", "Risk that higher evaporation rates may affect shallow billabongs and result in a loss of refuge habitat for species", and "Risk that sea-level rise will reduce the availability of freshwater refugia downstream of the mine site". c. Similarly, the following risks should be qualified in the context of whether the mine site is potentially a greater source of propagules than the surrounding environment: From Section 6.1, "The risk of weed encroachment from the mine site into Kakadu Park increasing as invasive species have a higher competitive advantage in changing climates" and "Risks that exotic grasses will become established following bushfires". d. Some risks in Section 6.2 might be incorrectly assigned "will affect the entire park and are not related to the mine closure" and might actually be cumulative stressors in the presence of mine-derived contaminants. Included	point d and a recommendation that future climate change risk assessments should consider cascading and compounding risks.

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
	here are higher water temperatures and the resultant effect on either dissolved oxygen concentrations or potential for algal blooms. Note too that "Risk that increased cyclone damage to riparian zone degrades water quality" should consider higher insolation of surface waters as a consequence (and hence water temperature interactions from above).	
2	Wording under Section 4.1, 'Post closure monitoring and maintenance phase 2026-2050', includes: "Post-closure monitoring will continue until it is demonstrated that the closure criteria have been achieved and a close-out certificate is issued." This is more accurately worded, "Post-closure monitoring will continue until it is demonstrated that the closure criteria have been achieved (including through satisfactory achievement of modelling outcomes or the point on the trajectory) and a close-out certificate is issued.".	Wording changed.
3	On page iii there is the following comment about gullying: 'The risk of gullying is considered to be low as there are no steep slopes on the site'. If deep gullies were to develop on the artificial landform, they could expose the tailings that have to be isolated from the environment for 10,000 years. Modelling by Hancock et al (2017) shows that gullying is highly likely but not deep enough to expose the tailings. The statement about the low probability of gullying (Section 6.3) needs to be qualified to take proper account of the modelling results. That is, the likelihood of gullying is high but the risk to the containment of the tailings is low. Also, given that gullying is likely, and the density of gullies may be high relative to the surrounds (SSB modelling outcomes), the constructed landform will not necessarily resemble the natural landscape.	Wording of risk statement changed from *Risk of erosion during storm events resulting in minor gullying on land and sedimentation in waterways.* to *Risk of erosion during storm events resulting in sedimentation in waterways.* Text in *Current and planned management* column (Section 6.3) updated. A separate risk for exposure of tailings due to climate driven erosion can be included in future climate change risk assessments.
Climate change adaptation		
1	BMT correctly identifies that discussions about the role of water bodies on the mine site as refugia are outside the scope of the report and need to be arranged with the Traditional Owners and relevant management agencies (Section 7.2).	No update to report required.

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
2	A similar and related stakeholder discussion is required on the following excerpt (from Section 2 of the report): *With changing climatic conditions, it is important to adapt ecological restoration techniques to make ecosystems more resilient to change. To increase the adaptive capacity of an ecosystem it is necessary to consider the genetic diversity and provenance of populations that are both currently present and being introduced as part of restoration. Climate adjusted provenancing involves enhancing a populations climate resilience by introducing a mix of genotypes from the climatic gradient biasing introduced individuals with adaptations in the predicted direction of climate change (Prober et al. 2015)."* With respect to ecosystem establishment, this proposal may be at odds with Environmental Requirement 2.2 if the outcome from above was an ecosystem different to/more resilient than etc the surrounding landscape: *"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"*	Report updated to acknowledge that the revegetation strategy uses only local species.
3	Nevertheless, aspect 2 above may now not be relevant for ecosystem establishment at least. Thus there are several references in Section 6.1 to selecting vegetation for ecosystem establishment that is more tolerant to dry conditions or better suited to waste rock. For savanna overstorey communities, stakeholders have now agreed that Eucalyptus tetrodonta/miniata open forest, which dominates the Ranger surrounds, will constitute the community type for establishment, making these climate-change-associated risk statements (or parts thereof) redundant, i.e.: e. Risk that changing climate will result in conditions unfavourable for target revegetation species and that vegetation communities will become unviable	Report updated to acknowledge that the revegetation strategy uses only local species. The relevant risks are retained but identified as redundant.

Comment ID	SSB comment (letter to Sharon Paulka ERA dated 7 January 2021)	Addressed in 2023 climate change assessment update report
	f. Risk that changes to tree species will have flow on effects to fauna. If deciduous trees dominate then hollow nesting species may be affected by the lower amount of shade that may eventuate. g. Risk that selecting vegetation more tolerant to dry conditions may have flow on consequences e.g. if trees drop leaves to cope with heat stress, ground cover gets impacted by sun and associated heat. h. Risk that vegetation which includes a mix of species better adapted to survival on waste rock sites will be more susceptible to fire	
Future work		
1	SSB concurs with key recommendations made in the report, including a. Water flow and water quality modelling based on potential future conditions, including sequential periods of long droughts and long wet seasons (based on the modelling of Cai et al. (2015)). b. Climate change risk assessment be updated when new information becomes available (e.g. following release of IPCC6 in 2022). Note, however, that a more recent report (CSIRO, 2020) is already available and should be consulted now to see if there are any differences in the predictions from the earlier reports c. Results of the current projects on ASS should be reviewed using a climate change lens to assess any implications for closure management	The 2023 update report a. Cites Cai et al. (2015) in the relevant recommendations. b. Includes an assessment conducted by ERA comparing information in CSIRO (2020) with that used in the 2020 assessment.
2	As a priority, SSB supports any modelling sensitivity analyses, including re-analyses based on updated IPCC predictions, for assessing (i) sustainability of ecosystems established on the rehabilitated landform under extreme drought conditions (e.g. plant available water), and (ii) landform erosion characteristics under extreme wet conditions.	Noted and included in recommendations.

Appendix F Comparison of future climate

Comparison of future climate; CSIRO 2020 vs Rissik & Iles 2020

From: Staggs, David (ERA) <David.Staggs@riotinto.com>
Sent: Wednesday, 10 February 2021 3:52 PM
To: Fagan, Elmarie (ERA)
Subject: Climate change comparison
Attachments: CSIRO 2020 Climate Change in the Northern Territory.pdf

Hi Elmarie,

Comparing the BMT climate change risk assessment with the latest 2020 CSIRO climate change in the Northern Territory report. The BMT report typically references work completed by CSIRO in 2014 and CSIRO and BoM in 2015 which is understandable as the later 2020 CSIRO report was not yet made public when the BMT report was written. BMT also reference other more globally focused studies where local projections are not available.

In general both reports have similar climate projections and predictions for all areas of climate change with one minor exception, rainfall towards the end of the century. The latest 2020 CSIRO report indicates the rainfall could either increase of decrease with little confidence as to which direction change, the earlier 2015 work by CSIRO and BoM which is referenced by BMT indicates that rainfall is likely to decrease in all seasons by end of the century.

More detailed discussion on each area of climate change discussed in the BMT report:

Temperature
Both advise temperature is increasing. The 2020 CSIRO report suggests near term (2030) increase will be between 0.7°C and 1.4°C, compared with BMT report which suggests 1°C to 3°C. Future projections at 2090 are near enough the same and have high levels of uncertainty associated with predictions. Both reports indicate the frequency of extreme hot days will increase and that warm spells will be longer. In general the assessment is fairly consistent between the two reports with improved confidence in near future predictions in the later 2020 CSIRO report.
CSIRO

Annual mean temperature change (°C) from 1986–2005 average

	2030			2050			2090		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Top End Monsoonal North (West)	0.8 (0.5 to 1.2)	0.9 (0.6 to 1.3)	1.0 (0.7 to 1.4)	1.0 (0.7 to 1.6)	1.3 (1.0 to 1.8)	1.8 (1.4 to 2.4)	1.0 (0.6 to 1.8)	1.8 (1.3 to 2.8)	3.7 (2.8 to 5.1)

BMT

> There is very high confidence that maximum, minimum and average temperatures will continue to rise in the coming years. For the near future (2030), the annually averaged warming is projected to be between 1°C and 3°C above the climate of 1986–2005. Under a high emission scenario, by the year 2090, the projected range of warming is 2.7°C to 4.9°C above the climate of 1990–2009 (Figure 2-2). Summer and autumn will experience the greatest rise in temperature (Figure 2-3).

Rainfall
Both advise in changes to average rainfall however the predictions are a little different. Both reports indicate near future (2030) rainfall patterns will be dominated by natural variability with influences of climate change not immediately noticeable. The 2020 CSIRO report indicates that future climate out towards end of the century could be either dryer or wetter with little confidence on which way things will change. The BMT report (based off 2015 CSIRO and BoM) indicates that a reduction in rainfall is more likely by the end of the century.

CSIRO

Table A3. Change in average rainfall (%) relative to 1995 (1986–2005). Note that changes in the dry season can appear large because they are changes on a small amount.

MONSOONAL NORTH (WEST)	2030 (2020–2039)			2050 (2040–2059)			2090 (2080–2099)		
	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5	RCP2.6	RCP4.5	RCP8.5
Annual	-2 (-10 to +5)	0 (-11 to +6)	0 (-6 to +6)	-3 (-10 to +5)	0 (-10 to +7)	-1 (-14 to +9)	-5 (-11 to +4)	-1 (-13 to +8)	+4 (-24 to +19)
Wet	0 (-8 to +6)	0 (-8 to +6)	-1 (-5 to +7)	-3 (-10 to +6)	+1 (-7 to +7)	0 (-7 to +8)	-3 (-11 to +5)	0 (-11 to +8)	+4 (-23 to +19)
Dry	-7 (-32 to +17)	-5 (-35 to +19)	-5 (-22 to +29)	-11 (-27 to +12)	-11 (-35 to 5)	-6 (-40 to +26)	-7 (-29 to +7)	-6 (-30 to +22)	-4 (-45 to +44)

BMT

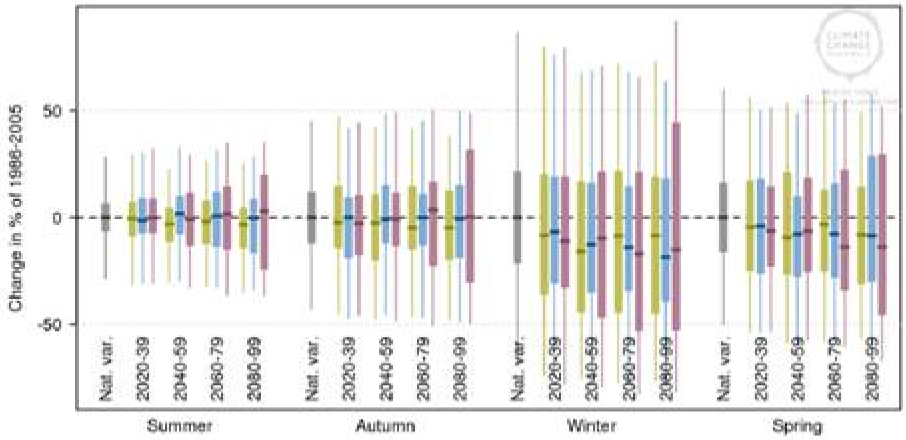


Figure 2-5 Projected change in seasonal precipitation for 2090 (2080-99). Graphs show change in (from left) summer, autumn, winter and spring. Anomalies are given in % relative to 1995(1986-2005) under RCP2.6 (Green), RCP4.5 (blue) and RCP8.5 (purple). Natural climate variability is represented by the grey bar. The middle (bold) line is the median value of the model simulations (20-year moving average climate); half the model results fall above and half below this line. Source: CSIRO and BoM 2015

Sea level rise
Both reports provide nearly identical predictions for sea level rise up to 2090 based off CSIRO and BoM. Projected sea level rise by 2090 does not directly impact on the mine site itself. Influence of sea level rise is constrained to downstream of Mudginberri based on map in BMT report. BMT also reference a report which details a global average of up to 2m sea level rise is possible so things could get worse still.

2020 CSIRO 0.38 to 0.85m sea level rise RCP 8.5
BMT 0.45 to 0.82m sea level rise

Fire weather
Both reports indicate fire weather will get worse with climate change. The 2020 CSIRO report indicates that fire weather will become more frequent and harsher. BMT details that the NT is projected to experience and increase in average and severe fire weather in the future.

Evapotranspiration
Both reports indicate that evapotranspiration will increase in all seasons with similar predictions.

Humidity
Both reports indicate similar projections. Humidity will have greatest change at the end of the century with a small reduction in relative humidity across all seasons.

Hope this helps.

Thanks,
Dave

David Staggs
Senior Hydrogeologist

Energy Resources of Australia Ltd
Level 3, Energy House, 18 - 20 Cavenagh Street, Darwin, 0800, Northern Territory
GPO Box 2394 Darwin 0801 Northern Territory
M: +61 (0) 421 327 842

The operations of Energy Resources of Australia Ltd are located on Aboriginal land and are surrounded by, but separate from, Kakadu National Park. Energy Resources of Australia Ltd respectfully acknowledges the Mirarr, Traditional Custodians of the land on which the Ranger mine is situated.

BMT has a proven record in addressing today's engineering and environmental issues.

Our dedication to developing innovative approaches and solutions enhances our ability to meet our client's most challenging needs.

Brisbane
Level 5, 348 Edward Street
Brisbane Queensland 4000
PO Box 203 Spring Hill Queensland 4004
Australia
Tel +61 7 3831 6744
Fax +61 7 3832 3627
Email environment@bmtglobal.com

Melbourne
Level 5, 99 King Street
Melbourne Victoria 3000
Australia
Tel +61 3 8620 6100
Fax +61 3 8620 6105
Email environment@bmtglobal.com

Newcastle
Level 1, 161 King Street
Newcastle New South Wales 2300
Tel +61 2 4940 8882
Fax +61 2 4940 8887
Email environment@bmtglobal.com

Adelaide
5 Hackney Road
Hackney Adelaide South Australia 5069
Australia
Tel +61 8 8614 3400
Email info@bmtdt.com.au

Northern Rivers
Suite 5
20 Byron Street
Bangalow New South Wales 2479
Australia
Tel +61 2 6687 0466
Fax +61 2 6687 0422
Email environment@bmtglobal.com

Sydney
Suite G2, 13-15 Smail Street
Ultimo Sydney New South Wales 2007
Australia
Tel +61 2 8960 7755
Fax +61 2 8960 7745
Email environment@bmtglobal.com

Perth
Level 4
20 Parkland Road
Osborne Park Western Australia 6017
PO Box 2305 Churchlands Western Australia 6018
Australia
Tel +61 8 6163 4900
Email environment@bmtglobal.com

London
Zig Zag Building, 70 Victoria Street
Westminster
London, SW1E 6SQ
UK
Tel +44 (0) 20 8090 1566
Email environment.uk@bmtglobal.com

Leeds
Platform
New Station Street
Leeds, LS1 4JB
UK
Tel: +44 (0) 113 328 2366
Email environment.uk@bmtglobal.com

Aberdeen
11 Bon Accord Crescent
Aberdeen, AB11 6DE
UK
Tel: +44 (0) 1224 414 200
Email environment.uk@bmtglobal.com

Asia Pacific
Indonesia Office
Perkantoran Hijau Arkadia
Tower C, P Floor
Jl: T.B. Simatupang Kav.88
Jakarta, 12520
Indonesia
Tel: +62 21 782 7639
Email asiapacific@bmtglobal.com

Arlington
2900 South Quincy Street, Suite 210
Arlington, VA 22206
United States
Tel: +1 703 920 7070
Email inquiries@dandp.com

APPENDIX 4.1: CHRONOLOGY OF COMPLETED ACTIVITIES

CHRONOLOGY OF COMPLETED ACTIVITIES

Date	Description of Event / Milestone
1969	Discovery of Ranger ore deposit by joint ventures Electrolytic Zinc Company of Australasia Ltd (EZ) and Peko-Wallsend Operations Limited (Peko).
1974	February: Submission of Environmental Impact Statement (and supporting material) under the Australian Government's *Environmental Protection (Impact of Proposal) Act 1974*.
1975	May: Submission of Supplements 1 and 2 to the Environmental Impact Statement.
	The Ranger Uranium Environmental Inquiry (Fox *et al.* 1976) commences.
1977	The Ranger Uranium Environmental Inquiry Reports (Fox *et al.* 1976 and 1977) recommend that uranium mining proceed.
	Much of the Alligator Rivers Region (ARR) is declared a National Park (NP) and Aboriginal people are given a major role in the management of Kakadu NP.
1978	Title to the Ranger Project Area (RPA) is granted to the Kakadu Aboriginal Land Trust, in accordance with the *Aboriginal Land Rights (Northern Territory) Act 1976* (Aboriginal Land Rights Act).
	The Commonwealth Government enter an agreement with the Northern Land Council (NLC) to permit mining to proceed.
	The role and function of the Supervising Scientist is established under the *Environment Protection (Alligator Rivers Region) Act 1978*.
1979	Section 41 Authority under the Commonwealth *Atomic Energy Act 1953* is issued.
	Construction at Ranger commences.
1980	Energy Resources of Australia Limited is established as a public company. It was the largest public float in Australian history at the time.
	May: Mining of Ranger Pit 1 orebody commences using open cut methods.
1981	13 August: The first drum of uranium oxide is produced.
1994	December: Mining of Ranger Pit 1 orebody is completed.
1995	Preparation of Pit 1 to receive tailings commences, including construction of an underdrain and a horizontal rock-filled adit from the base of the pit to intercept a vertical dewatering bore.
1996	May: Approval is granted to mine Pit 3 orebody.
	August: Tailings deposition into Pit 1 begins.
1997	July: Open cut mining of Pit 3 begins.
1999	Environmental Requirements revised to include rehabilitation conditions.
2000	August: Rio Tinto becomes a major shareholder in ERA.
2006	October: ERA announces an increase in Ranger mine's reserves due to a reduction in the cut-off grade of ores for processing, adding about six years to the predicted life of processing at Ranger to 2020.
2007	June: Approval received to deposit tailings into Pit 3.
	September: Extension of Pit 3 is announced, extending mining until 2012.

Date	Description of Event / Milestone
2008	Trial Landform (TLF) construction commences.
	November: ERA announces a significant mineral exploration target defined at Ranger 3 Deeps.
	December: Tailings deposition in Pit 1 ends.
2009	April: The laterite treatment plant is commissioned to extract uranium from weathered ores (referred to as laterite ores) that are unable to be processed through the existing mill circuit.
	Trial Landform is planted with seeds and seedlings.
2011	August: The ERA Board approves the construction of an exploration decline to conduct underground exploration drilling of Ranger 3 Deeps.
2012	February: ERA approves the design, construction and commissioning of a Brine Concentrator.
	May: Phase 1 construction of the Ranger 3 Deeps exploration decline begins.
	May – September 7,554 wick drains are installed in Pit 1.
	Onsite water management capacity was expanded to beyond potential flood levels, with the completion of Retention Pond 6 and Ranger Water Dam (RWD) wall lift.
	Magela Creek levee is constructed to guard Pit 3 from a potential large flood event.
	November: Mining of Ranger Pit 3 orebody is completed.
	Pit 3 backfill activities commence in preparation for the planned transfer of tailings from the then Tailings Storage Facility (now Ranger Water Dam) and the final repository of brine from the Brine Concentrator.
2013	January: The Ranger Mining Agreement is finalised with Mirarr Traditional Owners, the Northern Land Council, ERA, and the Commonwealth government. The Mining Agreement establishes the Relationship Committee.
	September: Completed construction of the Brine Concentrator. Commissioning tests and verification phase commences.
	October: Phase 2 construction of the R3 Deeps exploration decline begins including extending the decline and constructing a ventilation shaft.
	December: Completed the placement of approximately 70 per cent of the initial capping over Pit 1 tailings to assist in tailings consolidation and the ongoing dewatering of the pit.
2014	August: Underfill installed in Pit 3. An underdrain is constructed on top of the underfill, and five brine injection wells and an extraction pumping system installed.
	Ranger 3 Deeps underground drilling program completed
	Construction of the purpose-built tailings dredge completed.
2015	Tailings dredge, tailings transfer and water recovery/pumping infrastructure commissioned.
	Pit 3 brine injection piping and infrastructure installed and commissioned.
	Tailings from the mill begins to be transferred directly to Pit 3.
	June: ERA announces that the R3 Deeps underground mining project would not proceed, and the R3 Deeps exploration decline is placed into care and maintenance.
2016	January: Completed initial capping and impervious laterite layer in Pit 1. Bulk backfilling commences.

Date	Description of Event / Milestone
	All production tailings directed to Pit 3 and tailings transfer from RWD into Pit 3 commences.
	Brine injection into the Pit 3 underfill begins.
2017	April: Approval granted for ERA to begin the final stages of Pit 1 backfill.
2018	Laterite plant ceased operation due to exhaustion of laterite ore. Laterite plant placed under care and awaiting demolition as part of the site closure project.
2019	Ministerial approval granted to commence decommissioning of the R3 Deeps exploration decline.
	Remnant tailings cleaning from the walls of the RWD commences.
2020	19 February: Approval granted (High-Density Sludge (HDS) plant application), allowing the release of partially treated process water into the pond water circuit.
	July: Approval granted to leave the subfloor of the RWD in-situ rather than to remove and transfer into Pit 3.
	August: Final backfill and landform contouring on Pit 1 completed.
	November: Scarification of Pit 1 final landform.
2021	Production at the Ranger mine ceased on 8 January 2021, concluding processing activities on the RPA after ~40 years of operation.
	Dredging of tailing for transfer from the then TSF (now RWD) to Pit 3 is completed.
	Processing Plant is decommissioned.
	Planting on the backfilled surface of Pit 1 begins.
2022	January: Planting on the backfilled surface of Pit 1 is completed.
	Final remnant tailings are transferred from RWD to Pit 3 via truck.
	31 May: ERA sells final drum of uranium oxide.
2023	March: Directionally drilled brine injection wells completed and commissioned.
	April: Wicking in Pit 3 completed and wicking barge demobilised.
	June: Approval granted to dewater and begin drying the tailings in Pit 3.
	September: Pit 3 Capping, Waste Disposal and Bulk Material Movement Application is submitted.
	October: Pit 1 research trials and monitoring reach 2 year milestone – average 70% survival.

APPENDIX 4.2: COMPLETED BPT ASSESSMENTS

ERA Energy Resources Of Australia

Completed BPT Assessments

Ranger Mine Closure Plan 2023

Unique Reference	PLN007
Revision:	1.23.0

ERA Energy Resources Of Australia

TABLE OF CONTENTS

FIGURES

TABLES

1 SALT TREATMENT AND DISPOSAL

The need to dispose of saline water is a common process in several industries and, as a result, 25 methods were identified as potential salt management options and were considered for the BPT assessment. Many of the options considered had fatal flaws for Ranger and were hard show-stopped prior to the workshop. A total of seven options were assessed in detail (Table 1-1).

Table 1-1: Salt treatment and disposal options

Category	Brine injection	Crystallisation	Thermal distillation
Method	pit 3 underfill underground silos pit 3 underfill with rock screening	pit 3 placement underground silos placement	pit 3 underfill injection underground silos injection

The overall outcome of the BPT assessment was that brine injection to the underfill without rock screening was the highest ranked alternative. Brine injection to underground silos scored well but concerns were identified on Occupational Health and Safety issues during both the construction and the operational phases of this option. Major problems were identified for the crystallisation and distillation options, and it is considered unlikely that either option assessed would be viable. The only uncertainty remaining for the preferred option related to the potential for reactivity between the brine and the waste rock of the underfill and possible limitation on the volume available for the storage of brine.

It was concluded that this issue required further assessment prior to a final decision on the salt management option to be implemented. For this reason, crystallisation was taken forward into the overall strategy assessment pending further testing to confirm the brine injection option.

2 BRINE SQUEEZER

Report: *Application to operate a Brine Squeezer. 2019*

Water management is an environmentally and operationally relevant aspect of Ranger. Concentration and isolation of contaminants through water management is a significant component of the Ranger closure program. In January 2019, ERA presented the results of studies into additional processing options, to the Director of Mining Operations, to support the installation of the selected option, the Brine Squeezer (ERA, 2019b).

Treatment of pond water through the water treatment plants generates brines that are added to the process water inventory. This results in 200 to 1,000 ML/year of additional process water to be treated by the Brine Concentrator. However, the Water Treatment Plant (WTP) brines are less concentrated than process water (less than 25% brine of process water concentration), and treatment options that are more cost effective than treating WTP brines as process water are available. Additional processing of WTP brines will reduce the volume added to process water, reducing the total inventory to be treated by the Brine Concentrator, and reducing overall risks to the closure schedule and costs associated with water treatment.

ERA investigated options to concentrate WTP brines over many years. Given the high scaling and membrane fouling potential of WTP brines, it was necessary to consider alternatives to standard reverse osmosis. The implementation of the Osmoflo Brine Squeezer was established to be a cost-effective way to treat WTP brines as it minimised unnecessary additions to the pond water and process water inventory and optimised pond and process water treatment and disposal mechanisms.

To meet regulatory requirements of the Ranger Authorisation and facilitate the incorporation of novel technology at Ranger, a thorough BPT assessment process was undertaken. This began in 2013 with a preliminary desktop screening assessment that investigated 27 options. From this assessment 15 options were hard show-stopped, whilst four options were soft show-stopped and four options scored poorly relative to the remaining four options, which were considered appropriate to progress for further assessment. A second, BPT assessment was then conducted in 2018 on:

- vibratory shear enhanced processing (VSEP);
- Brine Squeezer;
- electro dialysis reversal (EDR); and
- additional reverse osmosis.

Using a 5-level technology ranking system where a ranking of three meets industry standards, the second BPT assessment showed the Brine Squeezer (Figure 2-1) to be the highest-ranking option.

Pilot studies and test work were completed on two options: VSEP and Brine Squeezer. The results of these studies were used to inform the BPT assessment and revise the relevant criteria of the 2013 BPT assessment. The seven-month Brine Squeezer pilot study, completed in 2016, conclusively demonstrated that this technology has the capability to treat the Ranger pond water treatment brine, thus minimising the volume of brine and maximising the volume of release quality water on site.

This outcome had a significant influence on the 2018 BPT assessment scores for the Brine Squeezer, particularly against criteria such as ‘Proven technology’, ‘Technical performance’ and ‘Inherent Availability and Reliability’ compared to the other three technologies. The result is that during the 2018 BPT, the technology with the highest BPT score was the Brine Squeezer, followed by the EDR, VSEP and additional reverse osmosis (Table 2-1 and following ranking matrices).

It has been demonstrated during field trials that WTP brine can be treated at up to 94% recovery of permeate of quality equal to, or better than, current WTP permeate. The plant, installed adjacent to the sand blast yard, comprises three trains, providing for 99% availability of two trains (1 standby/cleaning). Commissioning of the Brine Squeezer commenced in June 2019, with the plant now fully operational.

Table 2-1: Comparison of final BPT scores (2013 vs 2018)

Option ID	Description	2013 BPT Results	2018 BPT Results
BM1	VSEP - Vibratory shear enhanced processing (FilTek)	18.8	13.2
BM2	Brine squeezer (Osmoflo)	21.9	23.7
BM3	EDR - electro dialysis reversal	30.0	19.4
BM6	Additional reverse osmosis	31.3	11.1

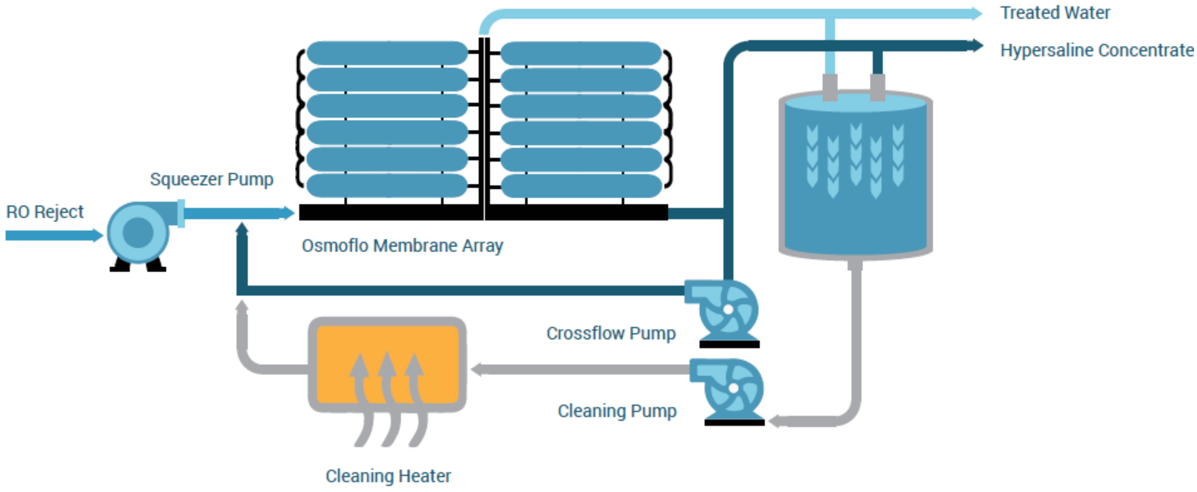


Figure 2-1: Brine Squeezer process flow diagram (source: http://www.osmoflo.com/)

BM	Brine Minimisation	Rehabilitation and Closure							Constructability		
		Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
		1	1	1	1	1	1	1	1	1	1
Option ID	Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Cost	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
BM1	VSEP (FilTek)	NA	NA	NA	NA	NA	3	4	4	4	3
BM2	Brine Squeezer (Osmoflo)	NA	NA	NA	NA	NA	3	4	4	4	3
BM3	EDR - Electro dialysis reversal	NA	NA	NA	NA	NA	3	4	4	4	3
BM6	Additional RO (includes pre-treatment step)	NA	NA	NA	NA	NA	3	3	4	4	3

	Inadequate	Poor	Acceptab le	Good	Excellent	Unable to evaluate	Not applicable to this option
Rank	1	2	3	4	5	UTE	NA

BM	Brine Minimisation				TO Culture & Heritage		Protection of People and the Environment				
		Show stopper column setting			Yes	Yes	Yes	No	Yes	No	Yes
				Rank weighting	1	1	1	1	1	1	1
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic impact local community	Ecosystems of Kakadu	Ecosystems of Project Area	Long-term Protection of Environment
BM1	VSEP (FilTek)	0	0	13.2	NA	NA	4	3	4	4	NA
BM2	Brine Squeezer (Osmoflo)	0	0	23.7	NA	NA	4	3	4	4	NA
BM3	EDR - Electro dialysis reversal	0	0	19.4	NA	NA	4	3	4	4	NA
BM6	Additional RO (includes pre-treatment step)	0	0	11.1	NA	NA	4	3	4	3	NA

3 RANGER 3 DEEPS

Report: *Application Ranger 3 Deeps Exploration Decline Decommissioning. 2018*

In May 2012, phase 1 construction works of the Ranger 3 Deeps (R3D) decline began after being approved in September 2011. This allowed for underground exploration that could provide further information regarding the viability of the proposed R3D underground mine. An additional application was submitted for phase II construction works and was approved for the extension to the exploration decline, installation of a ventilation shaft, and acquisition of bulk samples on 4 June 2013.

Exploration in the decline (Figure 3-1) continued until December 2014, whilst submissions were made for the construction of the R3D underground mine at the same time. In October 2014, a draft environmental impact assessment (EIS) was submitted but, following an ERA board decision in June 2015, the statutory assessment process for the proposed R3D mine was halted and the decline was placed in long-term care and maintenance.

The primary objective of the BPT assessment was to determine which combination of options was best practice for the closure of the exploration decline. For the assessment, the decline was divided into three closure areas:

- main decline (2,710 m) – seven BPT closure options assessed;
- portal (185 m) – three BPT closure options assessed; and
- ventilation shaft (located at -260 mRL; vertical length 280 m) – nine BPT closure options assessed.

The BPT assessment rankings reflect known hydrogeological conditions obtained during decline construction and core sampling of resource holes, and subsequent hydrological modelling completed by INTERA (2018). The assessment also took into consideration ground conditions and potential heavy mobile equipment limitations (e.g. gradient, manoeuvrability). The assessed option and BPT outcomes are presented in Table 3-1 and the ranking matrices at the end of this sub-section.

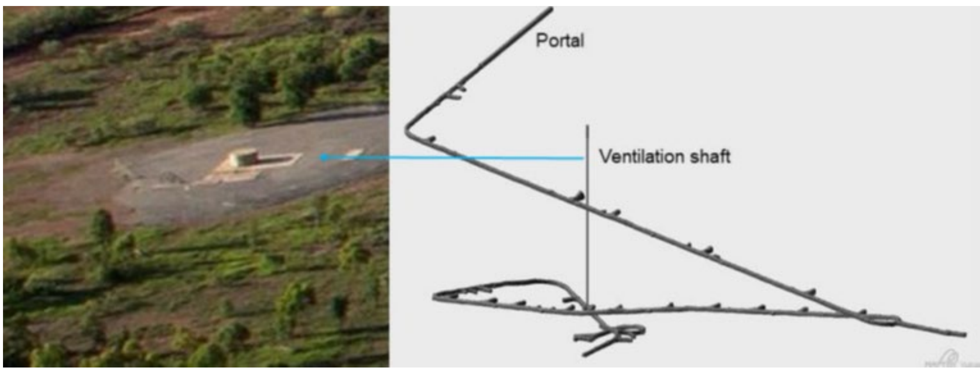


Figure 3-1: Aerial view of the ventilation shaft and underground infrastructure

Table 3-1: Decline options and best practicable technology assessment summary

Option ID	Option Description	Overall Rank
Decline closure (2,710 m)		
A1	Waste rock (full decline) and grouting of open holes	16.7
A2	A1 + bulkheads	12.5
A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~40 vertical m)	29.2
A4	A3 with cemented rock fill (CRF) instead of waste rock	25.0
A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	20.8
A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	-4.2
A7	A3 (without grouting of open holes and bulkheads)	41.7
Portal (185 m)		
B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	-11.5
B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	30.8
B3	Leave entire portal in situ and cover with waste rock	-10
Ventilation Shaft		
C1	Waste rock; concrete collar removed	-100
C2	Waste rock, concrete in situ	-100
C3	Crushed waste rock; concrete collar removed	31.6
C4	Crushed waste rock; concrete collar in situ	-100
C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	21.1
C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	-100
C7	Steel plate; concrete collar removed and allow to flood	13.2
C8	Steel plate and allow to flood; concrete collar in situ	-100
C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	39.5

3.1 Main decline closure

For the decline, options A1 and A2 rated poorly in comparison to the other options and were soft show-stopped based on occupational health and safety (OHS) concerns, cost and operability. Three options, scoring similarly, with one of these, A5, eliminated due to cost and reliability concerns. Option A6 was eliminated due to OHS and fitness for purpose. Option A7 (waste rock placed in the weathered zone) was allocated the highest assessment score of 41.7 and selected as the preferred option.

3.2 Portal closure

For the portal closure, B1 was ranked inadequate due to difficulty and complexity. Option B3 was rejected when it became apparent that the waste rock proposed to cover the portal would not blend with the final landform and therefore at odds with the cultural criteria. Option B2 (partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock) with a score of 30.8 and no show-stoppers, was ranked the highest and selected as the preferred option.

3.3 Ventilation shaft closure

Five of the ventilation shaft options were hard show-stopped based on fitness for purpose or cultural criteria (specifically visual amenity). Two options recorded soft show-stoppers for cultural criteria (also visual amenity) and two options, C3 and C9 scored closely on the BPT assessment. For its greater ability to mitigate potential long-term movement of groundwater to the surface via the ventilation shaft, option C9 (crushed waste rock up to weathered zone, then ten metres cemented rock fill and then ten metres of crushed rock to surface; concrete collar removed) was identified as the highest-ranking option with a score of 39.5 and selected as the preferred option.

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	Decline closure (2,710 m)				0.0						
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	4	3	5	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	4	3	5	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	4	3	5	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	4	3	5	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	4	3	5	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	1	3	5	1
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	4	3	5	3
	Portal (185 m)				0.0						
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	NA	NA	4	3	5	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	NA	NA	4	3	5	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0	1	NA	4	3	5	1
	Vent shaft				0.0						
1	C1	Waste rock; concrete collar removed	1	0	-100.0						
1	C2	Waste rock, concrete in situ	1	0	-100.0						
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	4	4	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0	1	1				

						TO Culture & Heritage		Protection of People and the Environment			
			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture ("Location")	Cultural heritage ("Location")	Community Health & Safety ("Social factors")	Socio-economic Impact on Local Communities ("Social factors")	Ecosystems & Natural world heritage values of Kakadu National Park ("Location" & "Proven effectiveness")	Ecosystems of the Project Area ("Location")
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	2	2	4	3	4	3
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0	1	1				
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	2	4	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0	1	1				
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	5	4	3	4	3

						Fit for Purpose				Operational Adequacy			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
	Decline closure (2,710 m)				0.0								
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	5	4	4	2	2	2	3	NA
	A2	A1 + bulkheads	0	1	12.5	4	4	5	1	2	2	3	NA
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	4	4	4	3	4	3	3	NA
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	4	4	4	2	4	3	3	NA
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	4	4	4	2	4	3	2	NA
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	1	1	1	5	4	5	5	NA
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	4	4	4	4	4	4	4	NA
	Portal (185 m)				0.0								
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	1	4	4	1	1	1	2	NA
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	4	4	3	3	3	4	NA
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0								
	Vent shaft				0.0								
1	C1	Waste rock; concrete collar removed	1	0	-100.0	1							
1	C2	Waste rock, concrete in situ	1	0	-100.0	1							
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	3	3	4	3	3	3	5
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0								

ERA Energy Resources Of Australia

Initial show stopper	Option ID	Option Description (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology ("Age/effectiveness of equipment")	Robustness ("Age/effectiveness of equipment")	Environmental Protection ("World's best practice" & "Proven effectiveness")	CAPEX / OPEX ("Cost effectiveness")	Occupational Health & Safety	Operability	Inherent availability and reliability (e.g. crusher availability)	Maintainability
						Fit for Purpose				Operational Adequacy			
			Show stopper column setting			No	No	Yes	No	Yes	No	No	No
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	5	3	4	2	3	3	3	5
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0								
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	1	3	3	5	3	4	5	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0								
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	5	3	4	3	3	3	3	5

			Show stopper column setting			Rehabilitation and Closure				
						Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
	Decline closure (2,710 m)				0.0					
	A1	Waste rock (full decline) and grouting of open holes	0	1	16.7	NA	NA	NA	NA	3
	A2	A1 + bulkheads	0	1	12.5	NA	NA	NA	NA	3
	A3	Grouting, bulkheads and waste rock placed only in the weathered zone (i.e. up to surface ~ 40 vertical m)	0	0	29.2	NA	NA	NA	NA	3
	A4	A3 with cemented rock fill (CRF) instead of waste rock	0	0	25.0	NA	NA	NA	NA	3
	A5	A3 with crushed & ground waste rock (hydraulic backfill) instead of waste rock	0	0	20.8	NA	NA	NA	NA	3
	A6	Cut and seal portal to 10 m below surface; grout open holes and flood decline	3	0	-4.2	NA	NA	NA	NA	3
	A7	A3 (without grouting of open holes and bulkheads)	0	0	41.7	NA	NA	NA	NA	3
	Portal (185 m)				0.0					
	B1	Remove entire steel portal, backfill portal to ground level and cover with waste rock	1	0	-11.5	4	NA	NA	NA	3
	B2	Partially remove portal structure to just below ground level, backfill portal to ground level and cover with waste rock	0	0	30.8	4	NA	NA	NA	3
	B3	Leave entire portal in situ and cover with waste rock	2	0	-10.0					
	Vent shaft				0.0					
1	C1	Waste rock; concrete collar removed	1	0	-100.0					
1	C2	Waste rock, concrete in situ	1	0	-100.0					
	C3	Crushed waste rock; concrete collar removed	0	0	31.6	4	5	3	4	3
1	C4	Crushed waste rock; concrete collar in situ	2	0	-100.0					
	C5	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar removed	0	2	21.1	4	5	3	4	3

						Rehabilitation and Closure				
			Show stopper column setting			Yes	Yes	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description** (Criteria from Ranger Environmental Requirements BPT explanatory material)	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation ("Location")	Radiation ("Location")	Erosion ("Location")	Water ("Location")	Schedule
1	C6	Crushed waste rock up to weathered zone and then CRF to surface; concrete collar in situ	2	0	-100.0					
	C7	Steel plate; concrete collar removed and allow to flood	0	3	13.2	2	5	3	4	3
1	C8	Steel plate and allow to flood; concrete collar in situ	2	0	-100.0					
	C9	Crushed waste rock up to weathered zone, then 10 m CRF and then 10 m of crushed rock to surface; concrete collar removed	0	0	39.5	4	5	3	4	3

4 PROGRESS OF PIT 1 TO FINAL LANDFORM

Report: *Application of Progress Pit 1 Landform. 2019*

To support progress of the Pit 1 final landform, additional work was undertaken to address Supervising Scientific Branch (SSB) comments (Department of the Environment and Energy 2018) on an earlier change application (ERA, 2018a). Works included:

- a risk assessment undertaken to update the 2016 risk assessment;
- solute mass balance and water balance;
- soil-vegetation-atmosphere modelling to estimate plant available water under various conditions;
- revision of the final landform cover on Pit 1 to maximise plant available water;
- review of research relevant to rehabilitation of the Ranger Mine;
- preliminary flood modelling and hydraulic design work were updated and refined from work in 2017 to create a Digital Elevation Model (DEM); and
- erosion and sediment control features were refined based on conceptual designs developed in 2017.

The digital elevation model (DEM) was also provided to the MTC for assessment and SSB feedback was included in the change application report (ERA, 2019a). The Pit 1 Progressive Rehabilitation Monitoring Framework was developed to facilitate successful rehabilitation of Pit 1 and inform ongoing rehabilitation across the RPA. These additional works supported ERAs continued backfilling of Pit 1 ahead of the initial tree planting of the Pit 1 landform surface.

An application was submitted to the Director of Mining Operations, DITT in March 2019 in accordance with the requirements of the Ranger Authorisation issued under the Mining Management Act (NT) and was approved in May 2019.

During the life of Pit 1, ERA has undertaken many studies and BPT assessments, including:

- assessment of the selected tailings deposition options for Pit 1, to ensure the long-term stability of tailings as part of the final rehabilitated landform in 1994;
- assessment of seepage limiting options in 2005; and
- closure studies undertaken as part of a 2008 PFS, 2009 feasibility study and further review and validation of the preferred Pit 1 closure option as part of the ITWC prefeasibility study in 2012.

Landform design has involved several iterations of the post-closure landscape models over the life of the mine with significant options analysis and refinement of the landscape reconstruction over several years. Through supporting investigations and thorough refinement processes, the backfilling option being implemented is optimal. In particular, bulk backfilling of Pit 1 has been completed using the selected bulk backfill methodology.

5 TAILINGS MANAGEMENT

5.1 Integrated tailings, water and closure – PFS 1

Report: *Integrated, Tailings, Water & Closure Prefeasibility Study (ITWC PFS): Analysis of Best Practicable Technology. 2013*

The focus of the ITWC PFS program was to evaluate the technology for reclamation, treatment and transfer of tailings from the TSF to the mined-out Pit 3, and salt management technology to ensure physical containment of brine (from the BC treatment of process water) within Pit 3 with no detrimental impact to the environment for a period of 10,000 years as required by the ERs.

Options were considered for the reclamation, treatment and deposition of tailings for mine closure, which are described in the sub-sections below.

5.1.1 Tailings reclamation

Three categories were considered for reclamation of tailings from the TSF: excavation, hydraulic mining and dredging. Each category had a subset of transfer options, giving a total of nine options taken into the BPT assessment (Table 5-1).

Table 5-1: Tailings reclamation options

Category	Excavation	Hydraulic Mining	Dredging
Transfer options	• dewater and truck • dewater and conveyor • slurry and pump.	• pump • thickener and pump.	• pump • thickener and pump • thickener, filtration and truck • thickener, filtration and conveyor.

Of the reclamation and transfer options, excavation rated poorly compared with hydraulic mining and dredging. The principal deficiencies identified were the sensitivity of excavation techniques to extreme rainfall events, environmental protection and OHS issues arising from dust from the disturbed tailings, the considerable operational effort that would be required, and the drainage requirements required for successful implementation of the process. Hence, excavation was rejected as a method for reclamation of tailings from the TSF.

Hydraulic mining and dredging emerged from the workshop with approximately equal BPT assessment scores. An overall assessment of the relative significance of the various advantages and disadvantages of the two options led to the conclusion that the disadvantages of the dredging option (operability, maintainability, radiation protection) are much more amenable to management than those associated with hydraulic mining (sensitivity to extreme rainfall, environmental protection, high capital costs). This is particularly the case for the issue of sensitivity to extreme rainfall events where management options are extremely limited, and the occurrence of such events could have a major impact on the rehabilitation schedule. For this reason, dredging was selected as the preferred option.

5.1.2 Tailings treatment

The principal technical advantage of filtration is the reduced time required for tailings consolidation. It was thought to have some advantages for long-term dispersal of contaminants in groundwater, but this was yet to be demonstrated and the advantage was considered to be small. Disadvantages of this option included high costs to construct, install and operate, and the high maintenance requirements. The assessment outcome of filtration at the tailings workshop was that the option should be retained for whole-of-project BPT assessment, but it appeared to be a very expensive option with limited advantages.

Cementation was considered an option to potentially reduce dispersion of solutes in groundwater if required, however, it did not emerge as a viable treatment option. The initial BPT workshop was conducted prior to the groundwater solute transport modelling from Pit 3; this option was assessed in case treatment of tailings was required in order to achieve the 10,000 year requirement for no detrimental environmental impact. Subsequent to this BPT assessment modelling has shown that additional tailings treatment is not required to mitigate solute transport.

Further trials would be required, capital costs would be high because of the need to include filtration as a preliminary step, and operational costs would be extremely high as a result of the high cement consumption implicit in the process

5.1.3 Tailings deposition

Options assessed for deposition of tailings into Pit 3 considered either subaerial or subaqueous techniques for thickened tailings and dry stacking or co-disposal with waste rock for filtered tailings.

The assessment outcome for deposition of thickened tailings was that either option would be acceptable, however subaqueous deposition was preferred principally because it rated higher on the operability and operating costs criteria and was assessed that Traditional Owners would have a distinct visual preference for tailings covered by water rather than an exposed tailings surface. Subsequently, initial BPT workshop consolidation modelling demonstrated that subaerial deposition would provide an advantage over sub aqueous deposition. Since both options were determined to be BPT, the method was changed without the need for an additional assessment.

With filtration of tailings being retained as an option, the deposition of tailings needed to be considered. Two options were considered: dry stacking, and co-disposal with waste rock. Co disposal of filter cake and waste rock led to higher maximum elevation of tailings in Pit 3, giving preference to dry stacking. There were, however, concerns expressed about the degree to which either technique had a proven track record, and it was noted that both would be sensitive to rainfall (a dry pit would be required).

The conclusions arising from the BPT workshop on tailings management were:

- dredging is the preferred tailings reclamation method;
- cementation is not currently considered viable as a treatment method; and
- tailings filtration should be retained as a potential treatment method to be considered in the overall strategic workshops but is a very expensive option that produces little benefit.

5.2 Integrated tailings, water and closure – PFS 2

The combination of the feasible tailings management options and the feasible salt management options resulting from PFS1 and the BPT assessment are provided below:

- dredged tailings, thickened and pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill);
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with injection of brine into the constructed base of Pit 3 (underfill);
- dredged tailings, thickened then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3; or
- dredged tailings, thickened, filtered, then pumped to Pit 3 combined with crystallisation of brine to be placed within Pit 3.

These options progressed through ITWC PFS2 and were assembled into closure strategies where the preferred technical options from PFS1 were combined with two possible processing cessation dates:

- milling will cease in 2016 - these options were given a 'C' designation; or
- milling will cease at the end of 2020 consistent with the terms of the Ranger Authorisation - these options were given a 'B' designation.

This provided a total of eight closure strategies that were assessed in two stages; these are shown in Table 5-2.

Table 5-2: Initial closure strategies to be assessed

Strategy	Brine strategy	Tailings strategy	Milling end
1C	Injection	Thickened	2016
2C	Injection	Thickened and filtered	2016
3C	Crystallisation	Thickened	2016
4C	Crystallisation	Thickened and filtered	2016
1B	Injection	Thickened	2020
2B	Injection	Thickened and filtered	2020
3B	Crystallisation	Thickened	2020
4B	Crystallisation	Thickened and filtered	2020

5.2.1 Stage 1 assessment

The BPT assessment of the eight identified strategies was divided into two stages. Stage 1, or the preliminary strategic assessment, was conducted soon after completion of the individual component assessments. The intention was to eliminate strategic options that clearly did not constitute BPT, and to more clearly identify information gaps in the remaining options needing to be addressed prior to the final BPT assessment of the strategic options.

The key options that were eliminated in the stage 1 assessment were tailings filtration and brine crystallisation. The results of the stage 1 assessment are shown in Figure 5-1.

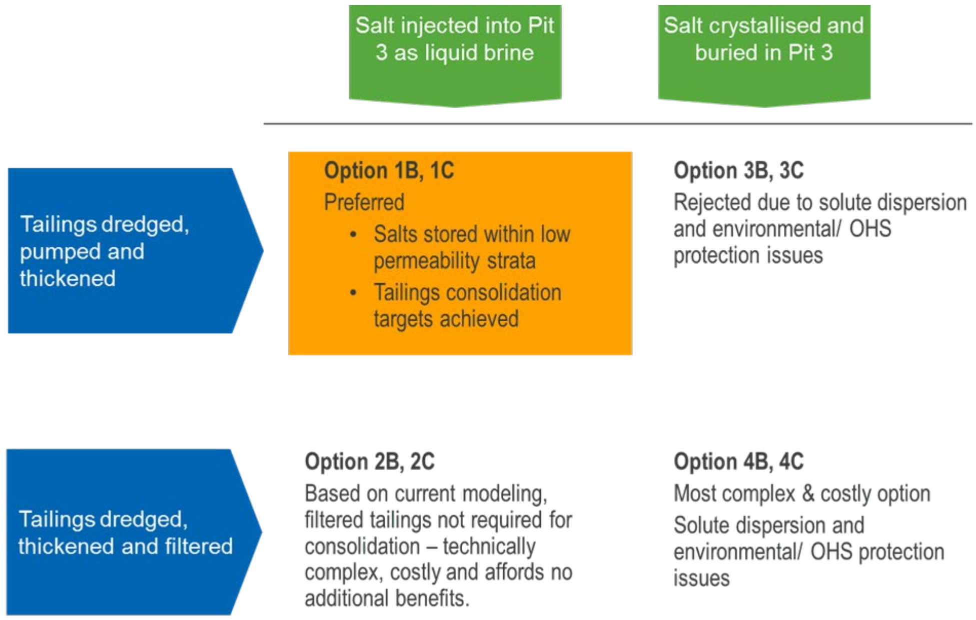


Figure 5-1: Outcomes of the Stage 1 assessment

The tailings management workshop confirmed filtration was a very expensive option with limited advantages and therefore it was decided that filtration of tailings (2C, 2B) should not be considered further in the development of the best practice strategy for rehabilitation and closure of the Ranger Mine.

Further analysis and test work completed following the initial technical options BPT workshops confirmed brine injection was the best option for management of salt. Further to this, the Stage 1 BPT confirmed brine crystallisation was not a viable option, performing poorly under several criteria. As a result, the strategies that included crystallisation (3B, 3C, 4B, 4C) of the brine stream from the water treatment plant were rejected.

5.2.2 Stage 2 assessment

Based on the Stage 1 BPT assessment, all filtration and crystallisation options were eliminated (this was further validated by programs conducted between the stage 1 BPT and the stage 2 BPT). As such, the closure strategies considered in the Stage 2 BPT workshop were limited to 1B and 1C, however, extended water treatment cases (5B and 5C) were considered as well. This was to allow for the scenario where process water volumes exceed the BC treatment capacity, allowing for longer term treatment of process water.

Table 5-3 lists the options assessed in Stage 2 (detailed ranking matrices at the end of Section 6.5).

Table 5-3: Final closure strategies assessed

Strategy	Brief description
1C	Brine injection, thickened tailings, milling until 2016
1B	Brine injection, thickened tailings, milling until 2020
5C	Strategy 1C with extended water treatment
5B	Strategy 1B with extended water treatment

The highest BPT score of 19 was recorded for Strategy 1B; the three other options scored 15. To put this result in perspective, changing the assessed score for any individual criterion by one unit would change the overall score for that option by about two units. Hence, these results imply that option 1B is the favoured option based on the BPT assessment process, but the result is marginal.

The criteria where differences were recorded were:

- socio-economic impact on Jabiru and the region: the two extended options provide additional time for community partnerships to run and continued retention of services, the 5B case also provides additional royalty income;
- technical performance: both 2020 options scored higher because the extended milling period enables the processing of lower grade ores, previously assessed as not commercially viable;
- capital expenditure: the two extended options scored higher primarily because only one BC is required for these options;
- maintainability: the 2020 milling option with extended water treatment results in the use of the BC for nine years beyond its planned lifetime;
- operating costs: the operating costs of the extended 2020 option would be higher because replacement of major BC parts would almost certainly be required; and
- schedule: both extended options scored lower than the primary options under the schedule criterion.

5.2.3 Supplementary integrated tailings, water and closure prefeasibility study

A review of the ITWC BPT assessment was conducted in August 2016. This determined, with the exception of tailings treatment, all technical options selected as BPT remained valid.

Eight options were assessed using the same assessment criteria, scoring and weighting, as used in the ITWC PFS assessment. The results are presented in Table 5-4. Of the eight options assessed, one hard show-stopper and four soft show-stoppers were identified by workshop participants.

Table 5-4: Supplementary tailings treatment assessment

Strategy	Technology	Show-stopper		Overall rank
		Hard	Soft	
A1	Thickened tailings (ITWC base case)			32.6
A2	Unthickened tailings	✓		-100
A3	Unthickened tailings, with prefabricated vertical drains (wicks)			41.3
A4	Unthickened tailings, with extended water treatment		✓	-6.5
A5	Unthickened tailings, with inline agglomeration and wicks			10.9
A6	Unthickened tailings with neutralisation and wicks		✓	17.5
A7	Thickened and filtered tailings (ITWC assessed)		✓	13.0
A8	Thickened, filtered and cemented tailings (ITWC assessed)		✓	6.8

For most of the detailed options assessed, a NA (not applicable) result was obtained for criteria in the 'Culture and Heritage', and 'Ecosystems and Natural World Heritage Values of Kakadu NP' categories. All activities associated with all options occur within the cultural heritage exemption zone. In addition, these methods do not have any impact on the surrounding ecosystems and World Heritage values of Kakadu during the operational phase. Hence, the BPT assessment of the tailings treatment options was dominated by the criteria under the 'Fit for Purpose', 'Operational Adequacy' and 'Constructability' categories.

The base case for this assessment assumed tailings would be unthickened, with three options being considered a) with wicks, b) with extended water treatment, and c) with inline agglomeration and wicks. These were assessed against the previous ITWC thickened tailings options.

The results of the BPT indicate that unthickened tailings with wicks (A3) have advantages over unthickened tailings and extended water treatment (A4) and unthickened tailings with inline agglomeration (A6). It was assessed that the use of wicks would be viewed more favourably by Traditional Owners under the 'Living Culture' criterion compared to unthickened (A2). The unthickened tailings option (A2) was hard show-stopped due to factors including: not all process water being removed during consolidation, subsidence and erosion of the landform, impacts on rehabilitation performance, impacts to water quality and the formation of visible salts in the landform surface, all of which could lead to an unwillingness for Traditional Owners to resume cultural practices on the site post-closure.

Unthickened tailings with wicks (A3) have been demonstrated as proven technology through its application in Pit 1. Prefabricated vertical drains, or wicks, present a sound technical method of achieving increased consolidation and ensuring the schedule requirements on rehabilitation on the RPA are met.

Inline agglomeration and wicks (A5) option faired less favourably across 'Fit for Purpose' and 'Operational Adequacy' categories than options A1 and A3, predominantly based on less certainty around achieving consolidation targets and potential reliability issues related to inconsistent input densities. There was also a high uncertainty around the complexity of integration with existing dredging operations, high operational expenditure and complexities associated with construction of the plant on the pit access ramp.

Unthickened with extended water treatment (A4) was soft show-stopped under category 'Construction, Environmental and Cultural risks' because of the increased number of vehicles through Kakadu National Park necessary to transport new infrastructure and the substantial increase in workforce required to construct a new water treatment plant. It emerged as the least favoured option, scoring 'inadequate to 'poor' against most categories under 'Fit for Purpose', 'Operational Adequacy' and 'Constructability'. The low ranking against these criteria was strongly influenced by high sustaining capital and operating costs associated with the existing BC, long procurement lead times required to purchase a new plant or additional infrastructure to expand the existing plant, and the complex operational nature of the plant potentially leading to a high number of interruptions and downtime.

Strategies A6 through A8 all recorded soft show-stoppers under 'Construction', 'Environmental' and 'Cultural' risks criterion, attributed to the effects of increased traffic volumes through Kakadu NP associated with new infrastructure and increased construction workforce in Jabiru. These options also recorded soft show-stoppers under OHS, attributed to increased risks of vehicle incidents during tailings transfer to Pit 3. In addition to the above, concerns identified during the ITWC PFS around strategy A8 (thickened, filtered and cemented) remain. These include the extremely high operational costs as a result of high cement consumption and uncertainty around the long-term stability of cement, which is susceptible to sulfate attack. Significantly more development work would be required before this would be considered a viable option when compared to strategies that were assessed.

5.2.4 Conclusions

The BPT assessment has considered viable thickened tailings options from the previous ITWC PFS and new, unthickened tailings treatments. Of the eight options assessed, one option was hard show-stopped (unthickened A2) and four were soft show-stopped.

Three options were considered viable; however inline agglomeration with wicks (A5) scored the lowest of the three with the assessment identifying some inherent issues around achieving consolidation targets, high operational costs and construction complexities, compared to the other two options (e.g. thickened and unthickened with wicks).

There was no material difference in the assessment scores for the thickened (A1) and unthickened with wicks (A3) options. However, ERA has extensive knowledge around strategy A3, based on the performance of the Pit 1 backfill strategy and subsequent tailings consolidation being achieved via this method.

6 TAILINGS DEPOSITION INTO PIT 3 FOR MILL TAILINGS AND DREDGE TAILINGS

Report: *Application Pit 3 Tailings Deposition. 2019*

In preparation for cessation of mining and processing activities at Ranger Mine, a further assessment of the methods for tailings deposition was undertaken. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in March 2019 to change the deposition method of tailings in Pit 3 from subaerial (to a tailings beach) to subaqueous (into water) (ERA, Alan Irving & Associates 2019). The application was approved in July 2019. The change was proposed to improve deposition, specifically to:

- prevent segregation;
- prevent accumulation of fine tailings in inundated areas of the pit; and
- accelerate backfilling with consolidated tailings.

Following detailed assessment of various subaqueous deposition configurations and multi spigot subaerial deposition options for Pit 3, a BPT assessment was undertaken in January 2019 to assess the range of potentially viable deposition options (GHD, 2019). To conduct this assessment, tailings under consideration were separated into either mill tailings or dredge tailings and scored against the six major criteria. This resulted in an overall ranking calculated for each option (Table 6-1 and the ranking matrices at the end of this sub-section).

Table 6-1: Tailings deposition options and best practicable technology assessment summary

Option	Option description	Overall Rank
Mill Tailings		
M1	Subaerial deposition from the current, multiple discharge points (one at a time, infrequently changing)	41.7
M2	Subaerial deposition from multiple spigots on the east wall (one at a time, frequently changing)	35.4
M3	Subaqueous deposition	16.7
Dredge Tailings		
D1	Dredge 1 and 2 subaerial	20.8
D2	Dredge 1 and 2 subaqueous	16.7
D3	Dredge 1 subaqueous & Dredge 2 subaerial	12.5
D4	Dredge 1 subaerial & Dredge 2 subaqueous	10.4

The BPT assessment found that for mill tailings, the two subaerial options (M1 and M2) were similarly effective, and slightly better, than subaqueous discharge (M3) due to the higher cost and greater complexity of subaqueous deposition. Option M2 has the advantage of maintaining a lower, more level tailings surface. Both M1 and M2 promote overall drainage from east to west and are more cost effective than subaqueous deposition. However, M1 scored lower on schedule and both M1 and M2 will result in a slightly higher tailings level in the east of the pit.

The assessment found that for dredge tailings, the subaerial options scored more favourably on costs, constructability, operability and maintainability criteria. This is primarily due to the lower complexity of the subaerial method and because most of the subaerial facilities are already in place. However, the subaerial options scored poorly on schedule and technical performance, as the tailings surface will be more steeply sloping with a higher maximum elevation in the pit requiring additional work to even out the tailings prior to commencement of pit capping.

Conversely, the subaqueous option scored more favourably on schedule, technical performance and environmental protection, since this method promotes less tailings segregation and more rapid consolidation, and the tailings surface will be flatter with a lower maximum elevation in the pit.

Whilst relative advantages and disadvantages were identified, and all options were considered acceptable against each of the assessment criteria, a combination of options M2 (subaerial deposition from multiple spigots on the east wall) and D2 (dredge 1 and 2 subaqueous) was selected.

BPT FINAL ASSESSMENT			Rank	Inadequate 1	Poor 2	Acceptable 3	Good 4	Excellent 5	Unable to evaluate UTE	Not applicable to this option NA
ITWC Project					TO Culture & Heritage		Protection of People and the Environment			
	Show stopper column setting			Yes	Yes	Yes	No	Yes	No	
			Rank weighting	1	1	1	1	1	1	
Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Town/Region	Ecosystems of Kakadu	Ecosystems of Project Area	
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	0	1	15	3	3	4	3	4	3	
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	0	1	15	3	3	4	3	4	3	
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	0	1	19	3	3	4	4	4	3	
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	0	1	15	3	3	4	4	4	3	

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option			
	1	2	3	4	5	UTE	NA			
ITWC Project	Fit for Purpose					Operational Adequacy				
	No	No		Yes	No	Yes	No	No	No	No
	1	1	1	1	1	1	1	1	1	1
Option Description	Proven technology	Technical performance	Robustness	Environmental Protection	CAPEX	Safety Occupational Health	Operability	Inherent availability and reliability	Maintainability	OPEX
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	4	3	4	3	3	4	4	3	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	4	3	4	4	3	4	4	3	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	5	3	4	3	3	4	4	3	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	5	3	4	4	3	4	4	2	2

BPT FINAL ASSESSMENT	Inadequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to this option		
	1	2	3	4	5	UTE	NA		
ITWC Project	Rehabilitation and Closure						Constructability		
	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
	1	1	1	1	1	1	1	1	1
Option Description	Revegetation	Radiation	Erosion	Water Quality	Tailings	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction Complexity
Strategy 1C: Brine injection; thickened tailings; Mill to 2016	4	3	3	UTE	2	2	3	4	3
Strategy 5C: Brine injection; thickened tailings; Mill to 2016 Water treatment 2026 - 2030	4	3	3	UTE	2	1	3	4	3
Strategy 1B: Brine injection; thickened tailings; Mill to 2020	4	3	3	UTE	2	2	3	4	3
Strategy 5B: Brine injection; thickened tailings; Mill to 2020 Water treatment 2026 - 2034	4	3	3	UTE	2	1	3	4	3

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area
A1	Thickened (ITWC base case)	0	0	32.6	4	NA	4	3	NA	3
A2	Unthickened	4	0	-100.0	1					
A3	Unthickened - wicks	0	0	41.3	3	NA	4	3	NA	4
A4	Unthickened - extended water treatment	0	1	-6.5	3	NA	4	3	NA	3
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	NA	4	3	NA	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	UTE	NA	4	4	NA	3
A7	Thickened & filtered tailings	0	3	13.0	4	NA	4	3	NA	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	NA	4	3	NA	2

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

		Show stopper column setting			Fit for Purpose					Operational Adequacy				
					No	No	No	Yes	No	Yes	No	No	No	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
A1	Thickened (ITWC base case)	0	0	32.6	5	4	3	4	2	4	4	4	4	3
A2	Unthickened	4	0	-100.0		1								
A3	Unthickened - wicks	0	0	41.3	5	3	2	4	3	4	5	5	5	5
A4	Unthickened - extended water treatment	0	1	-6.5	5	2	2	4	1	4	1	2	2	1
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	3	3	2	4	3	4	3	3	3	3
A6	Unthickened - neutralisation and wicks	0	2	17.5	5	UTE	2	4	2	2	4	4	4	1
A7	Thickened & filtered tailings	0	3	13.0	5	4	3	4	1	2	3	3	3	2
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	UTE	3	5	1	2	3	3	2	1

Rank	Adequate	Poor	Acceptable	Good	Excellent	Unable to evaluate	Not applicable to the option
	1	2	3	4	5	UTE	NA

		Show stopper column setting			Rehabilitation and Closure						Constructability		
					Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
A1	Thickened (ITWC base case)	0	0	32.6	4	4	3	4	4	3	4	3	4
A2	Unthickened	4	0	-100.0	1		1	1					
A3	Unthickened - wicks	0	0	41.3	4	4	3	4	4	3	3	4	4
A4	Unthickened - extended water treatment	0	1	-6.5	4	4	3	4	4	2	4	2	2
A5	Unthickened - inline agglomeration and wicks	0	0	10.9	4	4	3	4	4	3	3	3	2
A6	Unthickened - neutralisation and wicks	0	2	17.5	4	4	3	4	4	3	4	2	UTE
A7	Thickened & filtered tailings	0	3	13.0	4	4	3	4	4	4	4	2	3
A8	Thickened, filtered & cemented tailings	0	3	6.8	4	4	3	4	4	4	4	2	3

						Traditional Owner Culture & Heritage		Protection of People and the Environment			
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Ecosystems & the natural world heritage values of Kakadu	Ecosystems of the project area	Community Health and Safety	Socio-economic Impact on Local Communities	Ecosystems & natural world heritage values of Kakadu	Ecosystems of the Project Area
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	4	3	3	3	4	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	3	3	3	4	3
No	M3	Sub-aqueous	0	0	16.7	4	3	3	3	4	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	3	3	3	4	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	4	3	3	3	4	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	4	3

Best Practicable Technology Matrix continued...						Fit for Purpose					Operational Adequacy
			Showstopper column setting			No	No	No	Yes	No	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Proven technology	Technical performance	Robustness (closure only)	Environmental protection	CAPEX	Occupational health & safety
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	4	3	3	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	5	4	3	3	4	4
No	M3	Sub-aqueous	0	0	16.7	5	3	4	4	2	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	2	3	3	4	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	5	4	5	4	2	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	5	3	4	3	4	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	5	3	4	3	3	3

Best Practicable Technology Matrix continued...						Operational Adequacy				Rehabilitation and Closure	
			Showstopper column setting			No	No	No	No	Yes	Yes
Initial Showstopper	**Option #**	**Option Description**	**Showstopper 1 indicator**	**Showstopper 2 indicator**	**Overall rank**	Operability	Inherent availability & reliability	Maintainability	OPEX	Revegetation (closure only)	Radiation (closure only)
Mill Deposition											
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	5	5	5	5	3	3
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	4	5	4	4	3	3
No	M3	Sub-aqueous	0	0	16.7	3	4	3	2	3	3
Dredge Deposition											
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	5	3	4	4	3	3
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	2	3	3	2	3	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	3	3	3	3	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	3	3	3	3	3

Best Practicable Technology Matrix continued...						Rehabilitation and Closure				Constructability		
			Showstopper column setting			Yes	Yes	Yes	No	Yes	Yes	No
Initial Showstopper	Option #	Option Description	Showstopper 1 indicator	Showstopper 2 indicator	Overall rank	Erosion (closure only)	Water (closure only)	Tailings (closure only)	Schedule	Construction occupational health & safety	Construction environmental and cultural risks	Construction complexity
Mill Deposition												
No	M1	Sub-aerial, discharge from single point at a time - infrequent switching between two locations (current scenario)	0	0	41.7	3	NA	4	2	4	5	4
No	M2	Sub-aerial, discharge from a single point at a time - frequent switching between multiple locations (spigots)	0	0	35.4	3	NA	4	3	4	5	4
No	M3	Sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
Dredge Deposition												
No	D1	Dredge 1: sub-aerial Dredge 2: sub-aerial	0	0	20.8	3	NA	3	1	4	5	4
No	D2	Dredge 1: sub-aqueous Dredge 2: sub-aqueous	0	0	16.7	3	NA	4	3	3	5	3
No	D3	Dredge 1: sub-aqueous Dredge 2: sub-aerial	0	0	12.5	3	NA	3	2	3	5	3
No	D4	Dredge 1: sub-aerial Dredge 2: sub-aqueous	0	0	10.4	3	NA	3	2	3	5	3

7 REMNANT TAILINGS TRANSFER

The bulk of the tailings within the Tailings Storage Facility (TSF) was dredged and transferred into Pit 3 in 2020/2021. Remnant tailings, the material that remained on the TSF floor and walls after the bulk tailings transfer, also needed to be encapsulated in Pit 3 as per the ERs. This BPT investigated 10 options to determine the best method to undertake this activity.

A BPT workshop was conducted in February 2021 to assess the range of potentially viable transfer options. Each option was assessed against the relevant criteria and the resulting scores are shown in Table 7-1.

Table 7-1: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
1	Pre-Cap Pump (base case)	2
2	Post-Cap Truck (Pit 3 west end)	6
2a	Post-Cap Truck (Pit 3 east end)	0
2b	Post-Cap Truck (temp store in Pit 3 THWS rather than TSF SE temp cell)	-6
3	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall, tailings slurried to push lower into pit)	17
3a	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	6
3a (i)	Pre-Cap Truck (deposit into Pit 3 south west end, down pit wall)	4
3b	Pre-Cap Truck, sucker truck ramp to north wall (below cap)	2
3c	Pre-Cap Truck, Pit 3 west ramp, barge or floating conveyor transfer to west central end of pit	0
4	Bury tailings in TSF	Hard show-stopped

Option 3 was selected as the preferred method for the transfer of remnant tailings, having the highest score of 17. Each individual criteria ranked for Option 3 received as '3' or greater, indicating that the selected approach meets or exceeds current standards across all assessed fields.

The remnant tailings transfer commenced in Q2 2021, following construction of the Pit 3 tip head and upgrades to the required haul roads. Some of the remnant tailings have 'hung up' on the internal wall of Pit 3 and the most effective method to move these tailings deeper into the pit is the subject of current assessment.

8 HIGH DENSITY SLUDE PLANT RECOMMISSIONING

Report: *Application to release water from High Density Sludge (HDS) Plant. 2020*

The HDS plant was recommissioned on a trial basis in 2019 with the HDS product water recycled into the process water inventory. The recommissioning of the HDS plant was a planned strategy to increase the capacity of process water treatment during closure. An application was submitted to the Director of Mining Operations, DPIR (now DITT) in January 2020 to approve the release of HDS treated process water generated from the recommissioned plant by either of the following options:

- direct treatment through Water Treatment Plant 1 (WTP1) and subsequent release to the Corridor Creek Wetland Filter;
- indirect treatment by releasing HDS product into the pond water inventory, for subsequent treatment through any of the pond water treatment plants (WTPs).

Approval was granted in February 2020 with specification for discharge of water to RP2 when releasing HDS product water via indirect treatment as per the application. This approval was contingent on ERA implementing operational controls described in the revised application.

To support this application a BPT assessment was conducted to build upon the previous BPT analysis that was completed to support the original construction of the HDS plant in 2004. The recent BPT assessment evaluated twelve (12) options to address additional process water treatment capacity. The majority of options scored high (31 – 44.4) and differed marginally in the weighting of individual criteria namely 'Robustness', 'Cost', 'Schedule' and 'Construction complexity' (Table 8-1 and the ranking matrices at the end of this section).

Table 8-1: BPT Overall ranking for HDS recommissioning and release

Option	Option description	Score
5.1	Recommission the existing HDS plant, full treatment and transfer of product water direct to WTP1 (dry season only).	31.0
5.2	Recommission the existing HDS plant, full treatment and transfer product water direct to pond water inventory (year round).	33.3
5.3	Recommission the existing HDS plant, adaptive operation (full treatment) with product transfer to either WTP1 (dry season) or pond water storage (year round).	33.3
5.4	Recommission the existing HDS plant, partial treatment and transfer product water direct to WTP1 (year round).	31.0
6.1	Repurpose of mill infrastructure for large scale HDS treatment.	16.7
6.2	New build of larger HDS plant for large scale HDS treatment.	16.7
7.1	BC single train equivalent construction.	35.7
7.2	BC duplication construction.	33.3
8.1	Direct feed process water (untreated) to existing UF/RO infrastructure.	40.5
8.2	Direct feed process water (untreated) to new UF/RO infrastructure similar to current.	33.3
8.3	Discharge process water (untreated) direct to pond water inventory (untreated).	38.1
11	Do nothing.	44.4

All options exceeded current standards for environmental protection and proven technology. The options that ranked highest overall (38.1 – 44.4) were assessed as not feasible for current implementation on the basis that they did not align with the overarching objectives, required significantly high capital expenditure ($10M+), or would likely cause impacts to the closure schedule (i.e. construction delays or conflicts with other closure commitments).

The option identified as most suitable for implementation involved the use of the existing HDS plant under adaptive operational conditions to optimise treatment capability (option 5.3). This option received the mean overall ranking (33.3) and represents a rational approach to addressing project limitations whilst maintaining effective environmental outcomes.

					TO Culture & Heritage		Protection of People and the Environment			
		Show stopper column setting				Yes	Yes	No	Yes	Yes
Option ID	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local	Ecosystems & Natural world heritage	Ecosystems of the Project Area
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	3	4	4	3	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	3	4	4	3	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	3	4	4	3	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	3	4	4	3	4	4
6.1	Re-purpose mill infrastructure			16.7	3	4	3	3	4	4
6.2	New build HDS plant			16.7	3	4	3	3	4	4
7.1	BC single train equivalent			35.7	3	4	4	3	5	5
7.2	BC duplication			33.3	3	4	4	3	5	5
8.1	Direct feed to existing UF/RO infrastructure			40.5	3	4	4	3	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	3	4	4	3	4	4
8.3	Discharge direct to pond inventory			38.1	3	4	4	3	4	4
11	Do nothing			44.4	3	4	4	3	5	5

Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX	Occupational Health & Safety	Operability	Inherent availability and reliability	Maintainability	OPEX
					Fit for Purpose					Operational Adequacy				
		Show stopper column setting			No	No		Yes	No	Yes	No	No	No	No
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	4	4	3	4	4	4	3	3	3	3
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	4	4	3	4	4	4	3	4	3	3
5.4	Recommission the existing HDS plant, partial treatment			31.0	4	4	3	4	4	4	3	3	3	3
6.1	Re-purpose mill infrastructure			16.7	4	4	4	4	3	4	3	4	3	3
6.2	New build HDS plant			16.7	4	4	5	4	2	4	3	4	3	3
7.1	BC single train equivalent			35.7	4	5	4	5	2	4	4	4	4	3
7.2	BC duplication			33.3	4	5	5	5	1	4	4	4	4	3
8.1	Direct feed to existing UF/RO infrastructure			40.5	4	3	3	4	5	4	4	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	4	3	4	4	2	4	4	4	4	4
8.3	Discharge direct to pond inventory			38.1	4	3	2	4	5	4	4	4	4	4
11	Do nothing			44.4	5	4	1	4	5	4	NA	NA	NA	3

					Rehabilitation and Closure						Constructability		
		Show stopper column setting			Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
5.1	Recommission the existing HDS plant, product to WTP1, dry season only operation, full treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
5.2	Recommission the existing HDS plant, product to pond water, year round operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.3	Recommission the existing HDS plant, adaptive operation, full treatment			33.3	NA	NA	NA	4	NA	3	4	4	4
5.4	Recommission the existing HDS plant, partial treatment			31.0	NA	NA	NA	4	NA	3	4	4	4
6.1	Re-purpose mill infrastructure			16.7	NA	NA	NA	3	NA	2	3	3	2
6.2	New build HDS plant			16.7	NA	NA	NA	3	NA	2	3	3	2
7.1	BC single train equivalent			35.7	NA	NA	NA	4	NA	3	3	3	2
7.2	BC duplication			33.3	NA	NA	NA	4	NA	2	3	3	2
8.1	Direct feed to existing UF/RO infrastructure			40.5	NA	NA	NA	4	NA	3	4	4	4
8.2	Direct feed to new UF/RO infrastructure similar to current			33.3	NA	NA	NA	4	NA	3	4	4	3
8.3	Discharge direct to pond inventory			38.1	NA	NA	NA	4	NA	3	4	4	4
11	Do nothing			44.4	NA	NA	NA	4	NA	1	5	5	5

9 TSF NORTH NOTCH STAGE 3

Report: *Application to reduce the certified crest height of the Ranger Mine Tailings Storage Facility North Notch Stage 3. 2020*

The water level of the TSF continued to be lowered to maximise the efficiency of the dredges during the transfer of tailings to Pit 3. As a result of the lowering water level, there was a need to create notches within the TSF walls to increase the pumping efficiency and to maintain safe access to the floating infrastructure. An application was submitted to the Director of Mining Operations, Department of Primary Industry and Resources (DPIR) (now Department of Industry, Tourism and Trade [DITT]) in April 2020 to approve reduction of the clay core crest height to Relative Level (RL) 37.8 m and to manage future raises in crest height with the construction of clay bunds across the notch if required. The DPIR (now DITT) approved the application in June 2020 and agreed to the provision of water balance modelling updates of the inventory at the beginning of each dry season to ensure sufficient capacity for the upcoming wet season.

Notching the TSF wall proved to be fit for purpose and environmentally sound for the construction of the previous three notches. The construction of a further notch within the footprint of the North wall notch did not require a BPT assessment. However, the reduction in crest height to a level that enabled the completion of dredging presented a risk of inadequate water storage volume when considering the future needs of the TSF for process water storage facility. The purpose of this BPT assessment was to identify the most environmentally sound approach for ongoing safe access to the TSF during dredging whilst ensuring adequate crest height to meet the freeboard requirements of the Ranger Authorisation until 2024.

A total of six options were assessed as part of the BPT assessment (Table 9-1 and the ranking matrices at the end of the section).

Table 9-1: BPT options assessment for TSF notch

Option	Option description	Score
A1	Construct North Notch 3 to RL 36. (clay core RL 35.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A2	Construct North Notch 3 to RL 37.3 m (clay core RL 36.8 m) & construct clay bund in dry season if required as determined by process water inventory predictions for the following wet season.	0
A3	Construct North Notch 3 to RL 36.3 m RL. Infill the notch to Stage 2 level following completion of TSF cleaning operation.	0
A4	No additional notch. 1.1 Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services and gantry into a local cutting. Crane used from Notch 2 for large lifts.	-2.8
-A5	Continue use of North Notch 2 using large crane and modified gantry.	Hard show-stopper
A6	North-East Ramp. Remove current ramp in North-East corner of TSF. Cut in new ramp, beginning from further back, in stockpile area, and notching down into TSF wall to RL36.3m. Creates notch in North-East corner. Access as per A1.	-19.4

Most of the options received scores close to zero, indicating that they meet industry standard. No option was considered to substantially exceed industry standard. This is expected given the unfamiliar activity of removing tailings from a tailings storage facility. The continued use of North Notch 2, requiring a modified gantry and an estimated 600–700 tonne crane for ongoing access to the lift workboats, was hard show-stopped at the beginning of the assessment. Gantry modification to the extent required to meet safety requirements was considered to be prohibitively expensive.

Option A2, the construction of a third notch in the North wall to a height of RL 37.3 m, was determined to be the most suitable approach. This option includes the contingency to construct a clay bund within the notch if it is required to ensure adequate freeboard during the wet seasons. It is assumed that Pit 3 remains available to receive process water from the TSF during extreme weather events to minimise the risk of overflow into the notch.

Although options A1 and A3 received the same final overall ranking, option A2, with the higher notch level, has a lower capital expenditure and construction time than A1 and A2. Capital expenditure and construction time includes clay bund and notch infill. There is a risk of overtopping the notch resulting in seepage into the dam walls in option A2. This risk is removed with the infill of the notch as proposed in option A3. Proposed risk mitigation measures, such as the construction of a clay bund and the cessation of tailings pore water transfer from Pit 3 reduce this risk to an acceptable level and justified the selection of option A2 over option A3.

						Protection of People and the Environment			Fit for Purpose				
			Show stopper column setting			Yes	No	Yes	No	No		Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Community health & safety	Socio-economic impact on local communities	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Technical performance	Robustness (closure only)	Environmental Protection	CAPEX
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1			3	3	3	2	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1			3	3	2	2	4	4
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1			3	3	3	3	4	1
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6			3	2	2	3	3	3
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0								
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8			3	2	3	2	1	1

Energy Resources Of Australia

						Operational Adequacy					Rehabilitation and Closure		Constructability		
			Show stopper column setting			Yes	No	No	No	No	No	No	Yes	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Occupational Health & Safety	Operability	Inherant availability & reliability	Maintainability	OPEX	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Construct North Notch 3 to RL36.3m & construct clay bund if required.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A2	Construct North Notch 3 to RL37.3m & construct clay bund if required.	0	0	-3.1	3	2	3	3	3	3	3	3	3	3
	A3	Construct North Notch 3 to RL36.3m. Infill the notch again to Stage 2 height after the TSF cleaning operation.	0	0	-3.1	3	3	3	3	3	3	3	3	3	3
	A4	Excavate progressive ramp in upstream embankment face from current North Notch 2. Relocate services & gantry into cutting. Use crane for large lifts.	0	0	-15.6	3	2	1	3	4	3	3	3	3	2
Yes	A5	Continued use of North Notch Stage 2 with large crane and modified gantry			0.0										
	A6	NE Ramp & notch - cut in new ramp from the stockpile area, notch down to RL36.3m.	0	0	-18.8	3	3	3	3	3	3	3	3	3	3

10 TAILINGS STORAGE FACILITY SUBFLOOR MATERIAL MANAGEMENT

Report: *MTC Application Ranger Mine Tailings Storage Facility – Subfloor Material Management. 2020*

ERA undertook an assessment into the viable options for managing the TSF subfloor contaminated material as part of closure planning for the TSF and Pit 3. The assessment was aimed at assessing the environmental impact of leaving the contaminated material *in situ* rather than disposal into Pit 3. The reason for this tightly defined scope was to determine if the planning and application for the closure of Pit 3 was required to consider this subfloor material. The deconstruction of the TSF does not occur until later, and as such, this application was submitted prior to the Pit 3 application and the actual Pit 3 capping works.

Based on the outcomes of the BPT assessment, an application was submitted to the Director of Mining Operations, DITT for approval in March 2020. The application was updated in June 2020 following stakeholder feedback and the DITT approved the application in August 2020.

The BPT assessment involved comparing the option of leaving the contaminated subfloor material *in situ* against a number of methodologies for disposing the material within Pit 3 (Table 10-1 and the ranking matrices at the end of this section).

Option 1 was developed as a worst-case scenario for leaving the material *in situ*. Option 2 was omitted from further assessment, to allow for completion of the relevant supporting studies. It is intended that Option 2 will be reviewed on the basis that Option 1 demonstrates a greater 'net environmental benefit' than Option 3 as part of this initial assessment. A total of 12 options were reviewed for disposal of the material within Pit 3.

Table 10-1: BPT assessment options and overall ranks for TSF Contaminated Material Management

Option	Option description	Score
1a	Leave material *in situ*. TSF subfloor material left undisturbed in situ. All visible tailings removed. TSF is then used for process water storage.	38.2
2	Leave material *in situ*. TSF subfloor material left undisturbed in situ with some form of remediation which may use TSF wall material for capping or another methodology.	Initial show-stopper
3a.1	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 for use as secondary cap. TSF used for process water storage.	-17.6
3a.2	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, intermediate stockpile, with transfer to Pit 3 for use as primary cap.	Initial show-stopper
3a.3	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, no stockpile, placed within south-west of Pit 3 as primary cap wedge deposit. TSF used for process water storage.	-35.3
3a.4	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via dredging, not stockpiled, with transfer to Pit 3 for use as primary cap. TSF used for process water storage.	Initial show-stopper
3a.5	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, crush, screen and pump to Pit 3 (above tailings). TSF used for process water storage.	-41.2

Option	Option description	Score
3a.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed via mechanical removal, stockpiled, with transfer to Pit 3 and intermixed with mineralised waste rock (co-disposal). TSF used for process water storage.	-23.5
3a.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically, stockpiled, with transfer to south-west of Pit 3 as secondary cap wedge deposit. TSF used for process water storage.	-23.5
3b.1	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and use as secondary cap. TSF used for process water storage.	Initial show-stopper
3b.2	Dispose of material within Pit 3. 20 m of TSF subfloor material removed mechanically, stockpiled, partially transferred to Pit 3 and use as secondary cap with remainder to other onsite storage cell. TSF used for process water storage.	Initial show-stopper
3c.7	Dispose of material within Pit 3. 4 m of TSF subfloor material removed mechanically, stockpiled, transferred to Pit 3 and placed in south-west as secondary cap deposit. TSF used for process water storage.	-29.4
3d.6	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Schedule optimised.	-29.4
3d.7	Dispose of material within Pit 3. 2 m of TSF subfloor material removed mechanically after TSF use as water storage is complete. Solute optimised.	-29.4

To compare Options 1 and 3, an understanding of the risk of contaminants mobilising into the surrounding environment was necessary to determine how effectively the TSF subfloor could be isolated at each management location. Isolation effectiveness is assessed with regard to the likelihood of contaminants entering groundwater and surface waters, which create solute transport pathways and potentially increase exposure of contaminants to sensitive receptors. The management option that poses the lowest environmental risk and/or avoids having 'a net adverse effect' would be considered the most viable for implementation.

Option 1a (leave *in situ*) ranked highest overall and is the only option with a positive ranking of 38.2. This option scored highest overall for aspects such as 'Environmental Protection', 'Living Culture', 'Cultural Heritage', 'Ecosystems & Natural World Heritage', and 'Tailings', indicating that these aspects meet current standards and are more likely to achieve greater level of environmental and cultural protection than the other management options. This option scored lowest overall for 'Revegetation' (3) and 'Erosion' (2), indicating that this option presents greater risk to final landform management than the Pit 3 transfer options. Overall, this option had the least number of soft show-stopper aspects ('Community Health', 'Radiation' and 'Erosion') in comparison to the other options and was identified as the most viable option for contaminated material management.

ERA Energy Resources Of Australia

						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture (Closure)	Cultural heritage	Community Health & Safety	Ecosystems & Natural world heritage values of Kakadu National Park	Proven technology	Robustness (closure only)	Environmental Protection	CAPEX
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	5	2	3	5	5	4	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0								
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	2	3	2	2	4	4	3	2
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	2	2	2	2	2	4	3	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0								
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	2	3	2	1	2	4	3	1
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	2	2	2	2	4	4	3	2

						TO Culture & Heritage		Protection of People and the Environment		Fit for Purpose			
			Show stopper column setting			Yes	Yes	Yes	Yes	No	No	Yes	No
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Environmental Protection	CAPEX	Occupational Health & Safety	Inherent availability and reliability	Revegetation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0								
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0								
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	2	3	2	2	4	4	2	1
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** schedule optimised ** Note: **It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	2	2	2	2	4	4	3	1
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** solute optimised ** Note: **It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	2	2	2	2	4	4	3	1

Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Revegetation (Closure only)	Radiation (Closure only)	Erosion (Closure only)	Water (Closure only)	Tailings (Closure only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
						Rehabilitation and Closure						**Constructability**		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
	Option 1a	TSF subfloor material left undisturbed in situ, post tailings clean includes all visible tailings removed from the TSF floor. Then TSF used for process water storage.	0	3	38.2	3	2	2	2	3	5	5	5	5
Yes	Option 2	In situ remediation. As per Option 1. then remediated.	0	0	0.0									
	Option 3a.1	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	4	-17.6	4	2	3	1	2	2	3	3	3
Yes	Option 3a.2	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.3	TSF sub floor material removed to 2 m below composite floor via mechanical removal - no stockpile - move to south west of Pit 3 as primary cap wedge deposit. Then TSF used for process water storage.	0	7	-35.3	4	2	3	1	2	2	2	2	2
Yes	Option 3a.4	TSF sub floor material removed to 2 m below composite floor via dredging - no stockpile - move to Pit 3 and use as primary cap. Then TSF used for process water storage.	0	0	0.0									
	Option 3a.5	TSF sub floor material removed to 2 m below composite floor via mechanical removal - crush, screen & pump to Pit 3 (on top of tailings). Then TSF used for process water storage.	1	4	-41.2	4	2	3	1	1	1	2	3	2
	Option 3a.6	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use by co-disposal with mineralised waste rock. Then TSF used for process water storage.	0	6	-23.5	4	2	3	1	2	2	3	2	3
	Option 3a.7	TSF sub floor material removed to 2 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-23.5	4	2	3	2	2	2	3	2	2

						Rehabilitation and Closure						Constructability		
			Show stopper column setting			Yes	Yes	Yes	No	No	No	Yes	Yes	No
Initial show stopper	Option ID	Option Description	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	0	0	0	0	0	0	0	0	0
Yes	Option 3b.1	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - move to Pit 3 and use as secondary cap. Then TSF used for process water storage.	0	0	0.0									
Yes	Option 3b.2	TSF sub floor material removed to 20 m below composite floor via mechanical removal - stockpile - partially move to Pit 3 and use as secondary cap with remainder to other onsite storage cell. Then TSF used for process water storage.	0	0	0.0									
	Option 3c.7	TSF sub floor material removed to 4 m below composite floor via mechanical removal - stockpile - move to south west of Pit 3 as secondary cap wedge deposit. Then TSF used for process water storage.	0	6	-29.4	4	2	3	1	2	2	3	2	2
	Option 3d.6	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** schedule optimised ** Note: **It means to best maintain the closure schedule, thus the subfloor material would be near the surface of Pit 3 backfill.	0	6	-29.4	4	2	3	1	2	1	3	2	3
	Option 3d.7	TSF cleaned up then used for process water storage until required for use. TSF sub floor material removed prior to TSF deconstruction to 2 m below composite floor via mechanical removal ** solute optimised ** Note: **It means to stop work on Pit 3 backfill until the TSF subfloor material is available to put as low in pit as possible. Thus the closure schedule is exceeded by years.	0	6	-29.4	4	2	3	2	2	1	3	2	2

11 BLACKJACK WASTE DISPOSAL

Report: *Best Practicable Technology (BPT) Assessment Blackjack Waste Disposal. Coffey 2018*

July 2018, Coffey Services Pty Ltd (Coffey) facilitated a BPT workshop to assess options for the disposal of hydrocarbon waste generated by the Ranger Mine. As part of uranium ore processing, a hydrocarbon lubricant known as blackjack (gear oil), is injected onto the spindle of the ball mill. The inventory forecasted at closure is approximately 72 kL, which equates to approximately 10 (205 L) waste blackjack drums produced annually. There are potential risks associated with blackjack disposal.

Analysis of drummed waste blackjack concluded that the waste at Ranger is contaminated above exemption levels as set out in the National Directory for Radiation Protection (Welman, 2013). Therefore, the waste blackjack cannot be disposed of off-site at a non-radioactive waste facility. The disposal of blackjack is required to be in line with Rio Tinto and ERA policies and standards, and the Ranger ERs. Another risk includes the possibility of light-non-aqueous phase liquids to separate as free product from the blackjack and potentially leak into groundwater. As part of the BPT assessment, each option submitted for review identified and discussed the potential risks associated with the method proposed.

The BPT assessment considered five options for waste disposal including:

- Tellus ‑ National Geological Repository (A1)
    - Transport the blackjack drums in containers via road trains to the selected geological repository (multi-barrier safety case) located at Sandy Ridge (WA) to permanently isolate the waste from the biosphere. The waste will be pre-treated to immobilise contaminants prior to disposal in a bed of low permeability clay.
- Scholer ‑ Diesel fired waste incinerator (A2)
    - Design, manufacture and supply a two-stage waste oil incinerator for consecutive burning of black jack at the Ranger Mine. Overall, the two-stage incineration system ensures complete combustion, eliminating discharge of any toxic incompletely combusted compounds, including potential and actual carcinogenic combustion by-products.
- CDM Smith – Immobilisation & In-cell disposal of contained blackjack in Pit 3 (A3)
    - A proposal was submitted by CDM Smith based on a concept design to include an underground repository during the backfilling of Pit 3. The blackjack waste in this case would be pre-treated and immobilised, retained in a containment structure and buried in a multi-layered barrier system. With regards to pre-treatment, the blackjack waste will be treated physically (solidification process) and chemically (stabilisation process) then be encapsulated within a purpose-built cell in Pit 3 to provide additional layers of containment.

- In-cell disposal of contained blackjack in Pit 3 (A4)
    - Blackjack waste that is currently stored in metal drums will be placed in a containment structure and backfilled in-between waste rock and tailings in Pit 3. This excludes the pre-treatment process and immobilisation as per the CDM Smith A3 option above.
- National radioactive waste management facility (A5)
    - A national radioactive waste management facility was included as part of the original submissions of options however was removed from further consideration before the scheduled BPT assessment, as the proponents were unable to meet the closing date for submissions.

The BPT Assessment determined rankings for each of the five options (Table 11-1 and the ranking matrices at the end of this section).

Table 11-1: Blackjack disposal options and best practicable technology assessment summary

Option	Option description	Score
A1	Tellus – National Geolgoical Repositories	50.0
A2	Scholer – Waste Oil Incinerator	23.8
A3	CDM Smith – Immobilisation and in-cell disposal into Pit 3	-7.1
A4	In-cell disposal into Pit 3	-2.5
A5	National radioactive waste management facility	0.0

Tellus' National Geological Repository (Option A1) received the highest overall score, with 50 points. The second highest was Scholer's Waste Oil Incinerator, scoring 23.8 points. Tellus' National Geological Repository (Sandy Ridge) has received final approval and licencing to accept low-level radioactive waste and is the adopted option.

			Show stopper column setting			Yes	Yes	Yes	No	Yes	Yes	Yes
						TO Culture & Heritage		**Protection of People and the Environment**				
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Living culture	Cultural heritage	Community Health & Safety	Socio-economic Impact on Local Communities	Ecosystems & Natural world heritage values of Kakadu National Park	Ecosystems of the Project Area	Long term protection of the environment (Operations only)
	A1	Tellus - National Geological Repositories	No	No	50.0	3	3	4	NA	3	5	5
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	2	3	NA	3	3	5
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	4	4	NA	4	4	3
	A4	In-cell disposal into pit 3	No	Yes	-2.5	3	4	4	NA	4	4	1
	A5	**National Radioactive Waste Management Facility	Yes		0.0							

			Show stopper column setting			No	No	Yes	No	Yes	No	No	Yes	Yes	No
						Fit for Purpose			**Operational Adequacy**	**Rehabilitation and Closure**			**Constructability**		
Initial show stopper	**Option ID**	**Option Description**	Show stopper 1 Indicator	Show stopper 2 Indicator	Overall rank	Proven technology	Technical performance	Environmental Protection	OPEX	Environmental Acceptability (Operations only)	Cost (Operations only)	Schedule	Construction Occupational Health & Safety	Construction Environmental and Cultural risks	Construction complexity
	A1	Tellus - National Geological Repositories	No	No	50.0	4	3	4	5	5	5	5	NA	4	NA
	A2	Scholer - Waste Oil Incinerator	No	Yes	23.8	4	4	4	3	3	3	5	3	4	3
	A3	Immobillsation and In-cell disposal into pit 3	No	Yes	-7.1	4	2	2	3	1	3	2	2	4	2
	A4	In-cell disposal into pit 3	No	Yes	-2.5	4	2	1	4	1	3	2	2	4	3
	A5	**National Radioactive Waste Management Facility	Yes		0.0										

REFERENCES

Bryant PA, Croft J, Cole P. (2017). Integration of risks from multiple hazards into a holistic ALARA/ALARP demonstration. *J Radiol Prot*. 2018 Mar;38 (1):81-91. doi: 10.1088/1361-6498/aa8e53. Epub 2017 Dec 6. PubMed PMID: 29211686.

Department of the Environment and Energy. 2018. *RE: Ranger Pit 1 Final Landform*. 27 September 2018.

Ecologically Sustainable Development Steering Committee. 1992. *National Strategy for Evological Sustainable Development,* Available: http://www.environment.gov.au/about-us/esd/publications/national-esd-strategy [Accessed July 2019].

Energy Resources of Australia Ltd. 2018a. *Application to Progress Pit 1 Final Landform*, March 2018.

Energy Resources of Australia Ltd. 2018b. *Application: Ranger 3 Deeps Exploration Decline Decommissioning*, 21 September 2018.

Energy Resources of Australia Ltd. 2019a *Application to Progress Pit 1 to Final Landform.* For Energy Resources of Australia Ltd. 1 March 2019.

Energy Resources of Australia. 2019b. *Application to operate a brine squeezer*, 7 January 2019.

Energy Resources of Australia Ltd, Alan Irving & Assoc. 2019. *Application Pit 3 Tailings Deposition.* For Energy Resources of Australia Ltd, 29 March 2019.

GHD 2019*. Best Practicable Technology Assessment for Tailings Deposition in Pit 3.* For Energy Resources of Australia Ltd, 07 February 2019.

Hatch. (2021). *Pit 3 Capping Trade Off Study - Final Report*. Hatch. Document Number H366609-00000-100-066-0001.

IAEA (2010). Frequently Asked Questions on ALARA…optimization of doses for occupational exposure. IAEA consultancy meeting, 4th and 5th of March 2010 https://nucleus.iaea.org/sites/orpnet/resources/frquentlyaskedquestions/SitePages/Home.aspx accessed 19 September, 2019.

Johnston, A and Iles, M. 2013. *Integrated, Tailings, Water and Closure Prefeasibility Study - Analysis of Best Practicable Technology*. Energy Resources Australia Ltd, Darwin. April 2013, p 112.

Murphy, J, 2018. *Ranger 3 Deeps exploration decline decommissioning plan.* Energy Resources of Australia Limited, Darwin, NT.

Supervising Scientist. 2000. *Ranger Environmental Requirements Section 19.2 Explanatory Material: Best Practicable Technology*.

Supervising Scientist Branch. 2018. approval letter for Progress of Pit 1 to Final Landform. 27 September 2018.

Supervising Scientist Branch. 2020. SSB letter to L Bryce, pers comms, 12 October 2020.

Supervising Scientist Division. 2001. *Annual report 2000 - 2001*. Department of the Environment and Heritage, Canberra. 3 October 2001, p 32.

NLC. 2020. Northern Land Council letter to Paul Arnold, pers comms. Ref: E2020/13572, 1 September 2020.

APPENDIX 5.1: CONSOLIDATED KKN LIST

CONSOLIDATED KNN LIST

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
Landform					
LAN1A	What are the baseline rates of gully formation for areas surrounding the RPA?	Closed Out	Determine baseline extent, size and rate movement of gullies in undisturbed areas surrounding the mine site.	OSS	Cancelled
LAN1B	What are the baseline rates of sediment transport and deposition in creeks and billabongs?	Open	Assessment of sedimentation risk to on-site and off-site billabongs.	OSS	Completed
			What are the baseline rates of sediment transport and deposition in creeks and billabongs?	OSS	Active
			Mapping and characterisation of geomorphology of on-site creeks in and adjacent to the mine site, including historical change.	OSS	Completed
			Determine the baseline depths of 3 Billabongs downstream of the Ranger mine site using a comparison of standard survey methods and drone based survey.	OSS	Proposed
LAN2A	What major landscape-scale processes could impact the stability of the rehabilitated landform (e.g. fire, extreme events, climate)?	Open	Extreme natural events and the stability of tailing repositories at Ranger Uranium Mine, NT. Blong, R and Mitchell, P (1996).	ERA	Completed
			Ranger uranium mine closure first pass climate change assessment. BMT (2020).	ERA	Completed
			Evaluation of features, events and processes and safety functions for the Ranger uranium mine. Kozak, M, Sigda, J, Jones, T, Iles, M and Pugh, L (2017).	ERA	Completed
			SSB Paper: Managing for extremes: potential impacts of large geophysical events on Ranger Uranium Mine, N.T. Erskine, WD, Saynor, MJ, Jones, D, Tayler, K and Lowry, J (2012).	OSS	Completed
LAN2B	How will these landscape-scale processes impact the stability of the rehabilitated landform (e.g. mass failure, subsidence)?	Open	Impact of Cyclone Monica on Gulungul Creek catchment, Ranger mine site and Nabarlek area.	OSS	Completed
			Landslips in the upper Magela catchment.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
LAN3A	What is the optimal landform shape and surface (e.g. riplines, substrate characteristics) that will minimise erosion?	Open	Preliminary flood modelling and hydraulic design.	ERA	Completed
			Rock Size Distribution on Pit 1 final landform.	ERA	Completed
			Impact of rip lines on runoff and erosion from the Ranger trial landform.	OSS	Completed
			Water, Erosion and Sediment Control Plan incorporating LEM Revision.	ERA	Newly Proposed
LAN3B	Where, when and how much consolidation will occur on the landform?	Open	Pit 1 Tailings consolidation modelling.	ERA	Completed
			Pit 3 Tailings consolidation modelling.	ERA	Completed
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)?	Open	Ranger trial landform erosion research.	OSS	Active
			Assessing the geomorphic stability of the Ranger trial landform: calibrating model outputs.	OSS	Completed
			Determining and testing representativeness of long-term rainfall patterns for use in final landform modelling.	OSS	Completed
			Analysis of data from historical unpublished erosion studies in the ARR.	OSS	Completed
			Development of enhanced vegetation component for the CAESAR model.	OSS	Completed
			Calibrating suspended sediment outputs of the CAESAR-Lisflood LEM for application to the rehabilitated Ranger mine – Gulungul Creek scale.	OSS	Completed
			Weathering of Ranger waste rock to inform landform evolution model predictions.	OSS	Completed
			Assessment of the constructed Pit 1 landform using the CAESAR-Lisflood LEM.	OSS	Completed
			An improved method for modelling erosion and gully formation on the Ranger landform.	OSS	Completed
LAN3D	What are the erosion characteristics of the final landform under a range of modelling scenarios (e.g. location, extent, timeframe, groundwater expression and effectiveness of mitigations)?	Open	Assessing the geomorphic stability of the proposed rehabilitated Pit 1 landform.	OSS	Completed
			Model Geomorphic stability of Pit 1 landform.	OSS	Completed
			Model the geomorphic stability of the landform for up to 10,000 years – finalising longterm rainfall datasets and weathering impacts for the landform.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Model geomorphic stability of pre-mine landform for up to 10,000 years.	OSS	Completed
			Assessing the final landform design.	OSS	Active
			Assessing the impact of groundwater discharge on landform stability.	OSS	Completed
			Assessment of the constructed Pit 1 landform using the CAESAR-Lisflood LEM.	OSS	Completed
			An improved method for modelling erosion and gully formation on the Ranger landform.	OSS	Completed
LAN3E	How much suspended sediment will be transported from the rehabilitated site (including land application areas) by surface water?	Open	No open projects.	N/A	N/A
LAN4A	How do we optimise methods to measure gully formation on the rehabilitated landform?	Open	Development of a method for monitoring gully formation on the rehabilitated landform using stereopsis and LiDAR.	OSS	Active
LAN4B	What monitoring data are required for ongoing LEM validation?	Removed		N/A	N/A
LAN5A	How can we use suspended sediment in surface water (or turbidity as a surrogate) as an indicator for erosion on the final landform?	Open	Turbidity & suspended sediment relationships for Gulungul and Magela Creeks.	OSS	Active
			Operationalise billabong turbidity monitoring using a Remotely Piloted Aircraft System (RPAS).	OSS	Proposed
Water and Sediment					
WS1A	What contaminants (including nutrients) are present on the rehabilitated site (e.g. contaminated soils, sediments and groundwater; tailings and waste rock)?	Open	TSF Wall Drilling program.	ERA	Completed
			Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Acid sulfate sediments conceptual model.	ERA	Completed
			Soil assessments for LAA.	ERA	Completed
			Non-aquatic contaminated sites sampling.	ERA	Completed
			Processing plant contamination sampling.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			TSF floor drilling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
			Stockpile drilling program.	ERA	Completed
			Solute source area/concentration conceptual model update.	ERA	Completed
			Wetlands investigation program.	ERA	Proposed
WS1B	What factors are likely to be present that influence the mobilisation of contaminants from their source(s)?	Open	Literature review on mobilisation of contaminants.	ERA	Active
WS2A	What is the nature and extent of groundwater movement, now and over the long-term?	Open	Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
			Distribution of groundwater sources of Ranger mine contaminants in Magela sands.	OSS	Active
			Monitoring surface water and sediment chemistry of Magela creek pools.	OSS	Active
WS2B	What factors are likely to be present that influence contaminant (including nutrients) transport in the groundwater pathway?	Open	Literature review on mobilisation of contaminants.	ERA	Active
			Mg:Ca input into solute transport models.	ERA	Completed
WS2C	What are predicted contaminant (including nutrients) concentrations in groundwater over time?	Open	Background CoPC in groundwater.	ERA	Completed
			Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
WS3A	What is the nature and extent of surface water movement, now and over the long-term?	Open	Preliminary surface water modelling.	ERA	Completed
			Surface water groundwater interaction.	ERA	Completed
			Update surface water model.	ERA	Completed
			Spectral investigation of Ranger salts.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS3B	What concentrations of contaminants from the rehabilitated site will aquatic (surface and ground-water dependent) ecosystems be exposed to?	Open	Preliminary surface water modelling.	ERA	Completed
			Mg:Ca input into solute transport models.	ERA	Completed
			Update surface water model.	ERA	Completed
			Monitoring surface water and sediment chemistry of Gulungul & Mudginberri Billabong.	OSS	Active
WS3C	What factors are likely to be present that influence contaminant (including nutrients) transport in the surface water pathway?	Open	Update surface water model.	ERA	Completed
			Coonjimba Billabong hydrodynamic modelling.	ERA	Newly Proposed
WS3D	Where and when does groundwater discharge to surface water?	Open	Surface water groundwater interaction.	ERA	Completed
			GW/SW interaction model validation.	ERA	Active
WS3E	What factors are likely to be present that influence contaminant (including nutrients) transport between groundwater and surface water?	Open	Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Post closure solute transport modelling with uncertainty analysis.	ERA	Completed
			Preliminary surface water modelling.	ERA	Completed
			Surface water groundwater interaction.	ERA	Completed
			Coonjimba Billabong hydrodynamic modelling.	ERA	Newly Proposed
WS3F	What are the predicted concentrations of suspended sediment and contaminants (including nutrients) bound to suspended sediments in surface waters over time?	Open	Preliminary surface water modelling.	ERA	Completed
WS3G	To what extent will the interaction of contaminants between sediment and surface water affect their respective qualities?	Closed Out	Predicting uranium accumulation in sediments.	OSS	Completed
WS3H	Where and when will suspended sediments and associated contaminants accumulate downstream?	Open	Coonjimba Billabong hydrodynamic modelling.	ERA	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
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?	Open	Distribution of groundwater sources of Ranger mine contaminants in Magela sands.	OSS	Active
			Preliminary mapping of groundwater dependent ecosystems (GDEs) on the Ranger lease.	OSS	Completed
			Magela Creek sandbed water quality and subsurface fauna – pilot.	OSS	Completed
			Assess the ecological risks of mine water contaminants in the dry season, subsurface waters of Magela sand channel.	OSS	Completed
			Identification and mapping of groundwater dependent ecosystems (GDEs).	OSS	Completed
			Distribution of groundwater sources of Ranger mine contaminants in Magela sands.	OSS	Active
WS5A	Will contaminants in sediments result in biological impacts, including the effects of acid sulfate sediments?	Open	Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Acid sulfate sediments conceptual model.	ERA	Completed
			Surface water pathway risk assessments (release pathways onsite).	ERA	Active
			Sulfate-ASS risk & management options.	ERA	Active
			The toxicity of U to sediment biota of Gulungul Billabong.	OSS	Completed
			Effects of uranium on the structure and function of bacterial sediment communities.	OSS	Completed
			Review of acid sulfate soil knowledge and development of a rehabilitation standard for sulfate.	OSS	Completed
			Impact of acid sulfate soils on aquatic ecosystems.	OSS	Completed
WS5B	What are the factors that influence the bioavailability and toxicity of contaminants in sediment?	Closed Out	Predicting uranium accumulation in sediments.	OSS	Completed
WS5C	What would be the impact of contaminated sediments to surface aquatic ecosystems?	Removed	Predicting uranium accumulation in sediments.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS6A	What is the toxicity of ammonia to local aquatic species, considering varying local conditions (e.g. pH and temperature)?	Closed Out	Toxicity of ammonia to freshwater biota and derivation of a site-specific water quality guideline value.	OSS	Completed
			Toxicity of ammonia and other key contaminants of potential concern to freshwater mussels.	OSS	Completed
			Toxicity of ammonia to local species at a range of pHs.	OSS	Completed
WS6B	Can annual additional load limits (AALL) be used to inform ammonia closure criteria?	Removed		N/A	N/A
WS6C	What concentrations of nutrients (N and P) in waterbodies will cause eutrophication?	Open	Eutrophication risk study.	ERA	Superseded
			Monitoring surface water and sediment chemistry of Gulungul & Mudginberri Billabong.	OSS	Active
			Nutrients thresholds defining trophic status of ARR surface waters.	OSS	Completed
WS7A	Are current guideline values appropriate given the potential for variability in toxicity due to mixtures, modifying factors and different exposure scenarios?	Closed Out	Billabong macroinvertebrates responses to mine-derived solutes.	OSS	Completed
			The effect of dissolved organic matter on the bioavailability and toxicity of metals to tropical freshwater biota (PhD project).	OSS	Completed
			Effects of Mg pulse exposures on tropical freshwater species.	OSS	Completed
			Re-analysis of existing uranium freshwater chronic toxicity data to revise the site-specific and national U trigger values.	OSS	Completed
			Effect of manganese on tropical freshwater species.	OSS	Completed
			The effect of multiple Mg pulses on tropical freshwater species with an emphasis on recovery and carry over toxicity.	OSS	Completed
			Desktop assessment of historical Direct Toxicity Assessment data to evaluate multiple single toxicant water quality limits (including the magnesium Limit).	OSS	Completed
			Assessing the toxicity of mine water mixtures for operational and closure scenarios.	OSS	Completed
			Deriving a candidate Mg guideline value based on a mesocosm study (re-analysis of 2002 PhD data).	OSS	Completed
			Deriving site specific guideline values for copper and zinc.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS7B	What is the risk associated with emerging contaminants?	Open	Background CoPC in groundwater.	ERA	Completed
			Toxicity of treated process waters from Ranger uranium mine to five local freshwater species.	OSS	Completed
			Hazard and risk assessments for potential / emerging water quality contaminants and toxicity modifying factors.	OSS	Completed
			PFAS in Biota.	OSS	Proposed
WS7C	Are current guideline values appropriate to protect the key groups of aquatic organisms that have not been represented in laboratory and field toxicity assessments (e.g. flow-dependent insects, hyporheic biota and stygofauna)?	Closed Out	Seasonal sensitivity (to Mg) profile for macroinvertebrates in the Magela creek channel.	OSS	Completed
WS7D	How do acidification events impact upon, or influence the toxicity of contaminants to, aquatic biota?	Removed		N/A	N/A
WS7E	How will Mg:Ca ratios influence Mg toxicity?	Closed Out	Billabong macroinvertebrates responses to mine-derived solutes.	OSS	Completed
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)?	Closed Out	Effects of surface and ground water egress of mining-related solutes on stream ecological connectivity (NESP fish migration).	OSS	Completed
WS7G	What concentrations of contaminants will be detrimental to the health of (non-riparian) aquatic vegetation?	Closed Out	Evaluation of aquatic vegetation data.	OSS	Completed
WS7H	What concentrations of contaminants will be detrimental to the health of riparian vegetation?	Closed Out	Ecohydrology and sensitivity of riparian flora (NESP project).	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
WS8A	What are the physical effects of suspended sediment on aquatic biodiversity, including impacts from sedimentation and variation in sediment characteristics (e.g. particle size and shape)?	Removed		N/A	N/A
WS8B	To what extent does salinity affect suspended particulates, and what are the ecological impacts of this?	Removed		N/A	N/A
WS9A	How do we optimise methods to monitor and assess ecosystem health and surface and groundwater quality?	Open	Developing best practice and guidance documents for environmental omics in Australia.	OSS	Completed
			Drone water collection.	OSS	Active
			Develop a technique for automating snail egg counts for toxicity testing and monitoring.	OSS	Completed
			Developing videography-based methods for monitoring fish communities (CDU and SSB).	OSS	Active
			Building the metacode database for northern macroinvertebrate species.	OSS	Active
			Developing a short-term chronic toxicity test for the fish, Mogurnda mogurnda.	OSS	Completed
			Developing methods for monitoring fish communities in shallow lowland billabongs.	OSS	Active
			Use of DGTs for U (and other metal) measurement.	OSS	Active
			Development of improved biodiversity assessment methods f) omics for routine monitoring of the biogeochemistry of sediments.	OSS	Proposed
			Development of improved biodiversity assessment methods b) Macroinvertebrate communities: response measurement and diagnostics (e.g. trait-based or SPEAR assessments).	OSS	Proposed
			Assessment of algae populations with new technologies.	OSS	Suspended
			Automation of fish identification.	OSS	Completed
			Measuring river discharge from drones.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Development of in-situ metal analysers for continuous U.	OSS	Proposed
			Use of DNA to survey aquatic macroinvertebrate assemblages.	OSS	Active
			Acoustic backscatter sensors for total suspended sediment monitoring.	OSS	Active
			Building the DNA database of northern aquatic vertebrate species.	OSS	Completed
			Measuring fish community structure with eDNA.	OSS	Active
			Automating fish biomass estimated with stereo-videography and deep learning.	OSS	Completed
Ecosystems					
ESR1A	What are the compositional and structural characteristics of the terrestrial vegetation (including seasonally-inundated savanna) in natural ecosystems adjacent to the mine site, how do they vary spatially and temporally, and what are the factors that contribute to this variation?	Open	Conceptual model of final revegetation reference ecosystem.	ERA	Active
			Quantifying spatial and temporal change in savanna.	OSS	Completed
			Assessment of historical vegetation reference site information for use in ecological restoration at Ranger mine site.	OSS	Completed
			Using hyperspectral drone data for deriving species composition.	OSS	Active
			Factors affecting spatial and temporal change in savanna.	OSS	Completed
			Quantifying spatial and temporal change in riparian areas and seasonally-inundated savanna.	OSS	Suspended
			Vegetation similarity: updated data for conceptual reference ecosystem.	OSS	Completed
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
			Collection of data to inform development of the appropriate fire regime for the Ranger rehabilitated site.	OSS	Active
ESR1B	Which indicators of similarity should be used to assess revegetation success?	Closed Out	SERA standard and SSB ecosystem restoration standard.	OSS	Completed
			Vegetation similarity closure criteria: development of indicators.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
ESR1C	What values should be prescribed to each indicator of similarity to demonstrate revegetation success?	Open	Deriving species composition measures and their environmental correlates to assess ecosystem restoration similarity.	OSS	Completed
			Deriving vegetation community structural attributes that inform the conceptual reference ecosystem.	OSS	Completed
			Conceptual Reference Ecosystem and Completion Criteria.	ERA	Superseded
			Ecosystem (flora and fauna) similarity and sustainability completion criteria.	ERA	Superseded
ESR2A	What faunal community structure (composition, relative abundance, functional groups) is present in natural ecosystems adjacent to the mine site, and what factors influence variation in these community parameters?	Open	Terrestrial fauna objectives, closure criteria and recolonisation plan.	ERA	Superseded
			Ecosystem (flora and fauna) similarity and sustainability completion criteria.	ERA	Superseded
			Invertebrate assemblages at Ranger Uranium Mine's trial revegetation sites compared with natural reference sites (CDU NESP project).	ERA	Completed
			Recommendations for faunal standards for the rehabilitation of Ranger uranium mine (NESP).	OSS	Completed
			Fauna closure criteria: development of goals.	OSS	Completed
			Fauna closure criteria: development of indicators.	OSS	Completed
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active
			Ecosystem restoration trajectories for vertebrate fauna similarity indicators.	OSS	Active
ESR2B	What habitat, including enhancements, should be provided on the rehabilitated site to ensure or expedite the colonisation of fauna, including threatened species?	Open	Habitat features that influence the colonisation of fauna on the landform.	OSS	Superseded
			Nest box trials.	ERA	Active
			Habitat features and potential enhancements for fauna colonisation.	ERA	Active
ESR2C	What is the risk of introduced animals (e.g. cats and dogs) to faunal colonisation and long-term sustainability?	Open	Risk assessment for feral animals impacting faunal colonisation of the landform.	OSS	Superseded
			Exotic fauna monitoring.	ERA	Proposed
ESR3A	How do we successfully establish terrestrial vegetation, including understory (e.g. seed supply, seed treatment and timing of planting)?	Open	Ranger species establishment research program (SERP).	ERA	Active
			Assessment of ecosystem restoration on revegetated domains at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
ESR4A	What is the incidence and abundance of introduced animals and weeds in areas adjacent to the mine site, and what are the factors that will inform effective management of introduced species on the rehabilitated mine site?	Open	Improved understanding of sources and magnitude of sources of weeds off site using remote sensing.	OSS	Proposed
			Determining the incidence of declared weeds and other introduced flora in areas of Kakadu National Park adjacent to the Ranger mine.	OSS	Active
ESR5A	What are the key sustainability indicators that should be used to measure restoration success?	Open	Conceptual model of final revegetation reference ecosystem.	ERA	Active
			Assessing mine restoration trajectories through studies at Nabarlek.	OSS	Active
			Vegetation sustainability closure criteria: development of indicators.	OSS	Completed
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
			Flowering and fruiting phenology of dominant species in the reference ecosystem at Ranger mine.	OSS	Active
ESR5B	What are possible/agreed restoration trajectories (flora and fauna) across the Ranger mine site; and which would ensure they will move to a sustainable ecosystem similar to those adjacent to the mine site, including Kakadu National Park?	Open	State and Transition model.	ERA	Active
			Review of revegetation outcomes arising from historic mine sites in the Alligator Rivers Region.	OSS	Completed
			Long-term viability of the ecosystem established on the trial landform.	OSS	Completed
			Assessing mine restoration trajectories through studies at Nabarlek.	OSS	Active
			Assessment of ecosystem restoration on revegetated domains at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active
			Developing restoration trajectories to predict when the restored site will move to a sustainable ecosystem.	OSS	Completed
			Chemical, physical and biological indicator values supporting nutrient cycling.	OSS	Active
			Assessment of ecosystem development at Nabarlek mine site.	OSS	Cancelled
			Monitoring and assessment of ecosystem establishment and long-term viability on Pit 1 waste rock to inform trajectories.	OSS	Active
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Ecosystem restoration trajectories for vegetation similarity indicators.	OSS	Active
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
ESR6A	What concentrations of contaminants from the rehabilitated site may be available for uptake by terrestrial plants?	Removed		N/A	N/A
ESR6B	Based on the structure and health of vegetation on the Land Application Areas, what species appear tolerant to the cumulative impacts of contaminants and other stressors over time?	Open	No open projects.	ERA	N/A
ESR7A	What is the potential for plant available nutrients (e.g. nitrogen and phosphorus) to be a limiting factor for sustainable nutrient cycling in waste rock?	Open	Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
ESR7B	Will sufficient plant available water be available in the final landform to support a mature vegetation community?	Open	WAVES modelling (Plant available water balance modelling of the waste rock landform).	ERA	Active
			Plant available water balance modelling of the waste rock landform based on Ranger trial landform (ERA-CDU project 2013-2018).	ERA	Completed
			Study of Root Mass and depth on TLF.	ERA	Completed
			Ranger trial landform erosion research.	OSS	Active
			A review of compaction layers in mining landforms and possible implications for Ranger uranium mine.	OSS	Completed
ESR7C	Will ecological processes required for vegetation sustainability (e.g. soil formation) occur on the rehabilitated landform and if not, what are the mitigation responses?	Open	Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed
			Soil formation and nutrient cycling monitoring.	ERA	Active
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
ESR7D	Are there any other properties of the rehabilitated site that could be attributed to any observed impairment of ecosystem establishment and sustainability, including vegetation and key functional groups of soil fauna?	Open	Ranger species establishment research program (SERP).	ERA	Active
			Evaluation of key attributes of nutrient cycling in revegetated waste rock landform of Ranger uranium mine.	ERA	Completed
ESR8A	What is the most appropriate fire management regime to ensure a fire resilient ecosystem on the rehabilitated site?	Open	Trial landform fire report.	ERA	Completed
			Fire implementation and management plan for the Ranger Final Landform.	ERA	Proposed
			State and Transition model.	ERA	Active
			Collection of data to inform development of the appropriate fire regime for the Ranger rehabilitated site.	OSS	Active
ESR9A	How do we optimise methods to measure revegetation and faunal community structure and sustainability on the rehabilitated site, at a range of spatial/temporal scales and relative to the areas surrounding the RPA?	Open	Development of a low-cost method for continuous monitoring of water stress in eucalypt vegetation on a rehabilitated mine site.	OSS	Completed
			Developing monitoring methods for revegetation using RPAS: Jabiluka revegetation.	OSS	Completed
			Using hyperspectral drone data for deriving species composition.	OSS	Active
			Guiding ecological restoration at Ranger uranium mine with drone derived indicators of ecosystem health.	OSS	Active
			Assessment of ecosystem restoration on revegetated domains at Ranger to develop metrics to inform a long-term monitoring plan.	OSS	Active
			Develop metrics to confirm vegetation resilience to fire events.	OSS	Superseded
			Nutrient cycling indicator values for ecosystem sustainability in the state and transition model.	OSS	Active
			Measuring vegetation structure at the landscape scale.	OSS	Suspended
			Develop diagnostic tool to assessing/ monitoring impact of g/w solutes on riparian vegetation and aquatic macrophytes using remote sensing.	OSS	Suspended
			Terrestrial vertebrate faunal surveys using iDNA.	OSS	Active
			Developing a method to measure and monitor soil microbial communities to assess nutrient cycling.	OSS	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
			Application of AI to identifying vegetation species from drone data: pipeline development.	OSS	Completed
			Development of an omics-based method for undertaking terrestrial macroinvertebrate fauna surveys.	OSS	Active
			Flowering and fruiting phenology of dominant species in the reference ecosystem at Ranger mine.	OSS	Active
			Vegetation trajectory indicator values for ecosystem similarity in the state and transition model.	OSS	Active
			Application of AI to identifying vegetation species from drone data: model development.	OSS	Active
			Validating soil nutrient cycling assessments with eDNA using multi-omics approach.	OSS	Active
			Developing whole of site landform and ecosystem monitoring program at-scale.	OSS	Cancelled
Radiation					
RAD1A	What are the activity concentrations of uranium and actinium series radionuclides in the rehabilitated site, including waste rock, tailings and land application areas?	Open	Radiological Impact Assessment – Waste Rock & Tailings.	ERA	Active
			Radiological Impact Assessment – Rehabilitated Landform & LAA's.	ERA	Active
			Characterisation of contamination at land application areas at Ranger uranium mine.	OSS	Completed
RAD2A	What are the above-background activity concentrations of uranium and actinium series radionuclides in surface water and sediment?	Open	Non-aquatic contaminated sites sampling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
			Update groundwater solute transport modelling and conceptual model.	ERA	Completed
			Preliminary surface water modelling.	ERA	Completed
			Update surface water model.	ERA	Completed
			Radionuclide fluxes from the trial landform.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
RAD3A	What is the above-background concentration of radon and radon progeny in air from the rehabilitated site?	Closed Out	Atmospheric dispersion modelling of radon and particulate matter (consultant report: SLR 2018).	ERA	Completed
			Radon exhalation from the RUM Trial Landform.	OSS	Completed
			Radon exhalation fluxes expected from final landforms at the rehabilitated Ranger mine.	OSS	Completed
			Atmospheric dispersion of radon and radon daughters from the Ranger rehabilitated landform.	OSS	Completed
			Radon exhalation from waste rock on the Ranger trial landform.	OSS	Completed
RAD3B	If an assessment using conservative values shows a potential issue with meeting closure criteria (3A and 7A): What is the equilibrium factor between radon progeny and radon in air?	Removed		N/A	N/A
RAD3C	If an assessment using conservative values shows a potential issue with meeting closure criteria (3A and 7A): What is the unattached fraction of radon progeny in air?	Removed		N/A	N/A
RAD4A	If an assessment using conservative values shows a potential issue with meeting closure criteria (4B and 7A): What is the resuspension factor (or emission rate) of dust emitted from the final landform?	Removed		N/A	N/A
RAD4B	What is the above-background activity concentration in air of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	Closed Out	Modelling the atmospheric dispersion of radionuclides in dust from the Ranger final landform.	OSS	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
RAD4C	If an assessment using conservative values shows a potential issue with meeting closure criteria (4B and 7A): What is the activity median aerodynamic diameter of long-lived alpha-emitting radionuclides in dust emitted from the final landform?	Removed		N/A	N/A
RAD5A	What are the concentration ratios of actinium-227 and protactinium-231 in bush foods?	Open	Environmental fate and transport of Ac-227 and Pa-231.	OSS	Active
RAD6A	What are the representative organism groups that should be used in wildlife dose assessments for the rehabilitated site?	Closed Out	Ranger 3 Deeps draft EIS.	ERA	Completed
			Dose rates to non-human biota.	OSS	Completed
RAD6B	What are the whole-organism concentration ratios of uranium and actinium series radionuclides in wildlife represented by the representative organism groups?	Open	Dose rates to non-human biota.	OSS	Completed
			Radionuclide uptake in small proliferators.	OSS	Completed
			Radionuclide uptake in understorey vegetation.	OSS	Completed
			Radionuclide uptake in terrestrial invertebrates.	OSS	Active
			Updating the biota dose assessment for the Ranger final landform.	OSS	Suspended
RAD6C	What are the tissue to whole organism conversion factors for uranium and actinium series radionuclides for wildlife represented by the representative organism groups?	Removed	Dose rates to non-human biota.	OSS	Completed
RAD6D	What are the dose-effect relationships for wildlife represented by the representative organism groups?	Removed	Radiation dose-effect relationships for non-human biota.	OSS	Cancelled
RAD6E	What is the sensitivity of model parameters on the assessed radiation doses to wildlife?	Open	Radiological Impact Assessment.	ERA	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
RAD7A	What is the above-background radiation dose to the public from all exposure pathways traceable to the rehabilitated site?	Open	Radiological Impact Assessment.	ERA	Active
			Radionuclide uptake in traditional Aboriginal foods.	OSS	Completed
			Pre-mining radiological analogue for Ranger.	OSS	Completed
			Gamma radiation dose rates to the public from the Ranger final landform.	OSS	Completed
RAD7B	What is the sensitivity of model parameters on the assessed doses to the public?	Open	Radiological Impact Assessment.	ERA	Active
RAD8A	Will contaminant concentrations in surface water (including creeks, billabongs and seeps) pose a risk of chronic or acute impacts to terrestrial wildlife?	Open	Assessing whether contaminants in surface water pose a risk of chronic or acute impacts to terrestrial wildlife.	OSS	Cancelled
RAD9A	What are the contaminants of potential concern to human health from the rehabilitated site?	Open	Aquatic sediments (includes ASS) sampling.	ERA	Completed
			Soil assessments for LAA.	ERA	Completed
			Non-aquatic contaminated sites sampling.	ERA	Completed
			Background CoPC in groundwater.	ERA	Completed
RAD9B	What are the concentration factors for contaminants in bush foods?	Open	Deriving site-specific concentration factors for metals in bush foods to inform human health risk assessments for the Ranger final landform.	OSS	Completed
			Bush tucker sampling project.	ERA	Active
RAD9C	What are the concentrations of contaminants in drinking water sources?	Open	Preliminary surface water modelling.	ERA	Completed
			Update surface water model.	ERA	Completed
RAD9D	What is the dietary exposure of, and toxicity risk to, a member of the public associated with all contaminant sources, and is this within relevant Australian and/or international guidelines?	Open	Surface water pathway risk assessments (release pathways onsite).	ERA	Active
			Bush tucker sampling project.	ERA	Active

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
RAD10A	How do we optimise methods to monitor and assess radionuclides?	Open	Development of a model for radium-226 uptake in *Velesunio angasi* (freshwater mussel).	OSS	Completed
			Quantifying radon retention characteristics of ERISS acrylic gamma spectroscopy containers.	OSS	Completed
			Developing UAV-based remote sensing techniques for characterising radioactivity levels on the rehabilitated landform.	OSS	Proposed
Cross Theme					
CT1A	What are the cumulative risks to the success of rehabilitation on-site and to the off-site environment?	Open	Pollino, CA, Cuddy, SM & Gallant, S 2013. Ranger rehabilitation and closure risk assessment: problem formation. Canberra: CSIRO.	ERA	Completed
			Pollino, CA 2014. Ranger rehabilitation and closure risk assessment: Risk screening. Cangerra Australia: CSIRO Land and Water Flagship.	ERA	Completed
			An ecological risk assessment of the major weeds on the Magela Creek Floodplain, Kakadu National Park.	OSS	Completed
			Ranger rehabilitation & closure ecological risk assessment: phase 1, problem formulation.	OSS	Completed
			Ranger rehabilitation & closure ecological risk assessment: phase 2, risk analysis.	OSS	Completed
			Cumulative risk assessment for Ranger minesite rehabilitation and closure – Phase 1 (on-site risks).	OSS	Completed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – Phase 2 (aquatic pathways).	OSS	Completed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – periodic review and update (2024).	OSS	Proposed
			Cumulative risk assessment for Ranger mine site rehabilitation and closure – periodic review and update (2026).	OSS	Proposed
			Vulnerability Assessment Framework.	ERA	Completed
			Ranger Rehabilitation and Closure Risk Assessment: Problem Formulation.	ERA	Completed
			Ranger Rehabilitation and Closure Risk Assessment: Risk Screening.	ERA	Completed

KKN ID	KKN Question	KKN Status	Project Title	Project Owner	Project Status
CT2A	What World Heritage Values are found on the Ranger Project Area, and how might these influence the incorporation of the site into Kakadu National Park and World Heritage Area?	Closed Out	ERA cultural heritage management system & GIS.	ERA	Completed
			Closure criteria development – cultural.	ERA	Cancelled
			Cataloguing the natural World Heritage values on the Ranger Project Area.	OSS	Completed

APPENDIX 5.2: CONSOLIDATED LIST OF PREVENTATIVE CONTROLS

ERA Energy Resources Of Australia

CONSOLIDATED LIST OF PREVENTATIVE CONTROLS

Unique Identifier	Description of Preventative Control	Current Effectiveness (2023)	Active or K/A[1] type of control
C1	Final landform design and construction.	Marginal – Satisfactory	A
C2	Erosion control measures including preparation of final landform surface.	Marginal	A
C3	Sediment control measures including sediment basins.	Marginal – Satisfactory	A
C4	Drainage control structures including sinuous armoured drainage channels.	Marginal	A
C5	Revegetation of the final landform surface.	Marginal – Satisfactory	A
C6	Understanding final tailings elevations.	Satisfactory	K/A
C7	All tailings deposited into Pits 1 and 3.	Weak – Strong	A
C8	Tailings buried below predicted depth of gully formation.	Satisfactory	A
C9	Legal instruments.	Weak	K/A
C10	Low grade material (2s and 3s) buried below vadose zone in Pits 1 and 3.	Weak – Strong	A
C11	Pump and treat from Pits 1 and 3 until agreed criteria met or demonstrated that can be met.	Marginal – Strong	A
C12	Brine injected into Pit 3 underfill.	Marginal – Strong	A
C13	No water released from mine site unless it meets defined criteria and sufficient creek flow.	Satisfactory – Strong	A
C14	Understanding source terms, groundwater loads, surface water concentrations.	Satisfactory	K/A
C15	Understanding solute transport pathways, interactions and contaminant behaviour over time.	Satisfactory	K/A
C16	Refuelling and maintenance areas are appropriately bunded.	Strong	A
C17	Clay cap over RWD floor.	Satisfactory – Strong	A
C18	Retain clay core around RWD floor.	Satisfactory – Strong	A
C19	RWD and western stockpile interception trench.	Marginal – Satisfactory	A
C20	Use of approved pesticides as per instruction.	Satisfactory	A
C21	Fertiliser use based on identified nutrient need of plants.	Satisfactory	A
C22	Containment cell within RP2 for PFAS.	Satisfactory – Strong	A
C23	Excavate and dispose contaminated soil/sediments into Pit 3 and RP2.	Weak – Strong	A
C24	Detailed understanding of soil contamination levels and location.	Satisfactory	K/A
C25	Validation sampling.	Satisfactory	K/A
C26	In situ treatment of mildly contaminated, or culturally sensitive, sites.	Marginal	A
C27	Tilling.	Satisfactory	A
C28	Post-closure monitoring.	Marginal	K/A

Unique Identifier	Description of Preventative Control	Current Effectiveness (2023)	Active or K/A[1] type of control
C29	Development of appropriate vegetation CRE.	Satisfactory	K/A
C30	Weed management in non-waste rock areas within RPA.	Satisfactory	A
C31	Weed management on waste rock rehabilitation areas.	Marginal	A
C32	Application of pre-emergent herbicide.	Strong	A
C33	Implementation of suitable vegetation establishment strategy including propagation, seeding, planting and fertiliser application.	Satisfactory – Strong	A
C34	Provision of suitable irrigation.	Satisfactory	A
C35	Fire management in non-waste rock areas within RPA.	Strong	A
C36	Management of exotic and other threatening fauna.	Satisfactory	A
C37	Targeted pest and disease management.	Marginal	A
C38	Addition of organic material from surrounds.	Marginal	A
C39	Appropriate introduction of fire to rehabilitation areas.	Satisfactory	A
C40	Development of appropriate fauna CRE.	Satisfactory	K/A
C41	Installation of appropriate nest boxes and/or rockpiles.	Marginal	A
C42	Understanding radiation emissions, exposure pathways, radionuclide concentrations and doses.	Satisfactory	K/A
C43	Understanding Traditional Owner post-closure occupancy on the RPA, dietary intake and bioaccumulation in bush foods.	Satisfactory	K//A
C44	Maintain tailings in near saturated state, and active dust control (water trucks, water cannons) prior to capping tailings and during movement of higher grade material.	Satisfactory – Strong	A
C45	Final landform designed and constructed to meet Traditional Owner requirements.	Marginal – Satisfactory	A
C46	All sediment basins will be removed and rehabilitated.	Satisfactory	A
C47	Line of site assessment for cultural landscape features undertaken and incorporated into final landform design and execution.	Strong	K/A
C48	Management of the rehabilitated landform for weeds, exotic fauna, fire, pests and natural disturbances.	Satisfactory	A
C49	Clean-up of all existing infrastructure and rubbish.	Satisfactory	A
C50	Final land use consultation with Traditional Owners.	Satisfactory	K/A
C51	Implement Cultural Heritage Management System.	Marginal	K/A

[1] - K/A = Knowledge-based / Administrative Control.

APPENDIX 5.3: CONSOLIDATED LIST OF CORRECTIVE ACTIONS

CONSOLIDATED LIST OF CORRECTIVE ACTIONS

Unique Identifier	Description of Corrective Action	Current Effectiveness (2023)	Active or K/A[1]
A1	Maintenance of erosion and sediment control measures.	Satisfactory	A
A2	Undertaking earthworks to repair significant gullying or eroded areas.	Marginal – Satisfactory	A
A3	Extension of landform monitoring and maintenance phase.	Marginal	K/A
A4	Restricting access to any exposed tailings.	Marginal	A
A5	Removing any contaminated or impacted material (water and sediment).	Weak – Marginal	A
A6	Conducting health monitoring.	Satisfactory	K/A
A7	Increasing the frequency of field inspections for erosion and gully formation.	Satisfactory	K/A
A8	Planned duration of pump and treat extended to further reduce peak contaminant loads.	Satisfactory	A
A9	Additional remediation (as agreed with key stakeholders) of billabongs (e.g. sediment removal, lime treatment) if sediments do not achieve target levels.	Marginal – Satisfactory	A
A10	Short-term restrictions to land access and cultural activities.	Marginal – Satisfactory	A
A11	Infill planting and seeding to maintain suitable vegetative cover on final landform.	Marginal – Strong	A
A12	Additional interception system (e.g. passive reactive barrier).	Marginal	A
A13	Discontinue use/change pesticide.	Satisfactory – Strong	A
A14	Discontinue nutrient use/change fertiliser.	Strong	A
A15	Use of approved flocculant / coagulant.	Satisfactory	A
A16	Contaminated soils detected after the validation sampling will be excavated and disposed below the 2s cap in Pit 3 or into RP2.	Strong	A
A17	Tilled soils on the Magela LAA that do not reach target levels will be disposed to RP2 (or Pit 3 depending on timing) and the area will be replanted.	Strong	A
A18	Targeted weed management.	Marginal	A
A19	Targeted exotic fauna management.	Satisfactory	A
A20	Addition of organic material/s and or fertiliser beyond that planned.	Marginal	A
A21	Targeted pest and disease management.	Marginal	A
A22	Modified fire management.	Satisfactory	A
A23	Supplementation of habitat features and/or migration corridors.	Marginal	A

Unique Identifier	Description of Corrective Action	Current Effectiveness (2023)	Active or K/A[1]
A24	Remediation (as required) of surface radiation following construction and rehabilitation of final landform.	Satisfactory	A
A25	Increased monitoring of radiological contaminants in impacted environments and biota.	Marginal	K/A
A26	Reshape landform.	Satisfactory	A
A27	Remediation of surface sediment or salt deposition.	Marginal	A
A28	Early notification and consultation with Traditional Owners and implementation of agreed mitigation.	Satisfactory	K/A
A29	Initial response to prevent further damage.	Marginal	K/A

[1] - K/A = Knowledge-based / Administrative Corrective Action.

APPENDIX 7.1: RANGER MINE AQUATIC PATHWAYS RISK ASSESSMENT FOR PIT 3 CLOSURE

Ranger Mine Aquatic Pathways Risk Assessment for Pit 3 Closure - Draft Report

Customer	ERA
Project	A10754
Deliverable	004
Version	02
	07 September 2023

Document Control

Document Identification

Title	Ranger Mine Aquatic Pathways Risk Assessment for Pit 3 Closure - Draft Report – draft report
Project No	A10754 phase 10
Deliverable No	004
Version No	02
Version Date	07 September 2023
Customer	ERA

Author	Michelle Iles
Approved By	Darren Richardson
Project Manager	Michelle Iles

Amendment Record

The Amendment Record below records the history and issue status of this document.

Version	Version Date	Distribution	Record
01	28 August 2023	Energy Resources of Australia Ltd (ERA)	Report
02	07 September 2023	Energy Resources of Australia Ltd (ERA)	Report

Executive Summary

Background

Energy Resources of Australia Ltd (ERA) is planning the closure of its Ranger Uranium Mine. The Ranger Project Area (RPA) is surrounded by Kakadu National Park (KNP), KNP World Heritage Area, KNP Natural Heritage Place and KNP Ramsar site, and is on lands owned by the Mirarr Traditional Owners.

Waters from the closed mine must support protection of the people, ecosystem (biodiversity and ecological processes), and the values of the adjacent KNP, World Heritage Area, and Ramsar site. Impacts on the RPA are also to be as low as reasonably achievable (ALARA).

One challenge for closure is understanding the risks associated with contaminants of potential concern (CoPC) that will continue to discharge from the mine site via groundwater and surface water.

Pit 3 has been backfilled with brines and tailings and ERA is seeking regulatory approval for the final stages of its closure. ERA used the Ranger Surface Water Model to predict peak and 10,000-year concentrations of CoPC entering Magela Creek from Pit 3 and from multiple sources on the mine site, including Pit 3 (called Composite sources hereafter). CoPCs concentrations at one site upstream of Pit 3 (MG001) and five sites downstream of Pit 3 (MG003, MG005, MG009, End of RPA and Mudginberri Billabong) were predicted for three groundwater loads (P10, P50, P90) entering from the closed mine site. Concentrations at the latter three sites would be strongly influenced by contributions from sources other than Pit 3 which enter upstream of MG009.

Predicted concentrations of 18 CoPC (aluminium (Al), ammonia (as total ammoniacal nitrate, TAN; NH_3-N), cadmium (Cd), chromium (Cr^{3+}), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), calcium (as a ratio to Mg; Mg:Ca), manganese (Mn), nickel (Ni), nitrate-N (NO_3-N), radium-226 (^{226}Ra), selenium (Se), sulfate (SO_4), uranium (U), vanadium (V), and zinc (Zn) in Magela Creek surface waters downstream of Pit 3 were compared to guideline values (GV) for the protection of the following community values:

- Drinking and recreational water
- Animal drinking water,
- Protection against acid sulfate soils (ASS) formation, and
- Aquatic species protection (chemical and radiological).

The risk of eutrophication is related to loads rather than concentrations of nutrients and is being assessed through a separate project.

Key Findings

CoPC concentrations were predicted to fall below cultural water use (i.e. drinking and recreational water quality), animal drinking water, and ASS formation GVs. On this basis, mine-derived CoPCs resulted in Very Low consequences and Class 1 risks.

Biodiversity risks were assessed by comparing the predicted water quality to site-specific/adjusted GVs and default GVs (DGV) in ANZG (2018). GVs for the protection of aquatic species were met for all parameters except Mn and Al. The GV for Al is exceeded naturally, and a comparison of Al median concentrations for the “No Mine” scenario against median concentrations for the other scenarios showed very small mine contributions of Al.

Species protection consequences were assessed for all predicted Mn concentrations. The consequences for the P50 peak and 10,000-year Mn concentrations were used to classify the risks at all sites downstream of Pit 3 (consequences at the MG001 upstream of Pit 3 were very low which provides a Class 1 risk). The resulting risk classifications for species protection is shown in Figure 0.1.

Location (Sites)	Value and CoPC assessed	Risk classes for P50 contaminant source sceanrios (based on worst case for any site at the location)			
		Composite sources PEAK, P50	Pit3 PEAK, P50	Composite sources 10,000 Yr, P50	Pit 3 10,000 Yr, P50
ON the RPA (MG001 / MG003 / MG005 / MG009)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	III	II
	Aquatic species protection (all other CoPC)	I	I	I	I
OFF the RPA (Mudginberri Billabong / EndRPA)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	IV	I
	Aquatic species protection (all other CoPC)	I	I	I	I

Figure 0.1 Biodiversity (species protection) risk classification for the P50 load scenarios at each site

Although not above the DGVs used in this assessment, increases in Cr and Ni concentrations appear to be mine related and reliance on DGVs for these CoPC may underestimate the risk to biodiversity. Nevertheless, any risk associated with Cr and Ni will be mitigated by management actions to reduce Mn associated risks. Consideration could be given to the need for site specific/adapted GVs for these two CoPC.

This assessment assumes that (i) CoPC concentrations predicted by the RSWM were accurate, and (ii) all Mn is present in a bioavailable form. These conservative assumptions may overstate the risks associated with Mn.

ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered. Biogeochemical and microbial processes are now included in the conceptual model for risks via the surface water pathway. Assessing these is outside the scope of the APRA but studies that have addressed or will address these issues are discussed.

Whether the predicted concentrations of Mn in the water column will cause sediment Mn concentrations to increase beyond the natural variability is not assessed in this report. Local concentration factors and regional background datasets are available to assess this under a separate process if required.

Contents

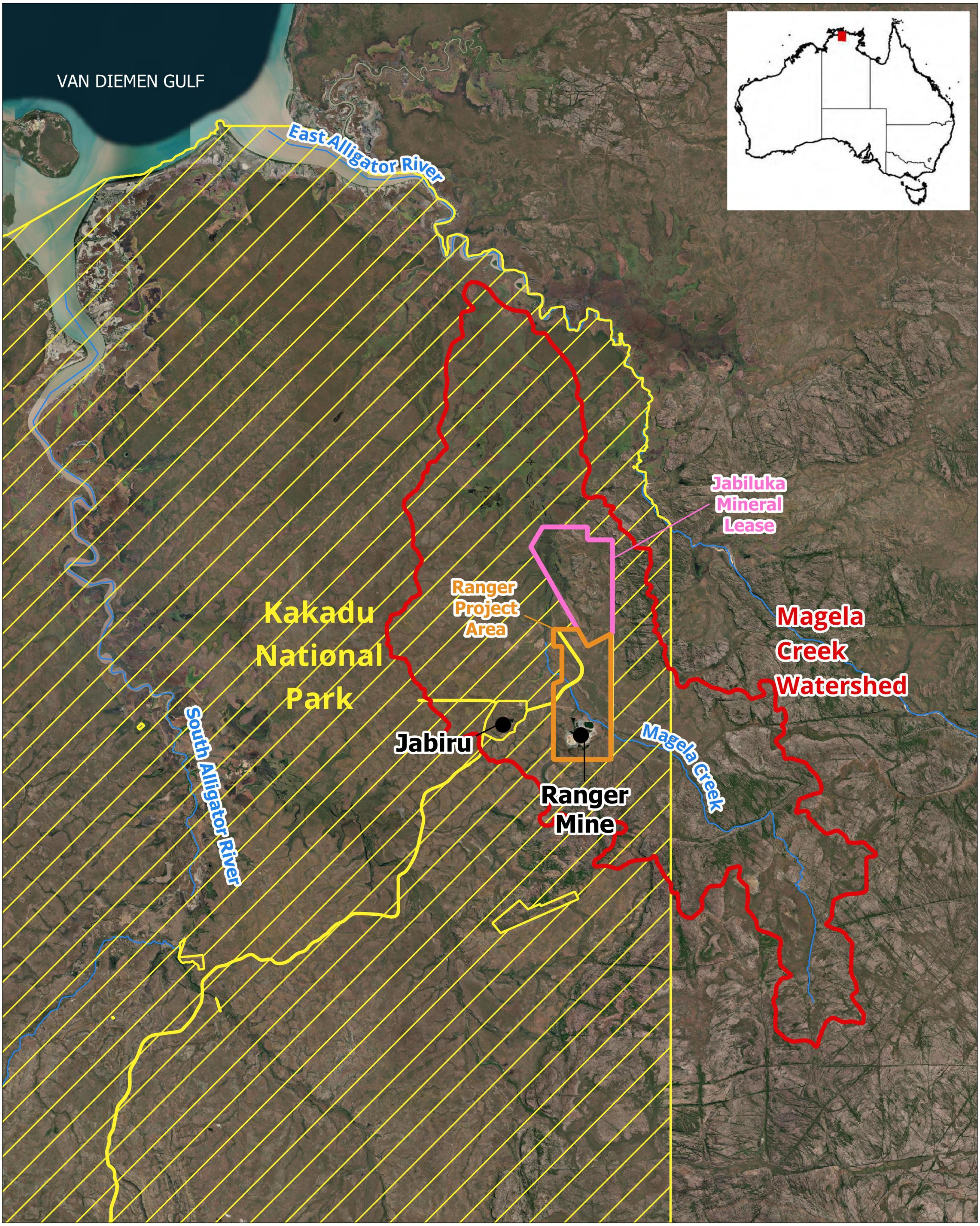
Table of Figures

Table of Tables

1 Introduction

1.1 Background

Energy Resources of Australia Ltd (ERA) is planning the closure of Ranger uranium mine in the Northern Territory of Australia (ERA, 2022). The Ranger Project Area (RPA; Figure 1.1) is surrounded by Kakadu National Park (KNP). KNP supports a listed World Heritage Area, Natural Heritage Place and Wetland of International Significance (KNP Ramsar site), all of which were matters of national environmental significance protected under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*.



Title:

Location of the Ranger Mine and Project Area

Figure: 1-1

Rev: 0

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 10 20 km

BMT

www.bmt.org

Filepath: I:\A10754.g.dr.ranger mine closure risk assessment\QGIS\A10754 Project Map.qgz

The release of contaminants from mineralised/contaminated materials (e.g. waste rock, tailings, water, soils) in mine areas into receiving environments is a potential environmental issue for operational and closure stages if inappropriately managed.

Waters from the closed mine must support protection of the people, ecosystem (biodiversity and ecological processes), and the values supported by the KNP. Furthermore, any impacts on the RPA are to be as low as reasonably achievable (ALARA).

The following tools have been developed to determine if these goals were met:

- water quality criteria for contaminants of potential concern (CoPC) for the protection of the biodiversity and human use values off the RPA (ERA 2020, Section 8.3.2),
- a process that involves a risk assessment to inform the development of criteria to ensure impacts are ALARA on the RPA (ERA 2020, Appendix 6.3),
- solute transport models for ground and surface water; the Ranger surface water model (RSWM) predicts the concentrations of the CoPC in the surface water on and adjacent to the RPA after closure,
- an Aquatic Pathways Risk Assessment (APRA) tool to assess the risks to aquatic receptors (ecosystems and people) posed by the post closure water quality predicted by the RSWM,
- an ecosystem Vulnerability Assessment Framework (VAF) to understand the vulnerability of ecosystem components exposed to CoPC concentrations greater than GVs, and
- Best Practice Technology (BPT) assessment criteria (Iles, 2020) that consider the feasibility and reasonableness of available design and impact mitigation technologies to ensure impacts within the RPA are as low as reasonably achievable.

The application of the APPRA tool is part of implementing the Water Quality Management Framework (ANZG 2018) (WQMF) and processes being used by ERA to inform closure plans that support impacts that are ALARA and development of water quality closure criteria for on the RPA.

1.2 The Issue

The first application of the APPRA tool, described in Iles and Rissik (2021), was based on preliminary surface water model predictions for the closure strategy reported in the 2020 mine closure plan, and results of sediment monitoring and field effect studies conducted on the RPA. Iles (2023) detailed the conceptual underpinning and methodology behind the APPRA tool for use in future assessments and incorporated feedback received from stakeholders on the 2021 report.

ERA is applying for regulatory approval to close out Pit 3 which contains buried tailings. Following the application of the APPRA tool to the base case for closure (Iles and Rissik, 2021), ERA reviewed its closure plans for Pit 3 and sought additional information to allow it to reassess the risks associated with the pit closure, including:

- updated contaminant source and transport studies which will culminate in updated predictions of surface water concentrations from the RSWM, and
- application of the APRA tool to the RSWM outputs; the subject of this report.

ERA now seeks to have the APRA tool applied using these recent water quality modelling results, which is the subject of this report.

The methodology for applying the APRA tool to the outputs of the RSWM is described in Iles (2023). Stakeholder feedback on Iles (2023) has been received. ERA has requested that the feedback, and necessary alterations to the APRA tool be considered when applying the tool to the Pit3 RSWM results.

1.3 Scope and Objectives

The key aims of this project were to:

- classify potential risk to aquatic receptors (ecosystems and people) associated with surface water concentrations of CoPC caused by contamination from Pit 3
- allow ERA to identify and understand potential risks to the community values for aquatic receptors on and off the Ranger Project Area (RPA), and
- identify locations where the VAF needs to be applied to provide a greater understanding of ecosystems response to CoPC concentrations posing a medium or higher risk to biodiversity.

The specific objectives of this report were to:

- describe the application of the APRA tool to the RSWM results for Pit 3
- document the consequence and risk outcomes of the assessment, and
- document the locations where the VAF is to be applied.

2 Approach

2.1 The APRA Tool

The methodology for applying the APRA tool to the outputs of the RSWM is described in Iles (2023). The same approach was used for this assessment with the following modifications:

- The scope only considered water quality issues. Risks from sediment-associated contaminants, eutrophication and effects of acid sulfate soils (ASS) were excluded from the present study but are considered by ERA in other assessments.
- The conceptual model has been updated to:
  - reflect the above scope of this assessment, and now includes detrital pools,
  - include detrital pools and microbial assemblages driving intermediary microbially mediated processes (as requested by Wong and Bolton, 2023). These processes were not assessed in the APRA tool but their importance and ways the issue is being considered are discussed (see Section 5.2), and
  - show that eutrophication is being addressed through a separate assessment.

2.2 Conceptual underpinning

Threats from CoPC were identified and assessed based on a conceptual understanding of sources, pathways, receptors and processes, and aligning these with the environmental and community values of the surrounding landscape. The focus of the integrated conceptual model for the APRA tool used by Iles and Rissik (2021) and described in Iles (2023) was the influence of the contaminant sources on environmental and community values.

Figure 2.1 shows the integrated source-pathway-process-receptor conceptual model underpinning this risk assessment. This is the conceptual model of Iles (2023) with changes (shown in red text) to include the detrital pool and microbial assemblages requested by ARRTC.

- Blue boxes show the contaminant sources and transport pathways included in the solute transport models used to predict future water quality.
- Orange boxes show sediment and soil contaminant sources and fate. The box outline is dashed indicating these contaminant sources were not considered in this risk assessment.
- Grey box shows the end points being assessed. The endpoints are aligned with the values derived from the Ranger Environmental Requirements.
- Solid green boxes show the assessment method used (i.e. exposure concentration versus GV).
- Boxes outlined in dashes show issues that were excluded from this risk assessment; they were being assessed by other assessments).

Limitations associated with excluding processes associated with detrital pools and microbial assemblages (the new additions to the conceptual model) are discussed in Section 5.2. The rationale for other exclusions is provided in Iles (2023).

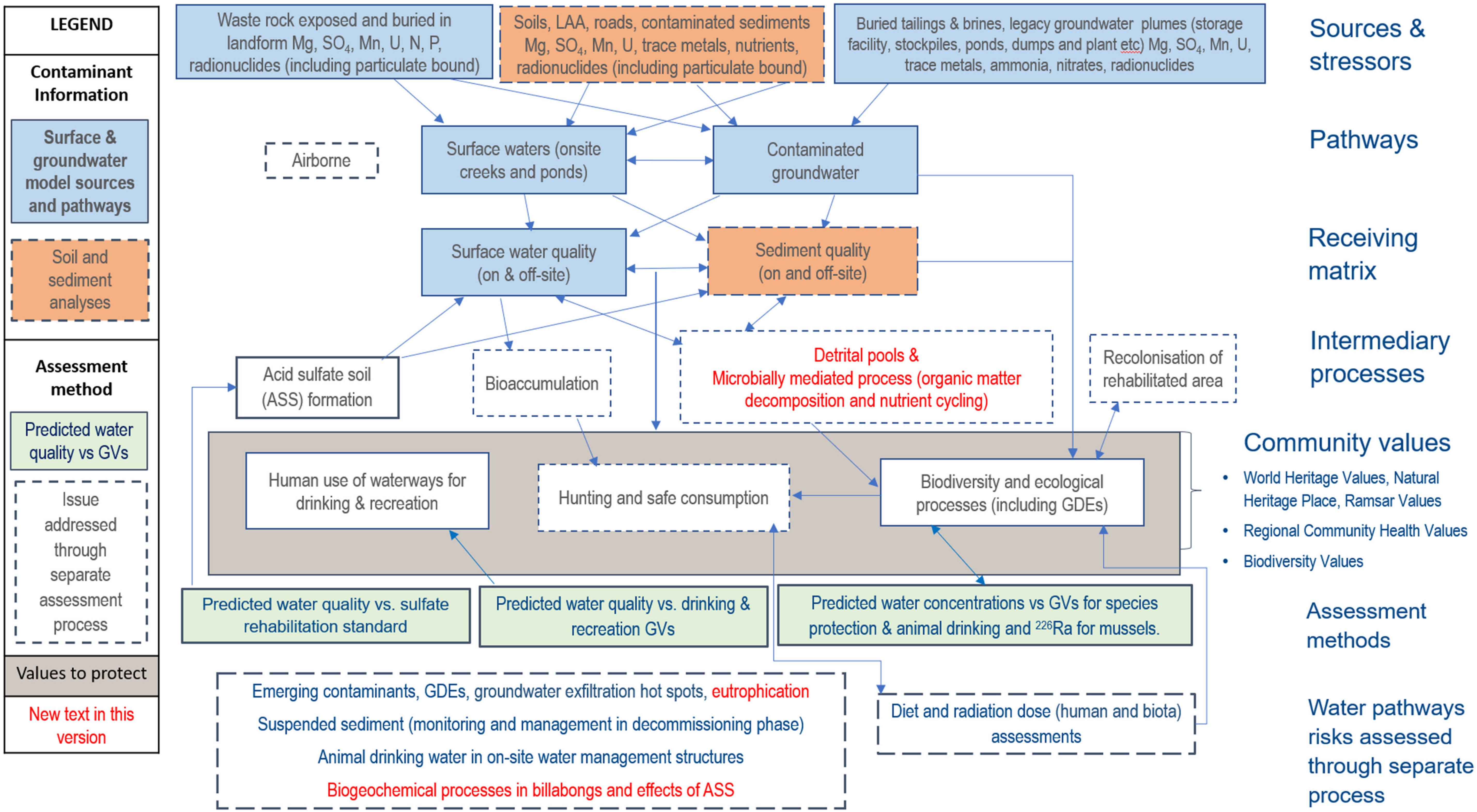


Figure 2.1 Conceptual model including source, pathway, receptors and processes assessed, assessment approaches used and issue included or excluded

2.3 Exposure scenarios

ERA requested that the RSWM results for the following scenarios be assessed at five sites in Magela Creek and at Mudginberri Billabong.

- peak concentrations and 10,000-year concentrations for 18 CoPC
  - aluminium (Al), ammonia (as total ammoniacal nitrogen, TAN; NH_3-N), cadmium (Cd), chromium (Cr^{3+}), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), calcium (as a ratio to Mg; Mg:Ca), manganese (Mn), nickel (Ni), nitrate-N (NO_3-N), radium-226 (^{226}Ra), selenium (Se), sulfate (SO_4), uranium (U), vanadium (V), and zinc (Zn),
- composite source terms (i.e. contaminants from all source terms across the site that were included in the RSWM) and Pit 3 only source terms (contaminants from Pit 3 only), and
- three different groundwater load scenarios (P10, P50 and P90)

The sites are described in 0 and shown in Figure 2.2.

Figure 2.2 Location of Coonjimba Billabong (CB) and assessment sites (red boxes) relative to Pit 3

Table 2.1 Reporting site details

Site ID	On or off the RPA	Description
GS01 or MG001	ON the RPA	Magela Creek upstream of pit 3, downstream of Corridor Creek/Georgetown Billabong.
409 or MG003		Magela Creek reporting node downstream of Pit 3, upstream of MG005
421 or MG005		Magela Creek reporting node downstream of Pit 3 and MG003, upstream of Coonjimba Billabong
GS09 or MG009		Magela Creek downstream of Coonjimba Billabong, upstream of Gulungul Billabong. Current compliance point
End RPA	OFF the RPA	Downstream of all above mentioned sites plus Gulungul Billabong.
Mudginberri Billabong or MB		Downstream of End RPA. Upstream of Magela Creek floodplain.

2.4 Assessment criteria

The GVs described in Iles (2023) were used as assessment criteria to assess the risks to human use of water for drinking and recreation, animals drinking water, biodiversity and potential acid sulfate soil formation. These GVs, shown in Table 2.2 were from the following sources.

- Site-specific, or site-adjusted ecotoxicity based guideline values developed by SSB for different species protection levels (SPL) for Cu, Mg, Mn, NH_3-N, U and Zn (Supervising Scientist 2021a – d respectively).
- National default guideline values (DGV) for different SPL for Al, Cd, Cr^{3+}, Ni, Pb, Se, V (ANZG 2018) and NO_3-N (ANZG 2023).
- National drinking guideline values for Al, Cu, Cd, Cr, Fe, Mn, Ni, NO_3, Pb, Se, SO_4, U and Zn from NHMRC, NRMMC (2011; v3.8 updated September 2022).
- National recreational guideline values for the same CoPCs as drinking water, where the health drinking water GV is multiplied by 10 as recommended by NHRMC (2008) and for sulfate from ANZEEC and ARMCANZ (2000).
- Animal (wildlife and/or livestock) drinking water guideline values for Al, Cu, Pb, Se, NO_3-N, and Zn (ANZECC and ARMCANZ 2000), U (long-term) from the British Columbian Ministry of Environment (MECC 2019) and U (acute) from Hink *et al.* (2010).
- The SSB rehabilitation standard of 10 mg/L sulfate in water (Supervising Scientist 2001e) to protect against ASS formation.
- The site-specific ^{226}Ra limit of 14 mBq/L (above background) for aquatic biota (Doering *et al.* 2019).

The most stringent GV for each CoPC is highlighted green. The 99% species protection level GV (99% SPL GV) were more stringent than the GVs for the other categories. For CoPC that do not have species protection GVs the most stringent GVs were for protection against ASS formation (sulfate) and human drinking water (Fe).

Eutrophication risks and those associated with exposure of ASS are being assessed under separate processes.

Table 2.2 Guideline values used as assessment criteria; most stringent GV highlighted green

COPC	Species protection level (%) (SPL)				Drinking water (total)[a]	Recreational water (total)[b]	Australian Livestock drinking water (long-term; total)[c]	International Wildlife/ Livestock drinking water (acute)[d]	Notes
	99	95	90	80					
Aluminium (µg/L) for pH < 6 waters	0.8				2000 aesthetic				ANZG (2018) default GV for unspecified level of species protection. Aesthetic drinking GV based on post-flocculation problems (ANZG, 2022)
Ammonia-N (NH_3-N) (mg/L)	0.4	0.6	0.79	6.81	-	-	-	-	Site specific SPL GV for pH 6.0, T 20°C. pH and temperature dependant (Supervising Scientist, 2021c). Could be more toxic in billabongs with higher pH and temperature.
Cadmium (µg/L)	0.06	0.2	0.4	0.8	2	20	10	-	ANZG (2018) default SPL GVs
Chromium 3+ (µg/L)	3.3				-	-	-	-	ANZG (2018) default GV for unspecified level of species protection. Cr^{3+} is relevant speciation for surface waters in the Ranger study area.
Copper (µg/L)	0.5	0.9	1.1	1.5	2000	2000	400 - 5000	300 (total)	Site specific SPL GV for Magela Creek conditions (Supervising Scientist, 2021d).. Potential to adjust for modifying factors in billabongs.
Iron	-				300 taste		-	-	
Lead (µg/L)	1.0	3.4	5.6	9.4	10	100	100	100	ANZG (2018) default SPL GVs
Magnesium (mg/L)	2.9	5.7	9.4	19	-	-	-	-	Site specific SPL GV applicable when Mg:Ca ≤9:1 (Supervising Scientist, 2021b).
Manganese (µg/L)	73	153	240	443	500	5000	-	-	Site specific SPL GV (Supervising Scientist, 2021a). Potential to adjust for modifying factors. Methods for GV adjustment not yet validated for Australian waters. Aesthetic drinking GV based on taste and staining
Nickel (µg/L)	8	11	13	17	20	200	1000	-	ANZG (2018) default SPL GVs
Nitrate (NO_3-N) (mg/L)	0.64	1.1	1.5	2.3	11.3	113	-	100	Drinking water GV protects bottle-fed infants under 3 months. Adults and children > 3 months can safely drink water with up to 100 mg/L nitrate. Nitrite rapidly oxidised to nitrate so not included separately.
Radium-226 (mBq/L above background)	14				-	-	-	-	Aquatic biota protection (Doering et al. 2019).
Selenium (µg/L)	5	11	18	34	10	100	20	5 / 30	ANZG (2018) default SPL GVs. The MECC (2019) guidelines use their aquatic 99% SPL GV to protect wildlife against accumulation (would be 5 in Australia using this logic). Canadian livestock value is 30 so an order of magnitude higher than their wildlife drinking GV.
Sulfate (SO_4) (mg/L)	-				500	400[c]	1000 - 2000	1000	10 mg/L seasonal average to avoid ASS formation (compare to the 50% exceedance probability concentration) (Supervising Scientist, 2021e).
Uranium (µg/L)	2.8	8.3	13	23	20	200	200	7000	Site-specific SPL GV can be adjusted for DOC conditions (Supervising Scientist, 2021a). Wildlife drinking water GV is acute value for mammals; birds an order of magnitude higher.
Vanadium (µg/L)	6				-	-	-	-	ANZG (2018) default GV for unspecified level of species protection.
Zinc (µg/L)	1.5	4.0	6.8	12.6	3000 taste		20000	2000 (chronic)	Site-adapted SPL GV for Magela Ck conditions (Supervising Scientist, 2021d). Potential to adjust for higher hardness in billabongs.

a) NHMRC, NRMMC, (2011; v3.8) health based GV or aesthetic GV if no health GV available.
b) Based on 10x drinking water GV for health as recommended by NHRMC (2008) and the value for sulfate from ANZEEC and ARMCANZ (2000).
c) ANZEEC and ARMCANZ (2000), Table 4.3.2 Livestock (long-term), update expected in 2020, not yet available.
d) Uranium GV from Hink *et al.* (2010); all other GVs from MECC (2019) except selenium, see notes column.

2.5 Consequences

The consequence descriptors used in this assessment were the same as those described in Iles (2023). A sliding scale approach that is stricter for sites off the RPA is used. The approach is illustrated in Table 2.3 using Mn site specific guideline values for different species protection levels (SPL).

As biodiversity consequences are related to exposure intensity, duration and/or repetition of exposure, the rating of consequences takes these factors into consideration. For species protection, meeting the 99% SPL GV results in very low (nil/negligible) consequences. Exposure to concentrations exceeding any GV for 1% or less of the flow period, or an exceedance of the 95% SPL GV only for less than 10% of the flow period, is characterised as having only a low consequence due to the unlikely adverse impacts associated with such short/infrequent periods of exposure above GV levels. Higher likelihoods of exposure above any of the GVs results in medium to very high species protection consequences depending on the exposure likelihood, the species protection level exceeded, and whether the location is on or off the RPA (Table 2.3).

Table 2.3 Example of a sliding scale consequence descriptor for species protection level.

<table>
<tr><th colspan="8">Predicted MANGANESE in water vs. SSGV; 73, 153, 240, 443 µg/L for 99, 95, 90, 80 % species protection level</th></tr>
<tr><th></th><th colspan="2">Exposure likelihood</th><th colspan="5">Consequence to species</th></tr>
<tr><th rowspan="6">Exceedance Probability predicted by RSWM</th><th>OFFSITE</th><th>ONSITE</th><th>Very Low</th><th>Low</th><th>Medium</th><th>High</th><th>Very High</th></tr>
<tr><td>≤1%</td><td>≤1%</td><td rowspan="5">No GV exceedance

(Mn concentration 0 - 73)</td><td>1% exceedance any GV</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td></td><td>>1-10%</td><td>74 -153</td><td>154 - 240</td><td>241 - 443</td><td>>443</td></tr>
<tr><td>>1-10%</td><td>>10-25%</td><td rowspan="3">NA</td><td>74 -153</td><td>154 - 240</td><td>>240</td></tr>
<tr><td>>10-25%</td><td>>25-50</td><td rowspan="2">NA</td><td>74 -153</td><td>>153</td></tr>
<tr><td>>25%</td><td>>50%</td><td>NA</td><td>>73</td></tr>
</table>

Table 2.4 shows descriptors for classifying the consequences for human use of water by comparing predicted Mn concentrations to the drinking water GV for health. Recreational water quality is assessed with the same approach as drinking water quality. (Note drinking and recreational water are contributors to human health; a comprehensive human health assessment is reported elsewhere. Aesthetic aspects of water quality are also assessed and reported elsewhere.)

Table 2.4 Example of a sliding scale consequence descriptor for human use of water.

Predicted MANGANESE in water vs. drinking water HEALTH GV (500 µg Mn/L)					
	Consequence for human use of water				
	Very Low	Low	Moderate	High	Very High
Exceedance Probability predicted by RSWM	1%	10% onsite	25% onsite; 10% offsite	50% onsite; 25% offsite	>50% onsite; >25% offsite

Consequences (and risks) for Community Trust, Compliance and Reputation were not scored in this report.

2.6 Risk classification

Risks were classified using the ERA risk spreadsheet and likelihood/probability and scoring matrices (Table 2.5and Table 2.6).

Table 2.5 ERA probability matrix

LIKELIHOOD	Rare	Unlikey	Probable	Likely	Almost certain
Frequency (multiple events)	Less than once per 100 years	Once in ten to once in 100 years	Once per year to once in ten years	Twice per year to once per year	More than twice per year
Probability (single events or probability distribution)	<5%	5-20%	21-50%	51-75%	>75%

Table 2.6 ERA risk classification matrix

	Consequence Severity				
Likelihood	Very low	Low	Moderate	High	Very high
Almost certain	Class II	Class III	Class IV	Class IV	Class IV
Likely	Class II	Class III	Class III	Class IV	Class IV
Possible	Class I	Class II	Class III	Class IV	Class IV
Unlikely	Class I	Class I	Class II	Class III	Class IV
Rare	Class I	Class I	Class II	Class III	Class III

Iles (2023) tested the sensitivity of the APRA tool to RSWM predicted concentrations for different groundwater load scenarios using a likelihood that aligned with the different load probabilities and found:

- the risk classification was very sensitive to changes in likelihood, with risks being understated or overestimated when using a likelihood of 10% (P90 loads) and overstated when using a likelihood of 90% (P10 loads), and
- the current combination of consequence descriptors and risk classification was most suited to assessing concentrations associated with P50 groundwater loads.

The risk classification for this assessment therefore focussed on consequences associated with RSWM predicted concentrations for both the P50 and P90 groundwater loads but used a probable likelihood of occurrence for both scenarios.

See Iles (2023) for further information on consequence, probability and risk used in the APRA tool.

3 Consequences of CoPC Concentrations

3.1 Screening for very low and low consequences

If predicted water quality meets the most stringent GV or only exceeds it with a 1% exposure likelihood the consequences were very low or low (see Table 2.3 and Table 2.4). If the most stringent GV was exceeded with a higher likelihood, then the full consequence matrix was applied.

Table 3.1 to Table 3.5 compares predicted CoPC concentrations to the most stringent GV for each CoPC (Table 2.2) at MG003, MG005, MG009, End of RPA and Mudginberri Billabong. Results are presented for multiple load scenarios (P10 loads at select sites, P50 and P90 loads at all sites) and multiple contaminant sources (No Mine, Composite sources, and Pit 3 only contaminant source). Any GV exceedances are highlighted red. If the No Mine scenario concentrations exceed the GV the results are highlighted yellow.

The only CoPC predicted to exceed GVs due to mining contamination was Mn, which exceeded the 99% SPL GV at all sites. The full consequence matrix needs was applied to Mn results (Section 3.2).

All predicted Al concentrations, including for the No Mine scenario, exceeded the SPL GV. Thus the species protection GVs for Al were not suitable and consequences could not be scored using the approach agreed for other CoPCs. ANZG (2018) suggests comparing the median concentration from a reference site (in this case the No Mine scenario) to the 80th percentile concentration at the exposed site, or to the median at the exposed site for high value locations. The reference condition approach for Al was also recommended by the Supervising Scientist (2018). The median Al concentration and percentage increase for each scenario compared to the No Mine scenario are shown in the screening tables (Table 3.1 to Table 3.5). The change in median Al concentrations were greatest the further from the mine the site was. For the P50 scenarios the Al increases were negative at the two sites closest to Pit 3 (MG003 and MG005), up to 3% at MG009, up to 5% at End of RPA and up to 9% at Mudginberri Billabong. Concentrations of Al and increases in the medians were higher for the P90 scenarios but followed the same pattern of increasing with distance from the mine. Therefore consequences associated with mine derived Al were considered to fall into the very low class. The other Al GV is for drinking water (aesthetics). Predicted concentrations were two orders of magnitude lower than the drinking water GV.

There was a 1% exceedance likelihood of the most stringent Mg GV for the P90 composite scenario at MG009; this results in a low consequence for species protection and very low consequences for all other endpoints which have higher GVs (drinking, recreation, wildlife drinking water) from Mg exposure at that site. All other results, including those for sites closer to Pit 3 were below the most stringent Mg GV and so consequences from Mg exposure for all endpoints were classified as very low at those sites.

No other GVs were exceeded so consequences for all other endpoints and CoPCs were classed as very low. Increased concentrations for Cr, V and Ni are shown in Table 3.1 to Table 3.5 and the limitations of the DGV for these CoPC and confidence in the consequence and risk classification are discussed in Section 5.2.

Consequences were very low for all CoPC for drinking water, recreational water, animal drinking water and ASS formation.

Summary tables for predicted concentrations at 10,000 years are shown in Annex A. Manganese exceeds GVs at 10,000 years for the P50 and P90 scenarios at sites on the RPA and the lease boundary. The consequences for both peak and 10,000-year concentrations are shown in Section 3.2.

Table 3.1 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for MG003 (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at MG003																								
Exccedance probability	1%	1690	640	200	174	0.8	74	0.3	0.1	0.01	130	0.6	0.13	0.77	0.32	0.0	106	0.1	4760	3				
	10%	1590	640	3.0	152	0.7	65	0.3	0.1	0.01	120	0.5	0.13	0.67	0.29	0.0	93	0.1	4000	3				
	25%	1570	630	3.0	149	0.7	64	0.3	0.1	0.01	110	0.5	0.13	0.49	0.29	0.0	70	0.1	3830	2				
	50%	840	550	3.0	61	0.3	27	0.2	0.0	0.01	90	0.5	0.11	0.21	0.19	0.0	34	0.1	1690	2	10	-11	31	-11
	75%	630	310	3.0	16	0.0	10	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	-0.1	8.5	0.1	549	2				
	90%	330	200	3.0	12	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	281	1				
	99%	230	160	3.0	7	0.017	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	168	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at MG003																								
Exccedance probability	1%	1350	590	200	144	0.3	55	0.3	0.1	0.01	120	0.5	0.13	0.77	0.30	0.0	106	0.1	3380	3				
	10%	1310	590	3.0	128	0.2	49	0.3	0.1	0.01	110	0.5	0.12	0.67	0.28	0.0	93	0.1	2740	2				
	25%	1290	590	3.0	122	0.2	48	0.3	0.1	0.01	100	0.5	0.12	0.49	0.27	0.0	70	0.1	2530	2				
	50%	790	540	3.0	49	0.1	21	0.2	0.0	0.01	80	0.4	0.11	0.21	0.18	0.0	34	0.1	1210	2	8	-13	29	-11
	75%	550	290	3.0	10	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	8.3	0.1	380	1				
	90%	310	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at MG003																								
Exccedance probability	1%	2110	690	200	265	1.1	108	0.4	0.2	0.01	140	0.7	0.16	0.78	0.53	0.1	107	0.1	6830	3				
	10%	1960	680	3.1	228	1.0	94	0.3	0.2	0.01	120	0.7	0.15	0.68	0.47	0.0	94	0.1	5790	3				
	25%	1930	670	3.1	224	0.9	92	0.3	0.2	0.01	110	0.7	0.15	0.50	0.46	0.1	71	0.1	5620	3				
	50%	900	550	3.1	90	0.4	38	0.3	0.1	0.01	90	0.5	0.120	0.23	0.26	0.0	36	0.1	2350	2	17	-4	49	-5
	75%	730	320	3.0	24	0.0	13	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	0.0	12	0.1	667	2				
	90%	350	210	3.0	16	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.1	0.1	354	2				
	99%	230	170	3.0	8	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	206	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG003																								
Exccedance probability	1%	1590	600	200	203	0.5	77	0.4	0.2	0.01	120	0.6	0.15	0.78	0.44	0.0	107	0.1	4520	3				
	10%	1520	600	3.0	180	0.4	68	0.3	0.2	0.01	110	0.6	0.14	0.68	0.40	0.0	94	0.1	3800	3				
	25%	1490	600	3.0	172	0.4	66	0.3	0.2	0.01	100	0.6	0.14	0.50	0.39	0.0	71	0.1	3590	2				
	50%	790	540	3.0	67	0.2	27	0.3	0.1	0.01	80	0.5	0.11	0.22	0.23	0.0	35	0.1	1580	2	12	-8	42	-7
	75%	610	300	3.0	11	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.11	0.13	-0.1	11	0.1	445	1				
	90%	320	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				

Table 3.1 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stingent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at MG003																								
Exccedance probability	1%	2470	710	200	334	1.7	138	0.4	0.3	0.01	150	0.9	0.19	0.80	0.71	0.2	111	0.1	8610	4				
	10%	2280	700	3.1	292	1.5	121	0.4	0.3	0.01	120	0.8	0.18	0.70	0.64	0.1	97	0.1	7400	3				
	25%	2240	690	3.1	285	1.4	118	0.3	0.3	0.01	110	0.8	0.18	0.52	0.62	0.1	74	0.1	7150	3				
	50%	960	550	3.1	111	0.5	48	0.3	0.1	0.01	90	0.5	0.13	0.24	0.31	0.1	39	0.1	2890	3	23	2	59	3
	75%	770	330	3.0	22	0.0	13	0.2	0.0	0.01	80	0.4	0.11	0.14	0.15	0.1	18	0.1	671	2				
	90%	370	210	3.0	15	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.0	0.1	319	2				
	99%	230	170	3.0	8	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	211	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG003																								
Exccedance probability	1%	1900	620	200	289	1.0	108	0.4	0.3	0.01	120	0.8	0.18	0.79	0.65	0.0	110	0.1	6170	3				
	10%	1800	620	3.1	256	0.9	96	0.4	0.3	0.01	110	0.7	0.17	0.69	0.59	0.0	97	0.1	5320	3				
	25%	1760	620	3.1	245	0.8	92	0.3	0.3	0.01	100	0.7	0.17	0.51	0.57	0.0	74	0.1	5020	3				
	50%	800	540	3.0	93	0.3	37	0.3	0.1	0.01	80	0.5	0.12	0.23	0.29	0.0	38	0.1	2090	2	19	-1	55	2
	75%	670	300	3.0	12	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.13	0.13	0.0	17	0.1	518	1				
	90%	340	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG003																					**Legend**			
Exccedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.100	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Table 3.2 Predicted peak CoPC concentrations (P50, P90 load scenarios) compared to the most stringent GVs for MG005

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P50 scenario at MG005																								
Exceedance probability	1%	2100	690	200	263	1.1	107	0.4	0.2	0.01	130	0.7	0.16	0.78	0.52	0.1	107	0.1	6790	3				
	10%	1960	680	3.1	227	1.0	93	0.3	0.2	0.01	120	0.7	0.15	0.68	0.47	0.0	94	0.1	5750	3				
	25%	1930	670	3.1	223	0.9	91	0.3	0.2	0.01	110	0.7	0.15	0.51	0.46	0.1	71	0.1	5590	3				
	50%	900	550	3.1	89	0.4	38	0.3	0.1	0.01	90	0.5	0.12	0.23	0.26	0.0	36	0.1	2340	2	17	-4	49	-5
	75%	720	320	3.0	24	0.0	13	0.2	0.0	0.01	70	0.4	0.10	0.12	0.16	0.0	12	0.1	665	2				
	90%	350	210	3.0	16	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.1	0.1	354	2				
	99%	230	160	3.0	8	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	199	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG005																								
Exceedance probability	1%	1580	600	200	201	0.5	76	0.4	0.2	0.01	120	0.6	0.15	0.78	0.43	0.0	107	0.1	4500	3				
	10%	1510	600	3.0	179	0.4	68	0.3	0.2	0.01	110	0.6	0.14	0.68	0.40	0.0	94	0.1	3790	3				
	25%	1490	600	3.0	171	0.4	66	0.3	0.2	0.01	100	0.6	0.14	0.50	0.39	0.0	71	0.1	3570	2				
	50%	790	540	3.0	66	0.2	27	0.3	0.1	0.01	80	0.5	0.11	0.22	0.22	0.0	35	0.1	1570	2	12	-8	42	-7
	75%	610	300	3.0	11	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.11	0.13	-0.1	11	0.1	444	1				
	90%	320	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted peak concentrations for COMPOSITE_P90 scenario at MG005																								
Exceedance probability	1%	2450	710	200	333	1.7	137	0.4	0.3	0.01	150	0.9	0.19	0.80	0.71	0.2	111	0.1	8550	4				
	10%	2270	700	3.1	290	1.5	120	0.4	0.3	0.01	120	0.8	0.18	0.70	0.63	0.1	97	0.1	7360	3				
	25%	2230	690	3.1	283	1.4	118	0.3	0.3	0.01	110	0.8	0.18	0.52	0.62	0.1	74	0.1	7110	3				
	50%	960	550	3.1	110	0.5	47	0.3	0.1	0.01	90	0.5	0.13	0.24	0.31	0.1	39	0.1	2870	3	23	2	58	3
	75%	770	330	3.0	22	0.0	13	0.2	0.0	0.01	80	0.4	0.11	0.14	0.15	0.1	18	0.1	669	2				
	90%	370	210	3.0	15	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.14	-0.2	6.0	0.1	319	2				
	99%	230	160	3.0	8	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	208	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG005																								
Exceedance probability	1%	1890	620	200	288	1.0	107	0.4	0.3	0.01	120	0.8	0.18	0.79	0.64	0.0	110	0.1	6140	3				
	10%	1790	620	3.1	254	0.9	95	0.4	0.3	0.01	110	0.7	0.17	0.69	0.58	0.0	97	0.1	5290	3				
	25%	1760	620	3.1	244	0.8	92	0.3	0.3	0.01	100	0.7	0.17	0.51	0.57	0.0	74	0.1	4990	3				
	50%	800	540	3.0	93	0.3	37	0.3	0.1	0.01	80	0.5	0.12	0.23	0.29	0.0	38	0.1	2080	2	19	-1	55	2
	75%	670	300	3.0	12	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.13	0.13	0.0	17	0.1	516	1				
	90%	330	200	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG005																					**Legend**			
Exceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

Table 3.3 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for MG009 (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at MG009																								
Excceedance probability	1%	2060	700	200	185	0.8	73	0.3	0.1	0.01	140	0.6	0.14	0.77	0.33	0.6	106	0.1	6130	3				
	10%	1890	680	5.6	163	0.7	64	0.3	0.1	0.01	120	0.6	0.13	0.68	0.30	0.2	94	0.1	5130	3				
	25%	1760	660	5.0	157	0.7	63	0.3	0.1	0.01	110	0.6	0.13	0.51	0.30	0.3	72	0.1	4720	3				
	50%	1010	550	4.1	78	0.3	32	0.2	0.0	0.01	90	0.5	0.11	0.24	0.21	0.3	38	0.1	2580	2	12	3	38	1
	75%	650	290	3.3	18	0.1	10	0.2	0.0	0.01	80	0.4	0.10	0.10	0.14	0.3	8.7	0.1	806	2				
	90%	350	200	3.0	12	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	288	1				
	99%	230	160	3.0	7	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	201	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at MG009																								
Excceedance probability	1%	1330	590	200	141	0.3	54	0.336	0.1	0.01	120	0.5	0.13	0.77	0.30	0.0	106	0.1	3320	2				
	10%	1290	590	3.2	125	0.2	48	0.3	0.1	0.01	110	0.5	0.12	0.67	0.28	0.0	93	0.1	2720	2				
	25%	1280	590	3.0	119	0.2	47	0.3	0.1	0.01	100	0.5	0.12	0.50	0.27	0.0	71	0.1	2480	2				
	50%	790	540	3.0	58	0.1	24	0.2	0.0	0.01	80	0.4	0.11	0.24	0.19	0.0	38	0.1	1380	2	9	1	33	1
	75%	490	270	3.0	13	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.09	0.14	-0.1	8.3	0.1	546	1				
	90%	300	190	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.0997	49.9	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at MG009																								
Excceedance probability	1%	2690	780	200	304	1.1	109	0.4	0.3	0.01	180	0.8	0.17	0.78	0.61	1.7	107	0.1	9040	4				
	10%	2420	750	8.2	268	1.0	96	0.3	0.2	0.01	140	0.8	0.16	0.69	0.55	0.9	95	0.1	7600	3				
	25%	2240	720	7.1	249	1.0	93	0.3	0.2	0.01	130	0.7	0.16	0.52	0.52	0.8	73	0.1	6940	3				
	50%	1250	560	5.1	127	0.5	46	0.3	0.1	0.01	110	0.6	0.13	0.26	0.32	0.6	39	0.1	3730	3	23	9	60	5
	75%	770	310	3.5	26	0.1	13	0.2	0.0	0.01	90	0.4	0.11	0.13	0.16	0.5	12	0.1	906	2				
	90%	390	210	3.0	17	0.0	9	0.2	0.0	0.01	50	0.4	0.10	0.07	0.15	-0.1	6.1	0.1	366	2				
	99%	230	170	3.0	9	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.0999	253	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at MG009																								
Excceedance probability	1%	1550	600	200	198	0.5	75	0.4	0.2	0.01	120	0.6	0.15	0.78	0.43	0.0	107	0.1	4440	3				
	10%	1500	600	3.25	176	0.4	67	0.3	0.2	0.01	110	0.6	0.14	0.68	0.39	0.0	95	0.1	3750	3				
	25%	1470	600	3.03	168	0.4	64	0.3	0.2	0.01	100	0.6	0.14	0.51	0.38	0.0	72	0.1	3510	2				
	50%	800	540	3.02	80	0.2	32	0.3	0.1	0.01	80	0.5	0.12	0.25	0.24	0.0	39	0.1	1830	2	15	4	47	3
	75%	540	270	3	14	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.11	0.14	0.0	11	0.1	622	1				
	90%	310	200	3	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	50	1				

Table 3.3 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at MG009																								
Exceedance probability	1%	3000	820	200	403	1.7	140	0.4	0.6	0.01	200	1.1	0.21	0.81	0.88	2.9	112	0.1	11500	4				
	10%	2720	780	12.9	352	1.5	123	0.4	0.5	0.01	160	1.0	0.20	0.71	0.78	1.7	98	0.1	9690	4				
	25%	2530	750	10.8	326	1.5	120	0.3	0.4	0.01	140	0.9	0.19	0.53	0.72	1.4	76	0.1	8850	3				
	50%	1380	560	6.83	165	0.7	58	0.3	0.2	0.01	120	0.7	0.15	0.27	0.43	0.9	42	0.1	4670	3	31	14	70	11
	75%	790	320	3.86	28	0.1	13	0.3	0.0	0.01	100	0.4	0.11	0.16	0.17	0.6	18	0.1	996	2				
	90%	400	210	3.01	15	0.0	9	0.2	0.0	0.01	60	0.4	0.10	0.07	0.14	0.0	6.0	0.1	325	2				
	99%	230	170	3	10	0.0	5	0.1	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.1	6.0	0.1	230	1				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at MG009																								
Exceedance probability	1%	1860	620	200	283	1.0	105	0.4	0.3	0.01	120	0.8	0.18	0.79	0.63	0.0	110	0.1	6030	3				
	10%	1770	620	3.27	250	0.8	94	0.4	0.3	0.01	110	0.7	0.17	0.70	0.58	0.0	97	0.1	5210	3				
	25%	1740	610	3.07	240	0.8	90	0.3	0.3	0.01	100	0.7	0.16	0.52	0.56	0.0	75	0.1	4920	3				
	50%	920	540	3.05	112	0.4	44	0.3	0.1	0.01	80	0.5	0.13	0.26	0.32	0.0	41	0.1	2460	2	23	9	60	9
	75%	610	280	3	16	0.1	8	0.3	0.0	0.01	60	0.4	0.10	0.14	0.15	0.0	17	0.1	700	2				
	90%	320	200	3	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted peak concentrations for NO MINE scenario at MG009																					**Legend**			
Exceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6.2	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6.0	0.1	50	1	Below GV			

Table 3.4 Predicted peak CoPC concentrations (P10, P50, P90) compared to the most stringent GVs for End of RPA (legend on next page)

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P10 scenario at End of RPA																								
Excedance probability	1%	1940	690	197	165	0.7	64	0.3	0.1	0.01	130	0.6	0.13	0.77	0.30	0.4	106	0.1	5400	3				
	10%	1860	680	8.6	159	0.7	63	0.3	0.1	0.01	120	0.6	0.13	0.70	0.30	0.2	96	0.1	4950	3				
	25%	1760	660	5.2	148	0.6	59	0.3	0.1	0.01	110	0.6	0.13	0.51	0.29	0.3	71	0.1	4570	3				
	50%	1310	510	4.7	110	0.5	44	0.3	0.1	0.01	90	0.5	0.12	0.25	0.24	0.4	39	0.1	3500	3	17	5	47	3
	75%	590	280	3.8	43	0.2	18	0.2	0.0	0.01	80	0.4	0.11	0.10	0.17	0.4	13	0.1	1560	2				
	90%	350	200	3.3	19	0.1	9	0.2	0.0	0.01	80	0.4	0.10	0.10	0.14	0.4	9	0.1	835	2				
	99%	250	170	3.1	8	0.0	6	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	0.4	8	0.1	272	1				
Predicted peak concentrations for PIT 3 ONLY_P10 scenario at End of RPA																								
Excedance probability	1%	1290	590	197	121	0.2	47	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2890	3				
	10%	1270	590	8.2	118	0.2	46	0.3	0.1	0.01	110	0.5	0.12	0.69	0.27	0.0	96	0.1	2460	3				
	25%	1240	580	3.0	110	0.2	43	0.3	0.1	0.01	100	0.5	0.12	0.50	0.26	0.0	71	0.1	2340	3				
	50%	940	450	3.0	82	0.2	33	0.2	0.1	0.01	80	0.5	0.11	0.25	0.22	0.0	39	0.1	1890	3	12	4	42	3
	75%	450	260	3.0	34	0.1	14	0.2	0.0	0.01	60	0.4	0.11	0.09	0.16	0.0	13	0.1	1030	2				
	90%	310	200	3.0	16	0.0	8	0.2	0.0	0.01	50	0.4	0.10	0.09	0.14	0.0	8	0.1	543	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	8	0.1	161	1				
Predicted peak concentrations for COMPOSITE_P50 scenario at End of RPA																								
Excedance probability	1%	2500	760	197	276	1.0	96	0.4	0.3	0.01	160	0.8	0.17	0.78	0.57	1.3	106	0.1	8010	3				
	10%	2380	740	10.1	261	1.0	94	0.3	0.2	0.01	140	0.8	0.16	0.71	0.54	0.9	98	0.1	7370	3				
	25%	2230	720	7.6	241	0.9	87	0.3	0.2	0.01	130	0.7	0.16	0.52	0.51	0.8	73	0.1	6780	3				
	50%	1650	560	6.4	178	0.7	65	0.3	0.2	0.01	120	0.6	0.14	0.26	0.40	0.8	**40**	0.1	5110	3	29	10	68	6
	75%	700	290	4.6	66	0.2	25	0.3	0.1	0.01	100	0.5	0.11	0.13	0.22	0.7	17	0.1	2100	2				
	90%	390	210	3.6	27	0.1	11	0.2	0.0	0.01	90	0.4	0.10	0.13	0.16	0.6	12	0.1	1030	2				
	99%	260	170	3.1	10	0.0	6	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	0.5	11	0.1	357	1				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at End of RPA																								
Excedance probability	1%	1480	600	197	170	0.4	65	0.3	0.2	0.01	120	0.6	0.14	0.77	0.39	0.0	106	0.1	3850	3				
	10%	1470	600	8.2	166	0.4	64	0.3	0.2	0.01	110	0.6	0.14	0.70	0.38	0.0	97	0.1	3470	3				
	25%	1420	600	3.0	155	0.4	60	0.3	0.1	0.01	100	0.6	0.14	0.51	0.36	0.0	72	0.1	3280	3				
	50%	1070	460	3.0	115	0.3	45	0.3	0.1	0.01	80	0.5	0.13	0.25	0.30	0.0	**39**	0.1	2560	3	20	6	57	5
	75%	490	260	3.0	45	0.1	18	0.2	0.0	0.01	60	0.4	0.11	0.11	0.19	0.1	15	0.1	1250	2				
	90%	320	200	3.0	19	0.1	9.2	0.2	0.0	0.01	60	0.4	0.10	0.11	0.15	0.1	11	0.1	641	2				
	99%	240	170	3.0	8	0.0	5.7	0.2	0.0	0.01	40	0.4	0.10	0.09	0.13	0.1	10	0.1	192	1				

Table 3.4 continued

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P90 scenario at End of RPA																								
Exccedance probability	1%	2800	800	197	365	1.5	124	0.4	0.5	0.01	180	1.0	0.20	0.79	0.81	2.2	109	0.1	10200	4				
	10%	2670	770	14.5	343	1.5	121	0.4	0.4	0.01	160	1.0	0.20	0.72	0.76	1.6	100	0.1	9420	3				
	25%	2500	750	11.5	316	1.4	112	0.3	0.4	0.01	140	0.9	0.19	0.53	0.71	1.5	75.5	0.1	8650	3				
	50%	1850	580	9.3	232	1.0	83	0.3	0.3	0.01	130	0.8	0.16	0.28	0.55	1.2	43	0.1	6450	3	39	15	76	13
	75%	770	300	6.0	85	0.4	31	0.3	0.1	0.01	110	0.5	0.12	0.16	0.27	0.9	21	0.1	2560	3				
	90%	410	210	4.2	33	0.1	13	0.3	0.0	0.01	100	0.4	0.11	0.15	0.18	0.7	18	0.1	1190	2				
	99%	260	170	3.2	12	0.0	7	0.2	0.0	0.01	80	0.4	0.10	0.12	0.14	0.5	15	0.1	415	2				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at End of RPA																								
Exccedance probability	1%	1750	620	197	243	0.8	91	0.4	0.3	0.01	120	0.7	0.17	0.78	0.56	0.1	108	0.1	5200	3				
	10%	1730	620	8.2	237	0.8	89	0.3	0.3	0.01	110	0.7	0.16	0.71	0.55	0.1	99	0.1	4850	3				
	25%	1660	610	3.1	222	0.7	84	0.3	0.2	0.01	100	0.7	0.16	0.52	0.53	0.1	75	0.1	4570	3				
	50%	1250	470	3.1	163	0.6	62	0.3	0.2	0.01	80	0.6	0.14	0.26	0.42	0.1	42	0.1	3490	3	30	11	69	11
	75%	550	260	3.0	61	0.2	24	0.3	0.1	0.01	70	0.5	0.11	0.14	0.23	0.2	20	0.1	1560	2				
	90%	340	200	3.0	24	0.1	11	0.2	0.0	0.01	60	0.4	0.10	0.13	0.16	0.2	16	0.1	767	2				
	99%	240	170	3.0	9	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.10	0.13	0.2	14	0.1	235	1				
Predicted peak concentrations for NO MINE scenario at End of RPA																					**Legend**			
Exccedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			

Table 3.5 Predicted peak CoPC concentrations (P50, P90) compared to the most stringent GVs for Mudginberri Billabong

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stingent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	8	1.6	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted peak concentrations for COMPOSITE_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1860	770	150	142	0.6	56	0.3	0.1	0.01	140	0.7	0.16	0.79	0.40	0.6	108	0.1	3870	3				
	10%	1740	720	6.6	133	0.5	52	0.3	0.1	0.01	120	0.7	0.15	0.56	0.37	0.6	80	0.1	3600	2				
	25%	1680	700	6.0	127	0.5	49	0.3	0.1	0.01	120	0.6	0.15	0.35	0.36	0.6	53	0.1	3420	2				
	50%	1500	630	5.8	115	0.4	45	0.3	0.1	0.01	110	0.6	0.14	0.18	0.33	0.6	30	0.1	3060	2	20	14	56	9
	75%	800	360	4.9	63	0.2	24	0.3	0.1	0.01	100	0.5	0.12	0.13	0.23	0.5	18	0.1	1900	2				
	90%	430	230	3.7	29	0.1	12	0.2	0.0	0.01	90	0.4	0.11	0.11	0.16	0.4	13	0.1	1070	2				
	99%	280	180	3.1	12	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.10	0.14	0.3	9.6	0.1	406	2				
Predicted peak concentrations for PIT 3 ONLY_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1300	680	150	89	0.2	39	0.3	0.1	0.01	120	0.6	0.15	0.78	0.30	0.0	108	0.1	1790	2				
	10%	1220	640	4.4	83	0.2	36	0.3	0.1	0.01	110	0.6	0.14	0.55	0.28	0.0	79	0.1	1640	2				
	25%	1180	620	3.5	79	0.2	34	0.3	0.1	0.01	90	0.5	0.13	0.35	0.27	0.0	53	0.1	1560	2				
	50%	1050	550	3.4	71	0.2	31	0.3	0.1	0.01	80	0.5	0.13	0.17	0.25	0.0	29	0.1	1410	2	13	9	43	7
	75%	590	330	3.3	41	0.1	18	0.2	0.0	0.01	70	0.4	0.11	0.11	0.19	0.0	17	0.1	1010	2				
	90%	350	220	3.0	21	0.1	10	0.2	0.0	0.01	70	0.4	0.10	0.10	0.15	0.0	12	0.1	658	2				
	99%	250	170	2.9	9	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.0	8.9	0.1	224	1				
Predicted peak concentrations for COMPOSITE_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	2080	790	150	186	0.8	71	0.4	0.3	0.01	150	0.8	0.18	0.79	0.53	1.1	109	0.1	5160	3				
	10%	1940	740	9.2	175	0.8	66	0.3	0.2	0.01	130	0.8	0.17	0.56	0.49	1.0	81	0.1	4810	3				
	25%	1870	720	8.4	167	0.7	63	0.3	0.2	0.01	130	0.8	0.16	0.36	0.47	1.1	55	0.1	4570	3				
	50%	1670	640	8.0	150	0.7	56	0.3	0.2	0.01	120	0.7	0.16	0.19	0.43	1.0	32	0.1	4080	3	28	20	67	15
	75%	880	370	6.3	81	0.3	30	0.3	0.1	0.01	110	0.5	0.12	0.14	0.28	0.7	21	0.1	2410	2				
	90%	460	240	4.4	36	0.2	15	0.3	0.0	0.01	90	0.4	0.11	0.13	0.18	0.5	16	0.1	1260	2				
	99%	280	180	3.2	14	0.1	7	0.2	0.0	0.01	80	0.4	0.10	0.11	0.14	0.3	12	0.1	479	2				
Predicted peak concentrations for PIT 3 ONLY_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1440	690	150	126	0.5	53	0.4	0.2	0.01	130	0.7	0.16	0.79	0.39	0.1	109	0.1	2480	2				
	10%	1350	650	4.4	118	0.4	49	0.3	0.1	0.01	110	0.6	0.15	0.56	0.37	0.1	80	0.1	2290	2				
	25%	1310	630	3.5	112	0.4	46	0.3	0.1	0.01	90	0.6	0.15	0.35	0.35	0.1	54	0.1	2160	2				
	50%	1170	560	3.4	100	0.4	42	0.3	0.1	0.01	80	0.6	0.14	0.18	0.33	0.1	31	0.1	1940	2	20	15	56	13
	75%	650	330	3.3	56	0.2	23	0.3	0.1	0.01	70	0.5	0.12	0.13	0.22	0.1	20	0.1	1300	2				
	90%	370	220	3.0	26	0.1	12	0.2	0.0	0.01	70	0.4	0.10	0.11	0.16	0.1	15	0.1	798	2				
	99%	260	180	2.9	10	0.0	7	0.2	0.0	0.01	50	0.4	0.10	0.10	0.14	0.1	11	0.1	276	1				
Predicted peak concentrations for NO MINE scenario at Mudginberri Billabong																								
Exccedance probability	1%	940	660	149	15	0.0	6	0.3	0.0	0.01	120	0.5	0.13	0.78	0.16	-	107	0.1	892	1				
	10%	880	620	4.3	8	0.0	6	0.3	0.0	0.01	110	0.5	0.12	0.55	0.15	-	78	0.1	536	1				
	25%	860	600	3.5	5	0.0	6	0.3	0.0	0.01	90	0.5	0.11	0.33	0.15	-	51	0.1	164	1				
	50%	760	530	3.4	5	0.0	6	0.2	0.0	0.01	80	0.4	0.11	0.16	0.15	-	27	0.1	56	1				
	75%	450	320	3.2	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.10	0.13	-	15	0.1	52	1				
	90%	300	220	3.0	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.08	0.13	-	10	0.1	50	1				
	99%	240	170	2.9	4	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-	6.9	0.1	45	1				

Legend

- Above GV
- No mine scenario above GV
- Below GV

3.2 Species protection consequences for Mn

The predicted Mn concentrations and species protection consequence classifications at each of the Magela Creek sites are shown in Table 3.6.

Peak consequences

The species protection consequences for P50 load peak concentrations were High or Very High at all sites downstream of Pit 3 for both the Composite source and Pit 3 only scenarios. Although the concentrations for the Pit 3 only source were predicted to be lower, the consequence classification was the same.

Concentrations, and in some cases consequences, increase for P90 loads (Table 3.6).

- At MG003 and MG005, the two sites closest to Pit 3, Mn concentrations and consequences were predicted to be almost identical. These Mn concentrations were higher than the site upstream of Pit 3 (MG001).
- At MG009 (downstream of Coonjimba Billabong):
  - The peak Composite source scenario concentrations increase as expected.
  - The concentrations for the peak Pit 3 only source were lower except for the 50 and 75% exceedance probabilities.
  - The consequences were higher for the Composite source scenarios (High for P10 and P50 to Very High for P90) than for the Pit 3 only scenarios (Very Low for P10 to High for P50 and P90).
- At End RPA the concentrations were lower than at MG009 for the 1- 25% exceedance probabilities but higher for the other exceedance probabilities.
- Mn concentrations at Mudginberri Billabong were lower than other Pit 3 receiving water sites, but consequences for the billabong were classified as High to Very High for the P50 and P90 scenarios. The High consequences for the Pit 3 only P50 were a result of a 25% exceedance of the 99% species protection GV by 5%. For the P90 scenario the GV was exceeded by higher percentage with greater probability.

10,000-year consequences

The P10 scenarios for both source combinations has Very Low consequences at all sites.

At MG003, MG005 and MG009 the species protection consequences were:

- Low and Very Low for Pit 3 only P10 and P50 scenarios.
- Medium for the P50 and P90 Composite source and the P90 Pit 3 only sources.

At End of RPA consequences for the P50 Pit 3 only source were Very Low, and Very High for the other P50 and P90 scenarios. At Mudginberri Billabong the consequences were rated as Very Low for all scenarios.

Table 3.6 Predicted three day rolling average manganese peak concentrations (µg/L) in Magela Creek and species protection consequences; full season results

		Consequence to species			Very Low		Low		Medium		High		Very High	
Location	**Exceed-ance probability**	**No Mine**	**Peak P10 Composite UA**	**Peak P50 Composite UA**	**Peak P90 Composite UA**	**Peak P10 Pit 3 Only UA**	**Peak P50 Pit 3 Only UA**	**Peak P90 Pit 3 Only UA**	**10k P10 Composite UA**	**10k P50 Composite UA**	**10k P90 Composite UA**	**10k P10 Pit 3 Only UA**	**10k P50 Pit 3 Only UA**	**10k P90 Pit 3 Only UA**
GS01/MG001 (Magela upstream of pit 3)	**1%**	14.4	42.6	75.8	59.7	14.4	14.4	14.4	23.5	30.8	29.1	14.4	14.3	14.4
	10%	11.5	32.9	57.9	45.8	11.5	11.5	11.5	16.5	22.0	20.8	11.5	11.3	11.5
	25%	6.67	29.9	52.4	41.6	6.67	6.67	6.67	14.50	18.8	17.8	6.67	6.54	6.67
	50%	4.50	20.0	33.0	26.7	4.50	4.50	4.50	11.00	13.1	12.7	4.50	4.50	4.50
	75%	4.50	12.6	17.4	14.9	4.50	4.50	4.50	6.66	7.62	7.42	4.50	4.50	4.50
	90%	4.49	8.39	10.5	9.60	4.49	4.49	4.49	5.50	6.00	5.89	4.49	4.49	4.49
	99%	4.45	4.50	4.50	4.50	4.45	4.45	4.45	4.50	4.50	4.50	4.45	4.45	4.45
409/MG003 (Magela mid-stream, d/s of Pit 3)	**1%**	14.4	174	265	334	144	203	289	68.2	106	155	56.1	86.0	137
	10%	11.6	152	228	292	128	180	256	57.3	89.8	133	48.1	76.2	122
	25%	6.89	149	224	285	122	172	245	54.8	86.3	130	45.7	72.4	116
	50%	4.50	60.5	89.5	111	48.5	66.5	93.2	25.8	37.4	52.4	21.6	30.9	46.4
	75%	4.50	16.3	24.3	22.4	10.4	11.4	12.3	8.31	9.92	11.0	7.49	8.80	10.3
	90%	4.49	11.8	16.0	14.5	4.50	4.50	4.50	5.78	6.45	6.38	4.50	4.50	4.50
	99%	4.47	6.78	7.76	8.16	4.47	4.47	4.47	5.20	5.58	5.60	4.47	4.47	4.47
421/MG005 (Magela mid-stream, d/s of Pit 3)	**1%**	14.4	173	263	333	143	201	288	67.7	105	154	55.8	85.6	136
	10%	11.6	151	227	290	127	179	254	57.0	89.2	132	47.9	75.8	121
	25%	6.91	148	223	283	121	171	244	54.5	85.9	129	45.4	72.0	115
	50%	4.50	59.9	88.5	110	48.1	66.1	92.8	25.6	37.1	51.9	21.4	30.7	46.1
	75%	4.50	16.2	24.2	22.3	10.4	11.3	12.3	8.28	9.88	10.9	7.47	8.78	10.2
	90%	4.49	11.7	15.9	14.5	4.50	4.50	4.50	5.78	6.45	6.37	4.50	4.50	4.50
	99%	4.47	6.75	7.69	8.06	4.47	4.47	4.47	5.19	5.56	5.59	4.47	4.47	4.47
GS09 (MG009, downstream of CB on lease)	**1%**	14.4	185	304	403	141	198	283	66.2	103	151	54.9	84.3	134
	10%	11.7	163	268	352	125	176	250	56.0	87.5	130	47.2	74.6	119
	25%	7.23	157	249	326	119	168	240	53.9	84.9	127	44.8	70.9	113
	50%	4.50	78.0	127	165	57.9	79.8	112	29.5	44.0	62.5	24.4	36.2	55.3
	75%	4.50	17.7	26.4	28.3	13.0	14.1	15.9	10.6	12.3	13.6	9.56	11.2	12.8
	90%	4.49	11.9	17.1	15.3	4.50	4.50	4.50	5.73	6.37	6.29	4.50	4.50	4.50
	99%	4.49	7.22	8.89	9.54	4.49	4.49	4.49	5.16	5.53	5.57	4.49	4.49	4.49
EndRPA (OFF the RPA)	**1%**	14.4	165	276	365	121	170	243	58.1	89.6	130	47.6	73.0	115
	10%	12.3	159	261	343	118	166	237	54.0	84.9	126	44.3	70.1	112
	25%	7.21	148	241	316	110	155	222	51.0	79.6	118	42.0	66.1	105
	50%	4.50	110	178	232	82.4	115	163	40.2	61.3	88.9	33.2	50.5	78.7
	75%	4.50	42.9	66.0	84.7	33.6	44.8	60.6	19.6	26.3	35.5	17.7	23.2	32.5
	90%	4.50	19.4	27.0	33.0	15.5	18.9	23.7	10.9	13.6	16.4	9.74	12.2	15.1
	99%	4.49	8.04	10.4	12.1	6.82	7.73	8.97	5.64	6.27	7.06	5.38	5.91	6.71
Mudginberri Billabong	**1%**	14.5	NA	142	186	NA	88.7	126	NA	48	69	NA	39	61
	10%	8.42	NA	133	175	NA	83.2	118	NA	45	65	NA	37	57
	25%	5.09	NA	127	167	NA	79.3	112	NA	43	62	NA	35	55
	50%	4.90	NA	115	150	NA	71.1	100	NA	39	56	NA	32	49
	75%	4.77	NA	63	81	NA	40.9	56	NA	24	33	NA	21	30
	90%	4.53	NA	29	36	NA	20.8	26	NA	14	18	NA	13	16
	99%	4.37	NA	12	14	NA	8.7	10	NA	7	8	NA	6	7

4 Risk Evaluation

Risks for the combinations of sites, scenarios, and values shown in Table 4.1 were evaluated using the ERA risk spreadsheet and classification schemes discussed above.

The risk evaluation and classification for cultural use of water based on drinking and recreational water quality and for animal drinking water quality for all CoPCs with relevant GVs is shown in Table 4.2 and Table 4.3 respectively. The consequences were very low so the risks were all Class I which is the lowest risk rating possible.

The risk evaluation and classification for biodiversity, based on comparison of modelled data to aquatic ecosystem species protection levels, is shown in Table 4.4.

The risk of ASS formation, not shown in the tables, was also Class I as the SO_4 GV was not exceeded.

The risk spreadsheet showing additional detail is provided in Annex B. The risk classifications are discussed in Section 5.1. Limitations of inputs to the risk evaluation and confidence or material effect of the limitations on the risk assessment are discussed in Section 5.2.

Table 4.1 Combinations of scenarios, sites, and values classified in the ERA risk spreadsheet

	Contaminant source sceanrios, vlaues and CoPCs assessed for risk classification			
Sites	**Composite sources PEAK, P50**	**Pit3 only PEAK, P50**	**Composite sources 10,000 Yr, P50**	**Pit 3 only 10,000 Yr, P50**
ON the RPA (MG001, MG003, MG005, MG009)	Drinking water (all CoPCs)			
	Recreational water (all CoPC)			
	Animal drinking water (all CoPC)			
	Acid sulfate soil formation (SO_4)			
	Aquatic species protection (Mn)			
	Aquatic species protection (all other CoPC)			
OFF the RPA (EndRPA, Mudginberri BB)	Drinking water (all CoPCs)			
	Recreational water (all CoPC)			
	Animal drinking water (all CoPC)			
	Acid sulfate soil formation (SO_4)			
	Aquatic species protection (Mn)			
	Aquatic species protection (all other CoPC)			

Table 4.2 Risk evaluation for cultural water use based on drinking and recreational GVs; applies to all CoPC with relevant GVs

Risk Type (T=Threat)	Category	Subcategory	Item	Risk Description: Evaluated 32 of 32 risks (0 Remaining) — Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Evaluation: Likelihood - Probability	Evaluation: Culture (drinking, recreation) OFF the RPA	Evaluation: Culture (drinking, recreation) ON the RPA	Rating: Culture (drinking, recreation) OFF the RPA	Rating: Culture (drinking, recreation) ON the RPA	Risk Management Class
T	J	02		**Land use (cultural use of water for drinking & recreation)**							
T	J	02	01	Water not suitable for drinking due to mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	02	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	02	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	02	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	02	05	Water not suitable for recreation due mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	02	06		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	02	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	02	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	02	09	Water not suitable for drinking due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	02	10		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	02	11		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	02	12		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I
T	J	02	13	Water not suitable for recreation due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	02	14		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	02	15		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	02	16		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

Table 4.3 Risk evaluation for animal drinking water; applies to all CoPC with relevant GVs

Ref.				Risk Description		Evaluation	Rating				Risk Management Class
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 32 of 32 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Likelihood - Probability	Animal drinking OFF the RPA	Animal drinking ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	
T	J	06		**Flora & fauna (animal drinking water)**							
T	J	06	01	Water not suitable for animal drinking water due to mine contaminants OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	06	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	06	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	06	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	06	05	Water not suitable for animal drinking water due to mine contaminants ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	06	06		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	06	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	06	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

Table 4.4 Risk evaluation for biodiversity, based on species protection GVs; applies to all CoPC with relevant GVs

Ref.				Risk Description		Evaluation			Rating		
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Likelihood - Probability	Biodiversity OFF the RPA	Biodiversity ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Risk Management Class
T	**J**	**07**		**Biodiversity & ecosystems (aquatic species protection)**							
T	J	07	01	Elevated Mn in water (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VH		**IV**		**IV**
T	J	07	02		Contaminated by **Pit 3 (PEAK, P50)**	P	VH		**IV**		**IV**
T	J	07	03		Contaminated by **Composite sources (10,000 Yr, P50)**	P	H		**IV**		**IV**
T	J	07	04		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	07	05	Poor water quality for CoPC except Mn (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	P	VL		I		I
T	J	07	06		Contaminated by **Pit 3 (PEAK, P50)**	P	VL		I		I
T	J	07	07		Contaminated by **Composite sources (10,000 Yr, P50)**	P	VL		I		I
T	J	07	08		Contaminated by **Pit 3 (10,000 Yr, P50)**	P	VL		I		I
T	J	07	09	Elevated Mn in water (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		H		**IV**	**IV**
T	J	07	10		Contaminated by **Pit 3 (PEAK, P50)**	P		H		**IV**	**IV**
T	J	07	11		Contaminated by **Composite sources (10,000 Yr, P50)**	P		M		**III**	**III**
T	J	07	12		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		L		**II**	**II**
T	J	07	13	Poor water quality for CoPC except Mn (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**	P		VL		I	I
T	J	07	14		Contaminated by **Pit 3 (PEAK, P50)**	P		VL		I	I
T	J	07	15		Contaminated by **Composite sources (10,000 Yr, P50)**	P		VL		I	I
T	J	07	16		Contaminated by **Pit 3 (10,000 Yr, P50)**	P		VL		I	I

5 Discussion

5.1 Risk profile

The risk profile for ON and OFF the RPA for the P50 load scenarios is shown in Figure 5.1.

Class I is the lowest risk possible. A risk that results in Class III or Class IV is considered a material risk that requires active management and consideration of additional control measures.

Location (Sites)	Value and CoPC assessed	Risk classes for P50 contaminant source sceanrios (based on worst case for any site at the location)			
		Composite sources PEAK, P50	Pit3 PEAK, P50	Composite sources 10,000 Yr, P50	Pit 3 10,000 Yr, P50
ON the RPA (MG001 / MG003 / MG005 / MG009)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	III	II
	Aquatic species protection (all other CoPC)	I	I	I	I
OFF the RPA (Mudginberri Billabong / EndRPA)	Drinking water (all CoPCs)	I	I	I	I
	Recreational water (all CoPC)	I	I	I	I
	Animal drinking water (all CoPC)	I	I	I	I
	Acid sulfate soil formation (SO_4)	I	I	I	I
	Aquatic species protection (Mn)	IV	IV	IV	I
	Aquatic species protection (all other CoPC)	I	I	I	I

Risk ranking is based on consequences for the full season data. If based on recessional flow data only the only change would be biodiversity protection at MG009 for the 10,000 year composite sceanrio increases from a class III to a class IV risk.

Figure 5.1 Risk profile for ON and OFF the RPA

Cultural water use and

The consequences for cultural water use (based on drinking and recreational water quality GVs for all CoPCs) were very low resulting in Class I risks at all sites; the lowest risk rating possible (Table 4.2 and Figure 5.1).

Wildlife drinking water and acid sulfate soil formation

Wildlife drinking water and acid sulfate soil formation risks were Class I at all sites.

Species protection

The risk classification for biodiversity (Table 4.3), was Class I for all CoPCs except Mn. Based on Mn ecotoxicity species protection GVs, the species protection risks were (Figure 5.1):

- Class I risks OFF the RPA for the 10,000-year Pit 3 only scenario.

- Class II risks ON the RPA for the 10,000-year Pit 3 only scenario.
- Class III risk ON the RPA for the 10,000-year composite sources scenario.
- Class IV risks both ON and OFF the RPA for both the peak composite and peak Pit 3 only scenarios.
  - For the two sites closest to Pit 3 the risk would be Class III but at MG009 risk is Class III for the Pit 3 only scenario and Class IV for the composite source scenario.

5.2 Limitations

Guideline values for aquatic ecosystem species protection

Site-specific, or site adjusted, GVs based on aquatic species sensitivity distributions (SSDs) protection were used in this assessment for Cu, Mg, Mg:Ca, Mn, NH_3-N, U and Zn. The reliability of the Cu and Zn GVs under the criteria recommended by Warne et al. (2018) is moderate (Supervising Scientist 2021d). There is a high level of confidence in the Mg GV (Supervising Scientist 2021b). The level of confidence or reliability for the GVs for Mn, U and NH_3-N is not stated in the rehabilitation standards where they are published (Supervising Scientist 2021a and 2021c respectively) however the Supervising Scientist has stated the level of confidence for these site-specific GVs is high (Supervising Scientist 2021g).

The Supervising Scientist (2018) found the same species protection DGV used in this assessment for Cd and Pb were suitable to apply to Magela Creek providing high confidence in these DGVs. They recommended that local GVs for Al, Cr, and V be based on reference site data to account for local background water quality conditions

Small increases in Al were predicted were predicted at sites immediately downstream of Pit 3. There was a trend of increasing concentrations above the reference condition with distance from the mine (Table 3.1 to Table 3.5). It was assumed therefore that the mine contribution to Al was small and the consequences to species protection were ranked as very low resulting in a Class I risk. The same assumptions applied to V as the trend for V concentrations above the reference condition was similar to that for Al.

Modelling predicted moderate increases above the reference condition for Cr with 12% to 23% increases for the P50 and P90 scenarios at the two sites immediately downstream of the Pit increasing to 20% to 30% at End of RPA (Table 3.1 to Table 3.5). Despite the moderate increases the concentrations remained less than an order of magnitude lower than the DGV for Cr^{3+}. A review of Magela Creek water quality data shows that the highest predicted Cr concentrations are less than double the reporting limit. It was therefore assumed these moderate increases would result in very low consequences and a Class 1 risk for species protection.

If the assumptions for Cr, V and Al are not valid the species protection consequences and risk may be higher.

Nickel was not included in the Supervising Scientist (2018) DGV assessment. The ANZG (2018) Ni DGV was used in this assessment in line with the method reported in Iles (2023). Nickel did not exceed the DGV, however it is important to note:

- the Supervising Scientist has suggested that the ANZG (2018) Ni DGV may be too high for Magela Creek

- the predicted proportional increase in Ni concentrations relative to background (i.e. the No mine scenario) was greater than predicted for other metals except Mn.

It is therefore plausible that the very low consequences and Class I risk may be underestimated.

The bioavailability and toxicity of Ni is dependent on several (often interactive) physico-chemical processes, which can be predicted based on generalised models. Stauber *et. al.* (2021) report Ni GVs adjusted for bioavailability in Australian and New Zealand waters using two biotic ligand models (BLM), two multiple linear regression (MLR) models and datasets for temperate, tropical, and combined temperate-tropical data. For Magela Creek the 99% protection GV varied between 9.9 and 0.48 µg Ni/L (Table 5.1) compared to the 8 µg Ni/L used in this assessment.

The two MLR based 99% SPL GVs for Magela Creek reported by Stauber et al. (2021) were exceeded by the Ni concentrations at sites downstream of Pit 3. The two BLM based GVs were not exceeded.

Stauber *et al.* (2021) report limitations for all four modelled approaches. Personal comments from Dr. Andrew Harford (Supervising Scientist) indicate more work would be required if a site-specific/adjusted GV for Ni is deemed necessary. Information and advice in Stauber *et al*. (2021) could be used to derive a site-specific/adjusted GV for Ni which may be lower than the GV used in this assessment and the predicted Ni concentrations.

Table 5.1 Species protection GVs for Ni (µg/L)

Species protection level				Reference and notes
99%	95%	90%	80%	
				National water type
8	11	13	17	ANZG 2018 default GVs (DGV)
0.4	3.0	5.4	14	Bioavailability adjusted GVs for pH 7.5, DOC 0.5 mg/L, hardness 30 mg $CaCO_3$/L. Stauber *et al*. 2021 main report and Tables S6-9.
				Soft water or Magela reek water
1.6	8.4	17	44	Bioavailability based GVs adjusted for pH 6.0, DOC 3 mg/L, hardness 12 mg $CaCO_3$/L, Ca 2 mg/L, Mg 1.6 mg/L. Closest to Magela Creek conditions of pH 6.1, DOC 3, Hardness 2, Ca 0.25, Mg 0.25 in Stauber *et al.* 2021 lookup tables S6-9. Toxicity in the softer Magela Creek could be higher.
1.9	3.4	-	-	Softwater BLM; Magela Creek. Stauber *et al.* 2021 Table 7.
0.48	2.5	5.0	10	Trophic-level-specific MLR; Magela Creek. Stauber *et al.* 2021 Table S5.
0.62	1.7	2.8	4.7	Pooled MLR; Magela Creek. Stauber *et al.* 2021 Table S5.
9.9	15	-	-	EU BLM; Magela Creek. Stauber *et al.* 2021 Table 7.

Confidence in the species protection consequence and risk classifications for Al, Cr, V and Ni is lower than for the other parameters. This will not pose a risk to the environment as the management actions required to mitigate the risks associated with Mn will also mitigate the risks from these CoPC.

Guideline value for the prevention of acid sulfate soil

The GV for prevention of ASS was recommended by the Supervising Scientist (2021e). It was based on a review of local water quality conditions believed to have caused ASS to form at Ranger and is identical to the nationally recommended guideline value to prevent the formation of ASS. No level of confidence is stated in Supervising Scientist (2021e) but it is stated that additional site-specific knowledge may lead to further refinement of this standard. If the GV is lowered then the consequences and risks may be higher than reported in this assessment.

Guideline values for animal drinking water

The GVs for animal drinking water are based on livestock drinking water and a limited number of reports in the international literature. These may not be protective of native species so the consequences and risks for this endpoint may be higher than stated. This should not pose a real risk as the management actions required to mitigate the risks associated with Mn being higher than GV for species protection will improve water quality.

Predicted water quality

Uncertainty analyses for the ground and surface water models have been reported elsewhere (INTERA, 2021; Water Solutions 2021). The models have been shown to have multiple layers of conservatism for concentrations, loads and flows.

Concentrations for 10%, 50% and 90% probability groundwater load input scenarios were assessed in this report. GVs were exceeded more frequently as the Px groundwater loads increase but the difference in concentrations between the P50 and P90 (the two highest loads) scenarios were not material to classifying consequences and risks as shown by Iles 2023.

Predicted Mn concentrations were conservative as Mn was treated as a non-reactive element. Parry (2023) reported studies of mine water mixed with Magela Creek/billabong waters where a large proportion (up to 50%) of Mn did not remain in the bioavailable fraction. The Supervising Scientist feedback was that other studies do not support this finding. This assessment assumed all Mn was bioavailable, so was conservative however it is noted that even a 50% reduction in Mn concentrations at End RPA would still constitute a Class IV risk under P50 load scenarios

Cumulative impacts

This study assesses the risks of multiple CoPC individually, as such cumulative impacts were not considered explicitly. However:

- cumulative impacts from a combination of CoPC above GV are not expected. Trenfield *et al.* (2021) studied the toxicity of Ranger mine waters with multiple CoPC present at above GV values. They found that antagonistic effects lowered the expected toxicity and concluded that "*existing individual GVs for contaminants would be adequately protective for ecosystems downstream of the mine in the event of exposure to a mixture of the contaminants of concern*", and
- only one CoPC (Mn) was predicted to be above the 99% SPL GV in the Magela creek sites assessed.
- Several studies have looked at the cumulative risks in the Ranger surface water pathway either explicitly or implicitly (i.e. looked at endpoints that would be effected directly or indirectly by exposure to multiple contaminants).
  - Harford *et al.* (2022) reported on the project Cumulative risk assessment for Ranger mine site rehabilitation and closure- Phase 2 (aquatic pathways)

- Bartolo *et al.* (2018) looked at cumulative impacts on ecological processes in different aquatic habitats and hydrological regimes.
- Field investigations at sites impacted by multiple CoPC (e.g. Chandler *et al.* 2021; SSB 2020; Batterham and Overall 2001, and several instances of biological monitoring that included sites with high Mn concentrations). These studies are being reviewed as part of the Mn VAF (BMT 2023).

Studies are planned to investigate multiple processes and stressors in Coonjimba Billabong and in the Magela Creek hyporheic zone (e.g. ASS, eutrophication).

Microbial and biogeochemical processes

Detrital pools, the role of microbial assemblages in organic matter decomposition, and biogeochemical cycles in general, were identified as a knowledge gaps in the APRA (Wong and Bolton 2023).

Microbially-mediated processes will be important in assessing some CoPCs, especially ammonia and sulfate. Direct effects upon microbes and decomposition processes can indirectly affect higher trophic levels. For example, Forrow and Moltby (2000) report that the rate limiting step in detritus decomposition was shredding by detritivore macroinvertebrates. Pre-processing (microbial conditioning) of detritus by microbes can make it more palatable to macroinvertebrates. Contaminant accumulation in detritus can also make it less palatable to detritovores.

Microbial and biogeochemical processes are now included in the conceptual model as a regulating (Intermediary) process. Wong and Bolton (2023) requested that the findings of this risk assessment discuss these issues.

The APRA is a screening tool used to assess modelled CoPC predictions in the surface water column against GVs for toxicity, and (sulfate) ASS risk. ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered.

Two of the site-specific GVs take biogeochemical and microbial impacts into consideration:

- Field impacts on billabong macroinvertebrates was used in developing the site-specific GV for Mg in water (Humphrey and Chandler, 2018). This line of evidence integrates impacts to a higher trophic level from biogeochemical and microbial processes.
- The site specific GV for U in sediments was based on field effects on sediment communities including bacteria and archaea (prokaryotes), and micro- and macro-invertebrates (eukaryotes) (Supervising Scientist, 2021f). McMaster *et al.* (2020) found that by meeting the site-specific water quality GV for U the sediment GV would also be met. This assessment found no exceedances of the U water GV therefore, the U sediment GV would also be met, protecting the benthic community.

Studies or assessments are being/have been conducted separately on Mn, ammonia and sulfate, CoPCs that are microbially mediated, and on potential impacts in the surface-ground water interface:

- Increased ammonia loads may cause eutrophication. Professor Perran Cook (Monash University) reviewed the eutrophication risk associated with Pit 3 closure and made recommendations on assessment approaches which will be reported elsewhere by ERA. His review considered microbially mediated transformation of nutrients.
- Biogeochemical reactions drive the speciation and therefore bioavailability of Mn. Parry (2023) summarises local studies that showed a reduction in dissolved Mn when mine impacted water was

mixed with Magela creek/billabong waters. This risk assessment is conservative as it considers all Mn is bioavailable. A separate project will assess the ecosystems vulnerability to elevated Mn concentrations in the waters at/near the RPA.

- Increased sulfate concentrations may increase the propensity for ASS to develop from shallow groundwater sources for the which the surface water GV may not necessarily apply. ERA is in the process of investigating this.
- Sediment studies being conducted separately will compare contamination levels to ANZG (2018) GVs based on protecting benthic communities. There is no such GV for Mn in sediments. Previous studies at Ranger mine have shown sediments overlain by waters with elevated Mn (even the sediments of wetlands used to treat contaminated water) contained Mn concentrations within the background range (Iles *et al.* 2010, Parry 2016, Esslemont and Iles 2017). Local concentration factors are available for Mn partitioning and could be used in a separate assessment to calculate the potential sediment concentrations of Mn for the predicted water column concentrations. The calculated median sediment concentrations could be compared to the median calculated by the same method for the No Mine scenario and the regional background concentrations.

Bartolo *et al.* (2018) identifies Magela Creek as a sandy channel water type with riparian zones fringing the creek. They define chemical processes as the '*interactions and associations between chemical substances and physical attributes of an ecosystem which affect the way that biota interact and function. Incorporates all biogeochemical processes*". Among the components listed under chemical process several were relevant to this issue i.e. nutrient and carbon cycling, nitrogen dynamics, energy and nutrient dynamics, microbial activity as purification service, physical, chemical and biological interactions. They report (in their Figure 4) that chemical processes are a low activity in sandy channels year-round but a high activity in the riparian zones, and in the lowland billabongs it was low in the wet and high in the dry season. The findings on relative activity concur with the observation by Wong and Bolton (2023) that processes associated with detrital pools were especially important for billabongs.

The sandy channel habitat and activity levels of chemical processes described by Bartolo *et al.* (2018) may not apply to residual pools in the creek channels or the hyporheic zone in Magela Creek which is anaerobic throughout the year (pers. comm. Chris Humphrey, SSB). Chandler *et al.* (2021) reported changes in microbial communities along a gradient of contamination in the Magela Creek hyporheic zone. Some of these changes occurred at concentrations within background variability and focused on ions causing salinity change. The risk to, and the importance of these processes, from other CoPC in the residual pools and hyporheic zone is a knowledge gap. SSB is conducting a study in the 2023 dry season on pools in Magela Creek which will help address this issue.

6 Conclusions

ERA provided predicted peak and 10,000-year surface water concentrations of 20 CoPC for P10, P50 and P90 groundwater loads at sites on the Magela Creek upstream and downstream of Pit 3.

The APRA tool was used to screen and classify risks in surface water pathway by comparing the predicted concentrations of 18 CoPC (Mg, Mg:Ca, Mn, NH_3-N, U, Al, Cd, Cu, Cr, Fe, Ni, Pb, Se, V, Zn, NO_3-N, SO_4 and ^{226}Ra) against GVs to protect (i) aquatic biota against chemical and radiological toxicity, (ii) sediments from forming ASS, (iii) cultural uses of water for drinking and recreation, and (iv) the health of wildlife drinking the creek waters.

No human drinking water or recreational water quality GVs were exceeded. Nor were the GVs for ASS formation and radiation protection of aquatic biota was also met for all scenarios.

The risk to cultural water use; based on drinking and recreational water quality, is Class I (the lowest risk). The same class risk applies to wildlife drinking water and ASS formation.

Apart from Mn and Al all GVs for protection of aquatic species were met. For all COPC other than Mn the risk was classified as Class I. The species protection GV for Al is exceeded naturally. A comparison of median concentrations for the No Mine scenario against median concentrations for the other scenarios showed no or very small contributions from the mine. Based on the incremental contribution from Ranger related sources, the risk from Al was classified as Class I.

The Cr, V and Ni DGVs for species protection have lower confidence than the other metals considered in this assessment. A comparison of medians for these CoPCs compared to the No Mine scenario median showed:

- No increases in V at the sites downstream of Pit 3 and increasing concentrations with increasing distance from MG009 to Mudginberri Billabong.
- Increased concentration of Cr of 12 – 23% at the two sites downstream of Pit 3 increasing at MG009 and again at End of RPA before reducing at Mudginberri Billabong but still remaining between 13 to 28% above background.
- Increased concentration of Ni of 42 – 59% at the two sites downstream of Pit 3 increasing at MG009 and again at End of RPA before reducing at Mudginberri Billabong but still remaining between 43 to 67% above background.

The trend of enriched Cr and Ni concentrations indicates a mining source and the consequences and risk to species protection might be higher than indicated by assessing these against DGVs. The need for site-specific or site adjusted GVs for these two CoPC needs to be considered. The risk from these two CoPCs will be mitigated by management actions being implemented to manage the high risks from Mn.

Manganese was the only COPC where risks were rated as being higher than Class I. Species protection consequences were assessed for all exceedance probability Mn concentrations predicted by the RSWM. The consequences for the P50 scenarios were used to classify the risks. The resulting risk classifications for species protection from Mn were:

- Class I risks OFF the RPA for the 10,000-year Pit 3 only scenario.
- Class II risks ON the RPA for the 10,000-year Pit 3 only scenario.

- Class III risk ON the RPA for the 10,000-year composite sources scenario.
- Class IV risks both ON and OFF the RPA for both the peak composite and peak Pit 3 only scenarios.
  - For the two sites closest to Pit 3 the risk would be Class III but at MG009 risk is Class III for the Pit 3 only scenario and Class IV for the composite source scenario.

The Mn VAF should be applied to the predicted Mn concentrations at the Magela Creek sites on the RPA.

This assessment assumed that (i) concentrations predicted by the RSWM were accurate, and (ii) that all Mn is present in the bioavailable form. These conservative assumptions may overstate the risks associated with Mn particularly under the assessed 10,000-year scenarios.

ARRTC and SSB recognised that while a risk might be classified as low or medium based on non/low frequency exceedance of GVs in the surface water, information on biogeochemical processes along the source-pathway-receptor conceptual pathway, including the surface-ground water interface, should also be considered.

Biogeochemical and microbial processes are now included in the conceptual model for risks via the surface water pathway. Assessing these is outside the scope of the APRA. As discussed, there are several studies that have addressed or will address these issues.

Whether the predicted concentrations of Mn in the water column will cause sediment Mn concentrations to increase beyond the natural variability is not assessed in this report. Local concentration factors and regional background datasets are available to assess this under a separate process.

7 References

ANZECC and ARMCANZ (2000). Australian and New Zealand guidelines for fresh and marine water quality. Volume 1, The guidelines. Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. Available at www.waterquality.gov.au/anzguideline

ANZG (2023). Toxicant default guideline values for aquatic ecosystem protection: Nitrate in fresh water. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. CC BY 4.0. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT, Australia. Available at waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/toxicants.

Bartolo RE, Harford AJ, Humphrey CL, George AK, van Dam RA (2018). Defining the importance of ecological processes for monitoring aquatic habitats for conservation and rehabilitation objectives at the Ranger uranium mine, Kakadu Region, Australia. *Marine and Freshwater Research* 69, 1026-1046. https://doi.org/10.1071/MF17256

BMT (2023). Ranger Mine Closure Manganese Vulnerability Assessment - Draft Implementation Report. August 2023.

Chandler L, Harford AJ, Hose GC, Humphrey CL, Chariton A, Greenfield P, Davis J (2021). Saline mine-water alters the structure and function of prokaryote communities in shallow groundwater below a tropical stream. Environmental Pollution, 284, 2021, 117318, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2021.117318.

Doering C, Carpenter J, Orr B, Urban D. (2019). Whole organism concentration ratios in freshwater wildlife from an Australian tropical U mining environment and the derivation of a water radiological quality guideline value. Journal of Environmental Radioactivity. 2019 Mar; 198:27-35. doi: 10.1016/j.jenvrad.2018.12.011. Epub 2018 Dec 19. PMID: 30579144.

ERA (2020). Ranger mine closure plan. Available at Mine Closure Plan - Energy Resources of Australia

ERA (2022). Pit 3 Capping, Waste Disposal and Bulk Material Movement Application Volume 2: Environmental Studies. CDM.03-1321-EY-APP-00003 rev 0. April 2022.

Esslemont G, Iles M. (2017). 2016 Billabong Sediment Sampling Program. Energy Resources of Australia Ltd. August 2017

Forrow DM, Maltby L. (2000). Toward a mechanistic understanding of contaminant-induced changes in detritus processing in streams: Direct and indirect effects on detritivore feeding. Environmental Toxicology and Chemistry, 19: 2100-2106. https://doi.org/10.1002/etc.5620190820

Harford AJ, Bartolo RE, Humphrey CL, Nicholson JD, Richardson DL, Rissik D, Iles M, Dambacher JM. (2022). Resolving ecosystem complexity in ecological risk assessment for mine site rehabilitation. *J Environ Manage*. 2022 Oct 1;319:115488. doi: 10.1016/j.jenvman.2022.115488. Epub 2022 Aug 3. PMID: 35982549.

Hinck J, Linder G, Finger S, Little E, Tillitt D, Kuhne W (2010). Biological Pathways of Exposure and Ecotoxicity Values for Uranium and Associated Radionuclides Hydrological, Geological, and Biological Site Characterization of Breccia Pipe Uranium Deposits in Northern Arizona. USGS professional paper. https://www.sciencedirect.com/science/article/pii/S0269749121009003

Humphrey CL, Chandler L (2018). Use of field-effects information to inform surface water guideline values for magnesium sulfate in Magela Creek. Supervising Scientist Report 212. (Supervising Scientist: Darwin, NT, Australia.). Available at: http:// www.environment.gov.au/science/supervising-scientist/publications/ssr

Iles M, Parry D, Klessa DA (2010). Characterisation of Ranger Wetland and Billabong Sediments: Volume 2: Project-based monitoring of on-site water bodies 2003 – 2006. Prepared by: EWL Sciences Pty Ltd. for: ERA Ltd.

Iles M, Rissik D (2021). Ranger Closure Aquatic Pathway Receptors Risk Assessment, Energy Resources Australia and BMT report, CDM.03–1114-MR-RAS-00001, version 0, Brisbane.

Iles M (2023). ERA Aquatic Pathways Risk Assessment tool. BMT Brisbane. R.B23879.001.00, 3 April 2023.

Iles M (2020). ALARA & BPT for Ranger mine closure: the process for identifying if impacts on the Ranger Project Area after closure are as low as reasonably achievable. Darwin: Energy Resources of Australia Ltd.

INTERA (2021). Final Report: Groundwater Uncertainty Analysis for Ranger Mine Closure, report for Energy Resources of Australia Ltd.

McMaster SA, Noller BN, Humphrey CL, Trenfield MA, Harford AJ (2020). Speciation and partitioning of uranium in waterbodies near Ranger Uranium Mine. Environmental Chemistry 18 (1) 12-19. https://doi.org/10.1071/en20096.

Ministry of Environment and Climate Change Strategy (MECC) (2019). British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife and Agriculture Summary Report. Water Protection and Sustainability Branch. August 2019. wqg_summary_aquaticlife_wildlife_agri.pdf (gov.bc.ca)

NHMRC (2008). Guidelines for Managing Risks in Recreational Water. National Health and Medical Research Council. February 2008, p 216. https://www.nhmrc.gov.au/guidelines-publications/eh38.

NHMRC, NRMMC (2011). Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Ministerial Council, Commonwealth of Australia, Canberra. p 1309. v3.8 updated September 2022.

Parry D (2016). Review of sediment quality data at Ranger Uranium Mine. Report to Energy Resources of Australia Ltd. Rio Tinto Project code: 590404001561 Report number: 1, Version: Final. June 2016.

Parry D (2023). Manganese speciation in Ranger Project Area surface waters. Prepared by David Parry, Principal Advisor Environment, Rio Tinto Alcan. Final, 14 June 2023.

Stauber J, Golding L, Peters A, Merrington G, Adams M, Binet M, Batley G, Gissi F, McKnight K, Garman E, Middleton E, Gadd J, Schlekat C (2021), Application of Bioavailability Models to Derive Chronic Guideline Values for Nickel in Freshwaters of Australia and New Zealand. Environmental Toxicology and Chemistry, 40: 100-112. https://doi.org/10.1002/etc.4885

Supervising Scientist (2018). Metals in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1) (Withdrawn). Supervising Scientist Branch, Darwin, NT

Supervising Scientist (2020). Impacts associated with a sustained acidification event in Coonjimba Billabong, December 2015 to February 2016: Data summary.

Supervising Scientist (2021a). Uranium and Manganese in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 2). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ss-rehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021b). Magnesium in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 2). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021c). Ammonia in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1.1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021d). Copper and zinc in surface water — Rehabilitation Standard for the Ranger uranium mine (version 1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications /ss-rehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021e). Sulfate in Surface Water — Rehabilitation Standard for the Ranger uranium mine (version 1.1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021f). Uranium in Sediments — Rehabilitation Standard for the Ranger uranium mine (version 1). Supervising Scientist Branch, Darwin, NT. http://www.environment.gov.au/science/supervising-scientist/publications/ssrehabilitation-standards. Cited 9/6/2021.

Supervising Scientist (2021g). Supervising Scientist Review Comments - Ranger closure aquatic pathway receptors risk assessment. 15 November 2021.

Trenfield MA, Pease CJ, Walker SL, Humphrey C, van Dam R, Markich S, Harford AJ (2021). Assessing the toxicity of mine-water mixtures and the effectiveness of water quality guideline values in protecting local aquatic species. Environmental Toxicology and Chemistry, 40, 2334-2346. doi:DOI: 10.1002/etc.5103

Warne MS, Batley GE, Van Dam RA, Chapman J, Fox D, Hickey C & Stauber J 2018. *Revised method for deriving Australian and New Zealand water quality guideline values for toxicants*. Prepared for the Council of Australian Government's Standing Council on Environment and Water (SCEW). Department of Science, Information Technology and Innovation, Brisbane, Queensland.

Water Solutions (2021). ERA Ranger Mine Closure RSWM - Verification and Updated Calibration. WS210136. Revision 0. October 2021.

Wong V, Boulton A (2023). Close-out notes, ARRTC Meeting 52, June 2023. (Provided by email from Michael Ryan, Umwelt, 26/2/23).

Annex A Summary tables for predicted concentrations at 10,000 years

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at MG003																									
Exccedance probability	1%	1320	640	200	68	0.1	29	15	0.3	0.0	0.01	120	0.5	0.11	0.77	0.20	0.00	106	0.1	1660	2				
	10%	1260	630	3.0	57	0.1	25	2.6	0.3	0.0	0.01	110	0.4	0.11	0.66	0.19	-0.01	92	0.1	1190	2				
	25%	1240	620	3.0	55	0.1	24	2.6	0.3	0.0	0.01	100	0.4	0.11	0.48	0.19	-0.01	69	0.1	917	2				
	50%	800	540	3.0	26	0.0	12	2.5	0.2	0.0	0.01	80	0.4	0.10	0.20	0.15	-0.04	33	0.1	728	2	4	-16	14	-14
	75%	540	310	3.0	8	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.08	0.13	-0.11	6.7	0.1	249	1				
	90%	300	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.18	6.0	0.1	70.2	1				
	99%	220	160	3.0	5	0.006	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.21	6.0	0.1	62	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at MG003																									
Exccedance probability	1%	1030	580	200	56	0.1	23	15	0.3	0.0	0.01	120	0.4	0.11	0.77	0.19	0.00	106	0.1	1530	2				
	10%	1020	570	3.0	48	0.1	21	2.5	0.3	0.0	0.01	110	0.4	0.11	0.66	0.18	-0.01	92	0.1	1070	2				
	25%	1010	570	3.0	46	0.1	20	2.5	0.3	0.0	0.01	100	0.4	0.11	0.48	0.18	-0.01	69	0.1	792	2				
	50%	780	530	3.0	22	0.0	11	2.5	0.2	0.0	0.01	80	0.4	0.10	0.20	0.15	-0.04	33	0.1	646	2	3	-17	13	-14
	75%	460	290	3.0	7	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-0.11	6.7	0.1	226	1				
	90%	280	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.18	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.21	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG003																									
Exccedance probability	1%	1480	650	200	106	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2340	2				
	10%	1400	640	3.0	90	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	0.0	92	0.1	1810	2				
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.25	0.0	69	0.1	1570	2				
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	912	2	7	-13	25	-13
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	7	0.1	313	1				
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	69.5	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	61.6	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG003																									
Excedance probability	1%	1110	580	200	86	0.2	35	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2210	2				
	10%	1080	580	3.0	76	0.1	31	2.5	0.3	0.1	0.01	110	0.5	0.12	0.67	0.23	0.0	92	0.1	1660	2				
	25%	1070	570	3.0	72	0.1	30	2.5	0.3	0.1	0.01	100	0.5	0.12	0.49	0.23	0.0	69	0.1	1430	2				
	50%	780	530	3.0	31	0.1	14	2.5	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	870	2	5	-15	22	-13
	75%	480	290	3.0	9	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	-0.1	7	0.1	295	1				
	90%	290	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG003																									
Excedance probability	1%	1750	670	200	155	0.3	60	15.1	0.3	0.1	0.01	120	0.6	0.14	0.77	0.36	0.1	106	0.1	3270	3				
	10%	1640	650	3.1	133	0.3	52	3.5	0.3	0.1	0.01	120	0.6	0.13	0.67	0.33	0.0	93.7	0.1	2650	3				
	25%	1610	640	3.0	130	0.3	51	3.5	0.3	0.1	0.01	100	0.6	0.13	0.49	0.33	0.0	71	0.1	2440	3				
	50%	810	540	3.0	52	0.1	22	3.0	0.2	0.0	0.01	80	0.5	0.11	0.22	0.20	0.0	35	0.1	1210	2	10	-10	36	-8
	75%	650	310	3.0	11	0.0	7	2.6	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	381	1				
	90%	330	200	3.0	6	0.0	6	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	78.7	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	67	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG003																									
Excedance probability	1%	1310	590	200	137	0.3	52	15	0.3	0.1	0.01	120	0.6	0.13	0.77	0.35	0.0	106	0.1	3050	2				
	10%	1270	580	3.0	122	0.3	46	2.6	0.3	0.1	0.01	110	0.5	0.13	0.67	0.32	0.0	94	0.1	2440	2				
	25%	1250	580	3.0	116	0.3	45	2.6	0.3	0.1	0.01	100	0.5	0.13	0.49	0.32	0.0	71	0.1	2230	2				
	50%	790	530	3.0	46	0.1	20	2.5	0.2	0.0	0.01	80	0.5	0.11	0.21	0.20	0.0	35	0.1	1110	2	9	-11	34	-8
	75%	540	290	3.0	10	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	360	1				
	90%	300	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG003																						**Legend**			
Excedance probability	1%	810	560	194	14	0.0	6	15	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	2.7	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	2.5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	2.5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	PO_4-P	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	NA; loads assessed in eutroph-ication assess-ment	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)											300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG005																									
Exceedance probability	1%	1470	650	200	105	0.2	40	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.27	0.0	106	0.1	2320	2				
	10%	1400	640	3.0	89	0.1	35	2.7	0.3	0.1	0.01	110	0.5	0.12	0.67	0.25	0.0	93	0.1	1800	2				
	25%	1380	630	3.0	86	0.1	34	2.7	0.3	0.1	0.01	100	0.5	0.12	0.49	0.24	0.0	69	0.1	1560	2				
	50%	800	540	3.0	37	0.1	16	2.6	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	908	2	7	-13	25	-13
	75%	580	310	3.0	10	0.0	6	2.5	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	-0.1	7	0.1	312	1				
	90%	310	200	3.0	6	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	69.5	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	61.6	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG005																									
Exceedance probability	1%	1100	580	200	86	0.2	34	15	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2200	2				
	10%	1080	580	3.0	76	0.1	31	2.5	0.3	0.1	0.01	110	0.5	0.12	0.67	0.23	0.0	93	0.1	1660	2				
	25%	1070	570	3.0	72	0.1	30	2.5	0.3	0.1	0.01	100	0.5	0.12	0.49	0.23	0.0	69	0.1	1420	2				
	50%	780	530	3.0	31	0.1	14	2.5	0.2	0.0	0.01	80	0.4	0.11	0.21	0.17	0.0	33	0.1	868	2	5	-15	22	-13
	75%	480	290	3.0	9	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	-0.1	7	0.1	294	1				
	90%	290	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG005																									
Exceedance probability	1%	1740	660	200	154	0.3	60	15.1	0.3	0.1	0.01	120	0.6	0.14	0.77	0.36	0.1	106	0.1	3250	3				
	10%	1640	650	3.1	132	0.3	52	3.5	0.3	0.1	0.01	120	0.6	0.13	0.67	0.33	0.0	93.7	0.1	2640	3				
	25%	1610	640	3.0	129	0.3	50	3.5	0.3	0.1	0.01	100	0.6	0.13	0.49	0.33	0.0	71	0.1	2430	3				
	50%	810	540	3.0	52	0.1	22	3.0	0.2	0.0	0.01	80	0.5	0.11	0.22	0.20	0.0	35	0.1	1200	2	10	-10	36	-8
	75%	650	310	3.0	11	0.0	7	2.6	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	379	1				
	90%	330	200	3.0	6	0.0	6	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	78.7	1				
	99%	220	160	3.0	6	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	-0.2	6.0	0.1	67	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG005																									
Exceedance probability	1%	1300	590	200	136	0.3	52	15	0.3	0.1	0.01	120	0.6	0.13	0.77	0.35	0.0	106	0.1	3040	2				
	10%	1260	580	3.0	121	0.3	46	2.6	0.3	0.1	0.01	110	0.5	0.13	0.67	0.32	0.0	94	0.1	2430	2				
	25%	1250	580	3.0	115	0.3	44	2.6	0.3	0.1	0.01	100	0.5	0.13	0.49	0.32	0.0	71	0.1	2210	2				
	50%	790	530	3.0	46	0.1	19	2.5	0.2	0.0	0.01	80	0.5	0.11	0.21	0.20	0.0	35	0.1	1100	2	9	-11	34	-8
	75%	530	290	3.0	10	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.10	0.13	0.0	10	0.1	359	1				
	90%	300	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	2.5	0.1	0.0	0.01	30	0.4	0.10	0.07	0.13	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG005																						**Legend**			
Exceedance probability	1%	810	560	194	14	0.0	6	15	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	2.7	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	2.5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	2.5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	2.5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	2.5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	2.5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at MG009																								
Exccedance probability	1%	1400	690	200	66	0.1	28	0.3	0.0	0.01	120	0.46	0.11	0.77	0.2	0.0	106	0.1	1630	2				
	10%	1330	670	3.2	56	0.1	25	0.3	0.0	0.01	110	0.45	0.11	0.67	0.2	0.0	93	0.1	1190	2				
	25%	1290	650	3.0	54	0.1	24	0.3	0.0	0.01	100	0.45	0.11	0.50	0.2	0.0	71	0.1	900	2				
	50%	810	550	3.0	30	0.1	14	0.2	0.0	0.01	80	0.42	0.10	0.23	0.2	0.0	37	0.1	766	2	4	-1	17	-1
	75%	510	290	3.0	11	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.08	0.1	-0.1	6.8	0.1	362	1				
	90%	300	200	3.0	6	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	69.1	1				
	99%	220	160	3.0	5	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0997	61.9	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at MG009																								
Exccedance probability	1%	1020	580	200	55	0.1	22	0.306	0.0	0.01	120	0.44	0.11	0.77	0.2	0.0	106	0.1	1510	2				
	10%	1010	570	3.2	47	0.1	20	0.3	0.0	0.01	110	0.44	0.11	0.67	0.2	0.0	93	0.1	1080	2				
	25%	1000	570	3.0	45	0.1	20	0.3	0.0	0.01	100	0.44	0.11	0.50	0.2	0.0	71	0.1	783	2				
	50%	790	540	3.0	24	0.1	12	0.2	0.0	0.01	80	0.42	0.10	0.23	0.2	0.0	37	0.1	673	2	3	-1	15	-1
	75%	420	260	3.0	10	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.08	0.1	-0.1	6.8	0.1	316	1				
	90%	280	190	3.0	5	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	50	1				
	99%	220	160	3.0	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0996	49.9	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at MG009																								
Exccedance probability	1%	1610	710	200	103	0.2	39	0.3	0.1	0.01	120	0.50	0.12	0.77	0.3	0.0	106	0.1	2290	2				
	10%	1520	680	3.3	88	0.1	34	0.3	0.1	0.01	110	0.49	0.12	0.67	0.2	0.0	93	0.1	1800	2				
	25%	1450	660	3.0	85	0.1	34	0.3	0.1	0.01	100	0.49	0.12	0.50	0.2	0.0	71	0.1	1540	2				
	50%	840	550	3.0	44	0.1	18	0.2	0.0	0.01	80	0.44	0.11	0.24	0.2	0.0	37	0.1	990	2	8	1	29	-1
	75%	560	290	3.0	12	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.09	0.1	0.0	7	0.1	455	2				
	90%	320	200	3.0	6	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.0999	68.5	1				
	99%	220	160	3.0	6	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.0997	61.5	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at MG009																								
Exccedance probability	1%	1090	580	200	84	0.2	34	0.3	0.1	0.01	120	0.49	0.12	0.77	0.2	0.0	106	0.1	2170	2				
	10%	1080	580	3.24	75	0.1	30	0.3	0.1	0.01	110	0.48	0.12	0.67	0.2	0.0	93	0.1	1670	2				
	25%	1070	570	3.01	71	0.1	29	0.3	0.1	0.01	100	0.47	0.11	0.50	0.2	0.0	71	0.1	1400	2				
	50%	790	540	3.01	36	0.1	16	0.2	0.0	0.01	80	0.43	0.11	0.24	0.2	0.0	37	0.1	920	2	6	0	25	-1
	75%	440	270	3	11	0.0	6	0.2	0.0	0.01	60	0.40	0.10	0.09	0.1	0.0	7	0.1	431	1				
	90%	280	190	3	5	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.2	6.0	0.1	50	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at MG009																								
Exccedance probability	1%	1910	720	200	151	0.3	59	0.3	0.1	0.01	120	0.58	0.14	0.77	0.4	0.1	106	0.1	3180	3				
	10%	1780	700	3.25	130	0.3	51	0.3	0.1	0.01	120	0.55	0.13	0.68	0.3	0.0	94	0.1	2620	3				
	25%	1700	680	3.04	127	0.3	50	0.3	0.1	0.01	100	0.55	0.13	0.51	0.3	0.0	72	0.1	2390	3				
	50%	960	550	3.03	63	0.1	26	0.2	0.1	0.01	80	0.47	0.11	0.24	0.2	0.0	39	0.1	1360	2	12	3	40	3
	75%	620	300	3	14	0.0	7	0.2	0.0	0.01	70	0.41	0.10	0.10	0.1	0.0	10	0.1	547	2				
	90%	340	210	3	6	0.0	6	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	77.2	1				
	99%	220	160	3	6	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	-0.1	6.0	0.1	66.9	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at MG009																								
Exccedance probability	1%	1280	580	200	134	0.3	51	0.3	0.1	0.01	120	0.56	0.13	0.77	0.3	0.0	106	0.1	3000	2				
	10%	1250	580	3.25	119	0.3	45	0.3	0.1	0.01	110	0.54	0.13	0.68	0.3	0.0	94	0.1	2430	2				
	25%	1240	580	3.03	113	0.3	44	0.3	0.1	0.01	100	0.53	0.13	0.51	0.3	0.0	72	0.1	2180	2				
	50%	790	540	3.02	55	0.1	23	0.2	0.1	0.01	80	0.46	0.11	0.24	0.2	0.0	39	0.1	1250	2	11	2	39	3
	75%	480	270	3	13	0.0	7	0.2	0.0	0.01	60	0.41	0.10	0.10	0.1	0.0	10	0.1	520	1				
	90%	290	190	3	5	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	0.0	6.0	0.1	50	1				
	99%	220	160	3	4	0.0	5	0.1	0.0	0.01	30	0.40	0.10	0.07	0.1	0.0	6.0	0.1	50	1				
Predicted 10,000 year concentrations for NO MINE scenario at MG009																								
Exccedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.40	0.10	0.77	0.1	-	105	0.1	893	1				
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.40	0.10	0.68	0.1	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.40	0.10	0.49	0.1	-	70	0.1	458	1				
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.40	0.10	0.24	0.1	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.40	0.10	0.07	0.1	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.40	0.10	0.07	0.1	-	6.2	0.1	50	1				
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.40	0.10	0.07	0.1	-	6.0	0.1	50	1				

Legend
Above GV
No mine scenario above GV
Below GV

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P10 scenario at End of RPA																								
Exccedance probability	1%	1350	670	197	58	0.1	25	0.3	0.0	0.01	120	0.4	0.11	0.77	0.19	0.0	106	0.1	1470	2				
	10%	1320	660	8.2	54	0.1	24	0.3	0.0	0.01	110	0.4	0.11	0.69	0.19	0.0	96	0.1	1090	2				
	25%	1270	650	3.0	51	0.1	23	0.3	0.0	0.01	100	0.4	0.11	0.50	0.18	0.0	71	0.1	889	2				
	50%	970	500	3.0	40	0.1	18	0.2	0.0	0.01	80	0.4	0.11	0.24	0.17	0.0	38	0.1	809	2	7	2	23	1
	75%	460	270	3.0	20	0.0	9	0.2	0.0	0.01	70	0.4	0.10	0.08	0.14	0.0	12	0.1	593	2				
	90%	310	200	3.0	11	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.08	0.13	0.0	7	0.1	341	2				
	99%	240	170	3.0	6	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	7	0.1	99.8	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P10 scenario at End of RPA																								
Exccedance probability	1%	1010	570	197	48	0.1	20	0.3	0.0	0.01	120	0.4	0.11	0.77	0.18	0.0	106	0.1	1360	3				
	10%	1000	570	8.2	44	0.1	20	0.3	0.0	0.01	110	0.4	0.11	0.69	0.18	0.0	96	0.1	1010	3				
	25%	990	570	3.0	42	0.1	19	0.3	0.0	0.01	100	0.4	0.11	0.50	0.18	0.0	71	0.1	761	3				
	50%	760	440	3.0	33	0.1	15	0.2	0.0	0.01	80	0.4	0.11	0.24	0.16	0.0	38	0.1	685	3	5	2	21	1
	75%	390	250	3.0	18	0.0	8	0.2	0.0	0.01	60	0.4	0.10	0.08	0.14	0.0	12	0.1	515	2				
	90%	280	200	3.0	10	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7	0.1	302	2				
	99%	230	160	3.0	5	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	0.0	7	0.1	89.7	1				
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at End of RPA																								
Exccedance probability	1%	1540	690	197	90	0.1	35	0.3	0.1	0.01	120	0.5	0.12	0.77	0.25	0.0	106	0.1	2030	2				
	10%	1500	680	8.2	85	0.1	34	0.3	0.1	0.01	120	0.5	0.12	0.69	0.24	0.0	96	0.1	1540	2				
	25%	1430	660	3.0	80	0.1	32	0.3	0.1	0.01	100	0.5	0.12	0.50	0.24	0.0	71	0.1	1490	2				
	50%	1090	510	3.0	61	0.1	24.5	0.2	0.0	0.01	80	0.5	0.11	0.24	0.21	0.0	**38**	0.1	1270	2	11	3	37	2
	75%	500	280	3.0	26	0.1	12	0.2	0.0	0.01	70	0.4	0.10	0.09	0.16	0.0	12	0.1	820	2				
	90%	320	200	3.0	14	0.0	7	0.2	0.0	0.01	60	0.4	0.10	0.09	0.14	0.0	8	0.0999	434	2				
	99%	240	170	3.0	6	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7	0.0999	126	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at End of RPA																								
Excceedance probability	1%	1070	580	197	73	0.1	30	0.3	0.1	0.01	120	0.5	0.12	0.77	0.23	0.0	106	0.1	1910	2				
	10%	1070	580	8.2	70	0.1	29	0.3	0.1	0.01	110	0.5	0.11	0.69	0.23	0.0	96	0.1	1410	2				
	25%	1040	570	3.0	66	0.1	28	0.3	0.1	0.01	100	0.5	0.11	0.50	0.22	0.0	71	0.1	1340	2				
	50%	800	450	3.0	51	0.1	21	0.2	0.0	0.01	80	0.4	0.11	0.24	0.20	0.0	38	0.1	1170	2	9	3	33	2
	75%	410	250	3.0	23	0.1	11	0.2	0.0	0.01	60	0.4	0.10	0.09	0.15	0.0	12	0.1	759	2				
	90%	290	200	3.0	12	0.0	6.8	0.2	0.0	0.01	50	0.4	0.10	0.08	0.14	0.0	8	0.1	408	1				
	99%	230	170	3.0	6	0.0	5.3	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.0	7	0.1	118	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at End of RPA																								
Excceedance probability	1%	1810	710	197	130	0.3	51.2	0.3	0.1	0.01	120	0.6	0.13	0.77	0.33	0.0	106	0.1	2810	3				
	10%	1760	690	8.2	126	0.3	49.7	0.3	0.1	0.01	120	0.5	0.13	0.70	0.32	0.0	96.8	0.1	2360	3				
	25%	1670	680	3.0	118	0.3	46.6	0.3	0.1	0.01	100	0.5	0.13	0.51	0.31	0.0	72	0.1	2260	3				
	50%	1260	520	3.0	89	0.2	36	0.2	0.1	0.01	80	0.5	0.12	0.25	0.26	0.0	39.2	0.1	1840	2	17	6	50	4
	75%	560	280	3.0	36	0.1	15	0.2	0.0	0.01	70	0.4	0.11	0.10	0.17	0.1	15	0.1	1020	2				
	90%	340	200	3.0	16	0.0	8	0.2	0.0	0.01	60	0.4	0.10	0.10	0.14	0.1	10	0.1	539	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.1	10	0.1	160	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at End of RPA																								
Excceedance probability	1%	1250	580	197	115	0.3	44	0.3	0.1	0.01	120	0.5	0.13	0.77	0.32	0.0	106	0.1	2610	2				
	10%	1240	580	8.2	112	0.3	43	0.3	0.1	0.01	110	0.5	0.13	0.70	0.31	0.0	97	0.1	2160	2				
	25%	1200	580	3.0	105	0.3	41	0.3	0.1	0.01	100	0.5	0.12	0.50	0.30	0.0	72	0.1	2060	2				
	50%	920	450	3.0	79	0.2	31	0.2	0.1	0.01	80	0.5	0.12	0.25	0.25	0.0	39	0.1	1690	2	15	5	48	4
	75%	440	260	3.0	33	0.1	14	0.2	0.0	0.01	60	0.4	0.11	0.10	0.17	0.1	15	0.1	964	2				
	90%	300	200	3.0	15	0.0	8	0.2	0.0	0.01	50	0.4	0.10	0.10	0.14	0.1	10	0.1	507	2				
	99%	240	170	3.0	7	0.0	6	0.2	0.0	0.01	40	0.4	0.10	0.08	0.13	0.1	10	0.1	149	1				
Predicted 10,000 year concentrations for NO MINE scenario at End of RPA																					Legend			
Excceedance probability	1%	810	560	194	14	0.0	6	0.3	0.0	0.01	120	0.4	0.10	0.77	0.13	-	105	0.1	893	1	Above GV			
	10%	810	560	6.8	12	0.0	5	0.3	0.0	0.01	110	0.4	0.10	0.68	0.13	-	95	0.1	763	1				
	25%	800	560	3.0	7	0.0	5	0.3	0.0	0.01	100	0.4	0.10	0.49	0.13	-	70	0.1	458	1	No mine scenario above GV			
	50%	630	440	3.0	5	0.0	5	0.2	0.0	0.01	80	0.4	0.10	0.24	0.13	-	38	0.1	69	1				
	75%	370	270	3.0	5	0.0	5	0.2	0.0	0.01	60	0.4	0.10	0.07	0.13	-	11	0.1	50	1				
	90%	270	200	3.0	5	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.07	0.13	-	6	0.1	50	1	Below GV			
	99%	220	160	3.0	4	0.0	5	0.2	0.0	0.01	40	0.4	0.10	0.07	0.13	-	6	0.1	50	1				

	COPC	Mg	Ca	NO_3-N	Mn	U	NH_3-N	Cu	Pb	Cd	Fe	Zn	Cr	V	Ni	^{226}Ra > bgd	Al	Se	SO_4	Mg:Ca	Increase above No Mine scanrio (%)			
Most stringent GV for each COPC	Species protection 99% or undefined %* (µg/L)	2900	NA. See Mg:Ca column	640	73	2.8	400	0.5	1	0.06	NA	1.5	3.3* (Cr^{3+})	6*	8	NA	0.8* pH<6.5 Back-ground > GV so compare medians	5	NA	9	Cr	V	Ni	Al
	Other (^{226}Ra mBq/L; others µg/L)										300 Drinking water (aesthetic)					14 mBq/L > bgd (aquatic biota)			10000 seasonal av. (acid sulfate soils)		No GV			
Predicted 10,000 year concentrations for COMPOSITE_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1360	740	150	48	0.1	22	0.3	0.0	0.01	130	0.6	0.14	0.78	0.23	0.0	108	0.1	1090	2				
	10%	1270	690	4.4	45	0.1	21	0.3	0.0	0.01	110	0.5	0.13	0.55	0.21	0.0	79	0.1	816	2				
	25%	1230	670	3.5	43	0.1	20	0.3	0.0	0.01	90	0.5	0.12	0.34	0.20	0.0	51.7	0.1	738	2				
	50%	1100	600	3.4	39	0.1	18	0.2	0.0	0.01	80	0.5	0.12	0.16	0.20	0.0	28	0.1	686	2	7	4	26	2
	75%	610	350	3.3	24	0.1	11	0.2	0.0	0.01	70	0.4	0.11	0.11	0.16	0.0	16	0.1	568	2				
	90%	360	230	3.0	14	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	10	0.1	400	2				
	99%	250	180	2.9	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7.5	0.1	140	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P50 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1090	670	150	39	0.1	19	0.3	0.0	0.01	120	0.5	0.13	0.78	0.22	0.0	108	0.1	1070	2				
	10%	1020	630	4.4	37	0.1	18	0.3	0.0	0.01	110	0.5	0.13	0.55	0.20	0.0	79	0.1	769	2				
	25%	990	610	3.5	35	0.1	17	0.3	0.0	0.01	90	0.5	0.12	0.34	0.20	0.0	52	0.1	666	2				
	50%	880	540	3.4	32	0.1	16	0.2	0.0	0.01	80	0.5	0.12	0.16	0.19	0.0	28	0.1	616	2	6	4	23	2
	75%	500	320	3.2	21	0.1	10	0.2	0.0	0.01	70	0.4	0.11	0.10	0.15	0.0	16	0.1	521	2				
	90%	320	220	3.0	13	0.0	7	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	10	0.1	369	1				
	99%	240	170	2.9	6	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	0.0	7.5	0.1	130	1				
Predicted 10,000 year concentrations for COMPOSITE_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1510	750	150	69	0.2	31.3	0.3	0.1	0.01	130	0.6	0.14	0.78	0.27	0.0	108	0.1	1300	2				
	10%	1410	700	4.4	65	0.2	29	0.3	0.1	0.01	110	0.5	0.13	0.55	0.25	0.0	79	0.1	1160	2				
	25%	1370	680	3.5	62	0.1	28	0.3	0.1	0.01	100	0.5	0.13	0.34	0.24	0.0	52	0.1	1100	2				
	50%	1220	600	3.4	56	0.1	25	0.3	0.1	0.01	80	0.5	0.13	0.17	0.23	0.0	29	0.1	1010	2	10	8	37	6
	75%	670	350	3.3	33	0.1	15	0.2	0.0	0.01	80	0.4	0.11	0.11	0.17	0.0	17.2	0.1	781	2				
	90%	380	230	3.0	18	0.1	9	0.2	0.0	0.01	70	0.4	0.10	0.10	0.15	0.0	12	0.1	523	2				
	99%	260	180	2.9	8	0.0	6	0.2	0.0	0.01	60	0.4	0.10	0.09	0.13	0.1	8.76	0.1	181	1				
Predicted 10,000 year concentrations for PIT 3 ONLY_P90 scenario at Mudginberri Billabong																								
Exccedance probability	1%	1180	670	150	61	0.2	27	0.3	0.1	0.01	120	0.6	0.14	0.78	0.26	0.0	108	0.1	1220	2				
	10%	1100	630	4.4	57	0.2	25	0.3	0.1	0.01	110	0.5	0.13	0.55	0.24	0.0	79	0.1	1050	2				
	25%	1070	610	3.5	55	0.1	24	0.3	0.1	0.01	90	0.5	0.13	0.34	0.24	0.0	52	0.1	994	2				
	50%	950	540	3.4	49	0.1	22	0.3	0.1	0.01	80	0.5	0.12	0.17	0.22	0.0	29	0.1	918	2	10	7	35	6
	75%	540	320	3.3	30	0.1	13	0.2	0.0	0.01	70	0.4	0.11	0.11	0.17	0.0	17	0.1	721	2				
	90%	330	220	3.0	16	0.1	8	0.2	0.0	0.01	70	0.4	0.10	0.09	0.14	0.0	12	0.1	487	2				
	99%	250	170	2.9	7	0.0	6	0.2	0.0	0.01	50	0.4	0.10	0.09	0.13	0.1	9	0.1	167	1				
Predicted 10,000 year concentrations for NO MINE scenario at Mudginberri Billabong																					**Legend**			
Exccedance probability	1%	940	660	149	15	0.0	6	0.3	0.0	0.01	120	0.5	0.13	0.78	0.16	-	107	0.1	892	1	Above GV			
	10%	880	620	4.3	8	0.0	6	0.3	0.0	0.01	110	0.5	0.12	0.55	0.15	-	78	0.1	536	1				
	25%	860	600	3.5	5	0.0	6	0.3	0.0	0.01	90	0.5	0.11	0.33	0.15	-	51	0.1	164	1	No mine scenario above GV			
	50%	760	530	3.4	5	0.0	6	0.2	0.0	0.01	80	0.4	0.11	0.16	0.15	-	27	0.1	56	1				
	75%	450	320	3.2	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.10	0.13	-	15	0.1	52	1				
	90%	300	220	3.0	5	0.0	5	0.2	0.0	0.01	70	0.4	0.10	0.08	0.13	-	10	0.1	50	1	Below GV			
	99%	240	170	2.9	4	0.0	5	0.2	0.0	0.01	50	0.4	0.10	0.08	0.13	-	6.9	0.1	45	1				

Annex B Populated risk spreadsheet

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	02		**Land use (cultural use of water for drinking & recreation)**																			
T	J	02	01	Water not suitable for drinking due to mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**	Restricted land use, decline in human health. Community trust and reputation. Closure criteria not met.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and times when water naturally not suitable for drinking/recreation not considered; need information on that if GVs not met.	Drinking and recreation GVs vs predicted CoPCNo GV s exceeded	P	VL						I						I
T	J	02	02		Contaminated by **Pit 3 (PEAK, P50)**					P	VL						I						I
T	J	02	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P	VL						I						I
T	J	02	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P	VL						I						I
T	J	02	05	Water not suitable for recreation due mine contaminants **OFF** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P	VL						I						I
T	J	02	06		Contaminated by **Pit 3 (PEAK, P50)**					P	VL						I						I
T	J	02	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P	VL						I						I
T	J	02	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P	VL						I						I
T	J	02	09	Water not suitable for drinking due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P		VL						I					I
T	J	02	10		Contaminated by **Pit 3 (PEAK, P50)**					P		VL						I					I
T	J	02	11		Contaminated by **Composite sources (10,000 Yr, P50)**					P		VL						I					I
T	J	02	12		Contaminated by **Pit 3 (10,000 Yr, P50)**					P		VL						I					I
T	J	02	13	Water not suitable for recreation due to mine contaminants **ON** the RPA.	Contaminated by **Composite sources (PEAK, P50)**					P		VL						I					I
T	J	02	14		Contaminated by **Pit 3 (PEAK, P50)**					P		VL						I					I
T	J	02	15		Contaminated by **Composite sources (10,000 Yr, P50)**					P		VL						I					I
T	J	02	16		Contaminated by **Pit 3 (10,000 Yr, P50)**					P		VL						I					I

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	06		Flora & fauna (animal drinking water)																			
T	J	06	01	Water not suitable for animal drinking water due to mine contaminants OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	Wildlife health impacted with potential flow on impacts to biodiversity, cultural practices, spiritual beliefs, community trust and reputation.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and all CoPC assumed to be in a bioavailable form.	Wildlife GVs vs predicted CoPC. No GV s exceeded	P					VL						I		I
T	J	06	02		Contaminated by **Pit 3 (PEAK, P50)**					P					VL						I		I
T	J	06	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P					VL						I		I
T	J	06	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P					VL						I		I
T	J	06	05	Water not suitable for animal drinking water due to mine contaminants ON the RPA	Contaminated by **Composite sources (PEAK, P50)**					P						VL						I	I
T	J	06	06		Contaminated by **Pit 3 (PEAK, P50)**					P						VL						I	I
T	J	06	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P						VL						I	I
T	J	06	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P						VL						I	I

Ref.				Risk Description						Evaluation							Rating						
Risk Type (T=Threat)	Category	Subcategory	Item	Evaluated 40 of 40 risks (0 Remaining) Threat Title	Causes (Contaminant sources as modelled by P50 load scenario RSWM WS210136_Rev9)	Impacts	Existing Controls	Additional Information	Evaluation Rationale	Likelihood - Probability	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Culture (drinking, recreation) OFF the RPA	Culture (drinking, recreation) ON the RPA	Biodiversity OFF the RPA	Biodiversity ON the RPA	Animal drinking OFF the RPA	Animal drinking ON the RPA	Risk Management Class
T	J	07		**Biodiversity & ecosystems (aquatic species protection)**																			
T	J	07	01	Elevated Mn in water (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**	Aquatic toxicity with potential flow on impacts to biodiversity, cultural practices, spiritual beliefs, community trust and reputation.	Water,tailings, brine management. Tailings flux treatment. BPT strategies. Peer reviewed studies. Reduced Pit PTF volume remaining.	Model predictions conservative, no COPC attenuation and all CoPC assumed to be in a bioavailable form.	Based on highest species protection consequences for predicted Mn at End of RPA or Mudginberri Billabong vs. the site-specific Mn GVs	P			VH						IV				IV
T	J	07	02		Contaminated by **Pit 3 (PEAK, P50)**					P			VH						IV				IV
T	J	07	03		Contaminated by **Composite sources (10,000 Yr, P50)**					P			H						IV				IV
T	J	07	04		Contaminated by **Pit 3 (10,000 Yr, P50)**					P			VL						I				I
T	J	07	05	Poor water quality for CoPC except Mn (mine related) causes biodiversity change OFF the RPA	Contaminated by **Composite sources (PEAK, P50)**				SPL GV met except for Al. Al above background (no mine scenario) increased with distance from mine sources so assumed not mine related	P			VL						I				I
T	J	07	06		Contaminated by **Pit 3 (PEAK, P50)**					P			VL						I				I
T	J	07	07		Contaminated by **Composite sources (10,000 Yr, P50)**					P			VL						I				I
T	J	07	08		Contaminated by **Pit 3 (10,000 Yr, P50)**					P			VL						I				I
T	J	07	09	Elevated Mn in water (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**				Based on highest species protection consequences for predicted Mn at MG003, MG005 or MG009 vs. the site-specific Mn GVs	P				H						IV			IV
T	J	07	10		Contaminated by **Pit 3 (PEAK, P50)**					P				H						IV			IV
T	J	07	11		Contaminated by **Composite sources (10,000 Yr, P50)**					P				M						III			III
T	J	07	12		Contaminated by **Pit 3 (10,000 Yr, P50)**					P				L						II			II
T	J	07	13	Poor water quality for CoPC except Mn (mine related) causes biodiversity change ON the RPA	Contaminated by **Composite sources (PEAK, P50)**				SPL GV met except for Al. Al above background (no mine scenario) increased with distance from mine sources so assumed not mine related.	P				VL						I			I
T	J	07	14		Contaminated by **Pit 3 (PEAK, P50)**					P				VL						I			I
T	J	07	15		Contaminated by **Composite sources (10,000 Yr, P50)**					P				VL						I			I
T	J	07	16		Contaminated by **Pit 3 (10,000 Yr, P50)**					P				VL						I			I

BMT is a leading design, engineering, science and management consultancy with a reputation for engineering excellence. We are driven by a belief that things can always be better, safer, faster and more efficient. BMT is an independent organisation held in trust for its employees.

Level 5
348 Edward Street
Brisbane
QLD 4000
Australia
+61 7 3831 6744

Registered in Australia
Registered no. 010 830 421
Registered office
Level 5, 348 Edward Street,
Brisbane QLD 4000 Australia

For your local BMT office visit www.bmt.org

Contact us

enquiries@bmtglobal.com

www.bmt.org

Follow us

www.bmt.org/linkedin

www.bmt.org/youtube

www.bmt.org/twitter

www.bmt.org/facebook

APPENDIX 9.1: REVEGETATION STRATEGY FOR SAVANNA WOODLAND CONCEPTUAL REFERENCE ECOSYSTEM

Revegetation Strategy for the Proposed Savanna Woodland Conceptual Reference Ecosystem

Ranger Mine Closure Plan 2023

Unique Reference: PLN007
Revision: 1.23.0

TABLE OF CONTENTS

FIGURES

TABLES

1 REVEGETATION STRATEGY FOR THE PROPOSED SAVANNA WOODLAND CONCEPTUAL REFERENCE ECOSYSTEM

The sections below summarise key aspects of the current revegetation strategy, based on a range of research trials, the reports listed below, relatively recent unreported monitoring data and advice from subject matter experts.

- Daws and Poole (2010): Construction, revegetation and instrumentation of the Ranger Uranium Mine trial landform: Initial outcomes.
- Daws and Gellert (2010): Initial (2009) revegetation monitoring on the trial landform.
- Daws and Gellert (2011): Ongoing (2010) revegetation monitoring on the trial landform.
- Gellert (2012): Ongoing revegetation monitoring on the trial landform 2011.
- Gellert (2013): Ongoing revegetation monitoring on the trial landform 2012.
- Gellert (2014): Ongoing revegetation monitoring on the trial landform 2013.
- Gellert and Lu (2015): Revegetation monitoring on the trial landform in 2014.
- Wright (2019a): Effects of the 2016 prescribed fire on revegetation at the trial landform (2016 and 2018 surveys).
- Parry and others (2022): Improved native understorey establishment in mine waste rock in Australia's wet-dry tropics.
- Additional unreported monitoring data (2018–2023).

1.1 Seed Provenance

The approved provenance zone for seed collection is based on assessment of environmental factors, species distributions, taxonomy, present and past gene flow, and species traits known to influence genetic variation in plants. Findings are presented in Zimmermann (2013) and Zimmermann and Lu (2015), with the GAC approved 'conservative provenance zone' clipped to the boundary of Kakadu National Park, as shown on Figure 1.

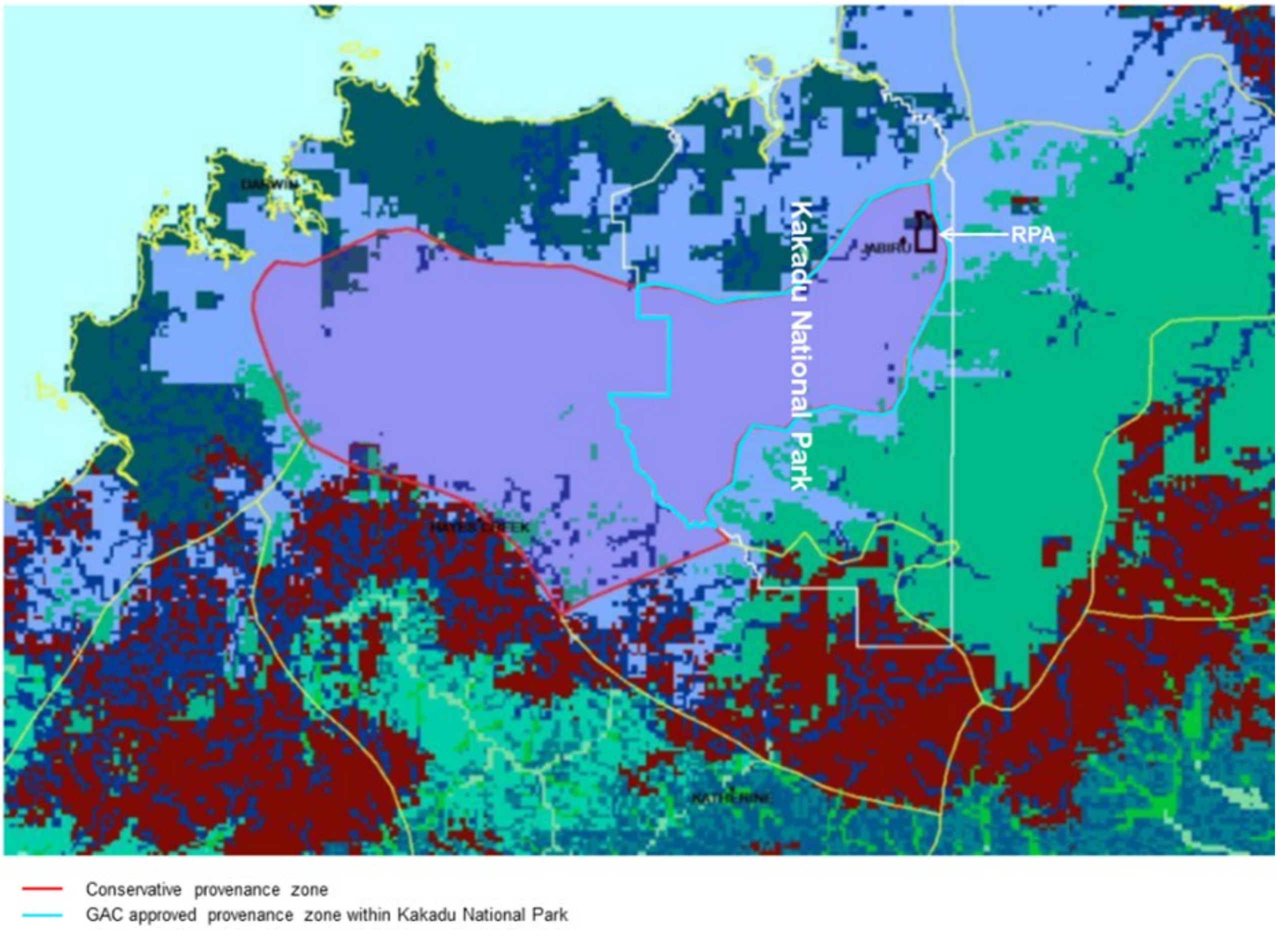


Figure 1: Proposed conservative provenance zone (bordered by the red line) and the GAC approved provenance zone within Kakadu National Park (bordered by the blue line)

Kakadu Native Plant Supplies Pty Ltd (KNPS) collect seeds within the established provenance zone as per the terms and conditions agreed with Kakadu National Park. The permit and approved provenance zone assist in ensuring:

- the genetic make-up of the revegetation and resilience is consistent with locally adapted populations of each species and provides a buffer for adapting to future climate change;
- seeds collected are well adapted to the environmental conditions and promote sufficient genetic diversity to prevent inbreeding; and
- the impact of seed collection to the natural and cultural values of Kakadu National Park are managed.

1.2 Tubestock propagation

For many rehabilitated mine sites, most flora species are established by direct seeding. Results can be variable and are often supplemented with tubestock planting, particularly in the case of hard-rock mines. At Ranger, the absence of available topsoil and the presence of prescriptive species composition, abundance and structure requirements have led to historic direct seeding trials indicating poor outcomes. At the Trial Landform (TLF), planted tubestock areas have generally out-performed direct-seeded areas in terms of plant survival, growth, stem density and species composition (Daws and Gellert, 2011; additional unreported data). In addition, the increased rates of germination under nursery conditions allow a significant reduction in the volume of seed required to achieve the same densities. This is favourable considering the restricted seed collection provenance zone and permit limitations within Kakadu National Park.

Understory species have seen similar results. Parry and others (2022) found that several understorey species planted from tubestock demonstrated increased growth, persistence, recruitment and spread, compared to individuals that were directly seeded, resulting in larger, more robust plants.

Pot type

Standard plastic nursery tubes are the commercial standard and were used for all revegetation trials at Ranger prior to 2017. Biopots have since been used in revegetation trials since 2018. The biopots are made from a compacted rice-hull and are a similar shape to the standard tubes. So far, the biopots have proven to be suitably durable under irrigation regimes and provide the added benefit of allowing tubestock to be planted whilst remaining in the pots. However, when compared to standard plastic tubes, the biopots planted on Pit 1 demonstrated poorer survival rates. In addition, the decomposition rates of biopots planted within waste-rock are uncertain and may result in poor root formation and restrict the movement of water and nutrients. With consideration of the above risks, standard plastic nursery tubes are specified as the preferred pot type and can be sterilised for repeat use. The use of biopots may still be considered for smaller planting areas.

Microorganism inoculation

Microorganism inoculation, often with commercially produced microbial additives, has become standard practice in many commercial nurseries due to the vital role that microbes perform in plant nutrient acquisition. Reddell and Zimmermann (2002) suggest that inoculation can be achieved using ectomycorrhizal fungi collected from surrounding areas. This was done for tubestock planted on the TLF, with apparent success. Whilst the field outcomes of inoculation trials on Stage 13 were inconclusive due to poor randomisation in the nursery prior to planting, the inoculated seedlings were visibly healthier and more robust than the control seedlings. In addition, the relative success of planting on Pit 1 indicates that commercially and locally sourced microbial additives are generally suitable. These are likely to be included in the standard potting mixes used for subsequent areas.

Promotion of genetic diversity

Sufficient genetic diversity of tubestock will improve the overall resilience to external threats and prevent issues associated with inbreeding. While each delivered seed lot is made up from several individual plants and will include a degree of genetic diversity.

Tubestock size and age

With regard to tubestock size and age, trials have indicated that tubestock with a larger 'root to shoot' ratio are less prone to root bounding, more resilient and have a reduced initial water demand after planting.

Perishable seed

Seed cannot be stored for particular species (e.g. *Planchonia careya*). In these cases, tubestock has previously been propagated when seed is available and then held for an extended period of time before planting, with transfer into larger pots to reduce root bounding. Although this method has proven successful, larger plants are more difficult to handle during planting and require larger holes, therefore will be avoided as much as possible.

Tubestock standard

To maintain tubestock quality, a tubestock standard has been developed for Ranger Mine Nursery, based on industry best practice, field trials, observations and local knowledge. This is presented in Table 1.

Table 1: Tubestock standard for Ranger Mine Nursery

Standard	Description
Pot type	Seedling supplied in standard plastic tube, unless otherwise directed, without significant damage.
Potting mix	Potting mix with appropriate water holding capacity, and incorporated slow release fertiliser and microbial additives, to a level within 5 mm of pot lip.
Genetic diversity	Sufficient genetic diversity.
Size and age	Seedling is appropriate size and age as verified by reference material (SERP) and/or ERA supervisor, i.e. with multiple sets of leaves and holding potting mix without major signs of root bounding.
General health	Leaf colour and size is true to species form, without signs of active pests, disease, dieback or injury.
Seedling structure	Seedlings should be growing in accordance with natural habit (i.e. free standing where applicable without staking or tip pruning).
Stem position	The seedling stem base should be at least 10 mm from the edge of the pot.
Arrangement	Prior to planting, seedlings must be arranged into planting trays as specified by the area-specific planting plan.

1.3 Provision of suitable irrigation and application of pre-emergent herbicide

These two steps are considered essential controls to ensure successful establishment and management of initial weed abundance, with further detail is provided in the main body of the 2023 Mine Closure Plan. At least four weeks should be allowed between application of pre-emergent herbicide and further disturbance, for maximum effect.

1.4 Preparation of planting holes

Preparation of planting holes has previously been executed using a custom-designed auger (designed by KNPS) attached to a small excavator (Plate 1). This method creates a hole approximately 400 millimetres (mm) deep and 150 mm wide. Monitoring data suggests that this approach is suitable and should be similarly adopted for larger scale planting.

Plate 1: Small excavator with auger attachment

1.5 Initial fertiliser application

A slow-release tabular and/or granular fertiliser (suitable for native plants) has previously been applied to the base of each planting hole during planting, and mixed with the backfilled substrate, which appears to be a suitable approach.

Re-application of a similar granular fertiliser has been applied during the following wet season to the base of establishing plants, however further refinement regarding the methodology and timing for this may be conducted.

1.6 Water crystals in non-irrigated areas (mainly non-waste rock)

In non-waste rock areas, planting without irrigation has proven to be successful if it can be timed with the onset of monsoon. In the case where irrigation is not able to be installed, a small handful of pre-soaked water crystals (Plate 2) will be added to the base of each planting hole.

Plate 2: Planting of tubestock with pre-soaked water crystals

1.7 De-potting and/or use of biopots

Plants should be carefully removed from plastic pots and placed into the planting hole to minimise loss of potting mix. Holes should be backfilled manually with the surrounding loosened substrate, focusing on contact with fines and removal of large rocks. The surface of the potting mix should be just below the final surface leaving a very slight depression which will assist with collecting water for the plant.

Biopots may still be used for some areas and should be lightly crushed at the bottom prior to planting to facilitate root development, and account for uncertainties with pot decomposition rates. The rims of biopots should be buried below the surface to improve thermal insulation of the root ball and prevent moisture wicking.

1.8 Direct seeding (for suitable species only)

Although establishment from tubestock is the preferred method for most species, the benefits from a resourcing and cost perspective have prompted several trials, with reasonable success for some understorey species and a few midstory species.

Key learnings, as described by Parry and others (2022) and applicable to direct seeding under a mature canopy, are described in the following points:

- Germination and persistence from seed is generally increased with the use of surface litter, likely due to retained moisture and reduced surface temperature. The surface litter may also protect the seeds/seedlings from rain wash or uprooting, and predation.
- Under optimal conditions, the use of fertiliser may account for waste rock nutrient deficiency and is found to increase growth, flowering and fruiting.

Further unreported trials at the TLF and Pit 1 have seen some success with direct seeding under warm and wet conditions, whilst heavy rain has been observed to wash away seed from relatively bare areas.

1.9 Establishment of Proposed Savanna Woodland CRE

The proposed savanna woodland conceptual reference ecosystem (CRE) (Table 4) is largely based on data provided by the Supervising Scientist (2021). There are however several species and vegetation groups for which composition/abundance has been modified (Table 2).

Table 2: Further modifications regarding the savanna woodland CRE

Species of vegetation group	Description of further modification in comparison to reference sites and/or previous experience
Understorey (particularly *Sorghum spp.)*	The dominance of *Sorghum spp.* in the understorey of reference sites has raised concerns. Too frequent fires in eucalypt savanna are considered to contribute to a dominance of *Sorghum spp* (Cook, 2021; Freeman *et al.,* 2018), which implies that most of the reference sites are influenced by an inappropriate fire regime and should not represent a direct target for a sustainable re-constructed ecosystem, at least with regards to understorey. This concept was discussed at a workshop on the 24th of June 2021, which involved relevant ERA, OSS and NLC personnel, as well as experts from Charles Darwin University and KNPS. One outcome was the adoption of a 'functional understorey approach' for understorey composition closure criterion. This allows for a target composition that does not necessarily include a dominance of *Sorghum spp*., will promote a more appropriate fire regime, and improve species richness and diversity. Following a workshop held on 8 August 2023, appropriate functional composition for understorey is currently being developed, with outcomes to be integrated into future iterations of the proposed Savanna Woodland CRE. In the interim, specific understorey species has not been included.
Acacias	There are concerns regarding the influence of inappropriate fire regimes and a corresponding dominance of *Acacia mimula* in surveyed reference sites. To investigate this concept and the influence of different fire regimes, a study has been initiated at Paradise Farm, an outstation within Kakadu NP, approximately 45 km south-west of the RPA. The Traditional Owners of this area have been documenting the effect of various fire regimes on species composition over several decades. These studies are currently in progress, with outcomes likely to influence the make-up of the Savanna Woodland CRE and understanding of appropriate fire management. In the interim, the relative abundance of *Acacia mimula* has been dramatically reduced, while the abundance of several other Acacia species, which are considered more vulnerable to inappropriate fire regimes, are increased.
Dry monsoon forest sub-community	Several species that have been identified as culturally significant and do not occur in reference sites (e.g. *Allosyncarpia ternata, Ficus spp*.) are proposed for establishment in 'clusters' of forest around rockpiles and/or broad concave slopes, with relatively low average densities across the landform.
Salmon Gum *(Eucalyptus tintinnans)*	This species has historically been included in approved planting lists and has demonstrated outstanding establishment success on the waste rock substrate. However, it occurs well outside of the distribution range of reference sites and was not identified as a locally culturally relevant species by Garde (2015). OSS have expressed concerns over the appropriateness of this species, given its absence from the immediate surrounds. Further, Traditional Owners have indicated concerns around the unintentional establishment of an inappropriately 'mixed' vegetation community on the final landform (Brady *et al*., 2021). In consideration of this, *Eucalyptus tintinnans* will not be included in future planting compositions unless requested specifically by the Traditional Owners.

Table 3 provides commentary for several of the attributes presented in Table 4.

Table 3: Description of the attributes relevant to the savanna woodland CRE

Attribute	Description
Relevance	Indication of relevance with regard to relative density in reference sites, identified cultural species, and/or functional attributes.
Target stems per hectare or percentage ground cover (minimum and maximum)	Prescription of the allowable range, which is derived from, and reflects the high degree of variability between reference sites. This will encourage a variable composition across the landform, which may be tailored to suit localised variations in the topography and structure of the waste rock landform. Default ranges are applied for species that do not occur in reference sites (OSS 2019), but have been identified culturally (Garde 2015) or experienced previous success.
Target stems per hectare or percentage ground cover (minimum average)	Prescription of the minimum average across the final landform, which is derived from average stem densities in reference sites, however reduced proportionately to allow increased species richness without overcrowding. Relatively small minimum average densities are included by default for species that do not occur in reference sites.
Proposed establishment method	By tubestock, direct seeding or natural recruitment, based on research outcomes.
Expected survival (%)	Stabilised survival after early establishment (two-years post planting), unless otherwise specified. Majority of values are based on Pit 1 results, followed by TLF and Stage 13 where not available. Some estimated values have been provided for species lacking revegetation experience – these are identified in the comments column.
Initial planting density (minimum, maximum and average)	Calculations based on target stems and expected establishment success, and applicable for establishment from tubestock.

Table 4: Proposed Savanna Woodland Vegetation CRE and planting density for midstorey and overstorey species (Note: understorey composition/abundance is still in development and will be included in subsequent revisions)

Species	Growth form	Reference	Target stems[1] (min)	Target stems[1] (max)	Target stems[1] (ave)	Proposed Establishment Method	Expected survival at 2-years post-planting (%)	Initial planting density[1] (min)	Initial planting density[1] (max)	Initial planting density[1] (ave)	Comment
Acacia difficilis	Shrub	Identified cultural species	0	30	15	Tubestock	65	0	46	*23*	Reduced population in reference sites possibly influenced by fire regime
Acacia dimidiata	Shrub	Patchy coverage in reference sites, identified cultural species	0	30	15	Tubestock	60	0	50	*25*	Remaining uncertainty regarding recruitment potential, reduced population in reference sites possibly influenced by fire regime
Acacia hemignosta	Tree	Sparse in reference sites	0	30	15	Tubestock	70	0	43	*21*	
Acacia lamprocarpa	Tree	Sparse in reference sites, identified cultural species	0	30	15	Tubestock	80	0	38	*19*	
Acacia latescens	Shrub	Spare in surrounding environment. High density in Ranger EIS	0	30	15	Tubestock	70	0	43	*21*	
Acacia mimula	Shrub	Dominant in reference sites (potentially influenced by inappropriate fire regime)	20	180	60	Tubestock	75	27	240	*80*	
Acacia oncinocarpa	Shrub	Patchy, sparse coverage in reference sites	0	50	15	Tubestock	65	0	77	*23*	
Allosyncarpia ternata	Tree	Identified cultural species	0	5	1	Transplant	80	0	6	*1*	Suitable for dry monsoon sub-community
Alphitonia excelsa	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience. Suitable for dry monsoon sub-community
Antidesma ghaesembilla	Shrub	Bush food	0	1	0	Tubestock	70	0	1	*0*	Some success with direct seeding into established vegetation, suitable for dry monsoon sub-community
Brachychiton diversifolius	Tree	identified cultural species	0	5	1	Tubestock	65	0	8	*2*	
Brachychiton megaphyllus	Tree	Patchy coverage in reference sites, identified cultural species	0	20	5	Tubestock	95	0	21	*5*	Propagation difficult in cooler months
Breynia cernua	Shrub	Bush food	0	1	0	Tubestock	90	0	1	*0*	Requires fresh seed, suitable for dry monsoon sub-community
Buchanania obovata	Tree	Sparse in reference sites, identified cultural species	0	20	5	Tubestock	80	0	25	*6*	
Callitris intratropica	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience. Reduced population in reference sites possibly influenced by fire regime
Calytrix achaeta	Shrub	Sparse, patchy in reference sites	0	5	0	Tubestock	50	0	10	*0*	No reveg experience
Calytrix brownii	Shrub	identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience
Calytrix exstipulata	Shrub	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	70	0	7	*1*	
Carallia brachiata	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience. Suitable for dry monsoon sub-community
Clerodendrum floribundum	Shrub	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	
Cochlospermum fraseri	Shrub	Sparse in reference sites, identified cultural species	0	10	1	Tubestock	80	0	13	*1*	Waste rock coloniser and high recruitment. Will only plant sparsely, also potential for direct seeding

Species	Growth form	Reference	Target stems[1] (min)	Target stems[1] (max)	Target stems[1] (ave)	Proposed Establishment Method	Expected survival at 2-years post-planting (%)	Initial planting density[1] (min)	Initial planting density[1] (max)	Initial planting density[1] (ave)	Comment
Coelospermum reticulatum	Shrub	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience
Corymbia bleeseri	Tree	Patchy coverage (shallower soils?) in reference sites, identified cultural species	0	390	60	Tubestock	70	0	557	*86*	
Corymbia chartacea	Tree	Patchy coverage (shallower soils?) in reference sites	0	100	15	Tubestock	80	0	125	*19*	
Corymbia disjuncta	Tree	Identified cultural species	0	5	1	Tubestock	80	0	6	*1*	
Corymbia foelscheana /latifolia	Tree	Common in reference sites, identified cultural species	0	20	2	Tubestock	75	0	27	*3*	
Corymbia polycarpa	Tree	Identified cultural species	0	5	1	Tubestock	80	0	6	*1*	No tubestock experience, however some direct seeding in depressions
Corymbia polysciada	Tree	Sparse, patchy in reference sites, identified cultural species	0	5	1	Tubestock	85	0	6	*1*	
Corymbia porrecta	Tree	Dominant in reference sites	0	220	60	Tubestock	70	0	314	*86*	
Croton arnhemicus	Shrub	Sparse in reference sites	0	10	2	Tubestock	50	0	20	*4*	No reveg experience
Dolichandrone filiformis	Tree	Sparse in reference sites	0	1	0	Tubestock	65	0	2	*0*	
Elaeocarpus arnhemicus	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience. Suitable for dry monsoon sub-community
Erythrophleum chlorostachys	Tree	Common in reference sites, identified cultural species	0	80	20	Tubestock	70	0	114	*29*	
Eucalyptus miniata	Tree	Dominant in reference sites, identified cultural species	10	200	70	Tubestock	65	15	308	*108*	Very sensitive to waterlogging
Eucalyptus phoenicea	Tree	Identified cultural species	0	5	1	Tubestock	75	0	7	*1*	
Eucalyptus tectifica	Tree	Sparse, patchy in reference sites	0	5	1	Tubestock	90	0	6	*1*	
Eucalyptus tetrodonta	Tree	Dominant in reference sites, identified cultural species	60	240	110	Tubestock	70	86	343	*157*	
Ficus platypoda	Tree	Identified cultural species	0	5	1	Tubestock	75	0	7	*1*	Suitable for dry monsoon sub-community
Ficus racemosa	Tree	Identified cultural species	0	5	1	Natural	N/A	N/A	N/A	*N/A*	Suitable for dry monsoon sub-community
Fluggea virosa	Shrub	Bush food	0	1	0	Tubestock	80	0	1	*0*	Requires fresh seed, suitable for dry monsoon sub-community
Gardenia fucata	Tree	Identified cultural species	0	5	1	Tubestock	55	0	9	*2*	
Gardenia megasperma	Tree	Common, patchy in reference sites, identified cultural species	0	10	2	Tubestock	80	0	13	*3*	Requires fresh seed, reduced population in reference sites possibly influenced by fire regime
Grevillea decurrens	Tree	Common in reference sites, identified cultural species	0	10	1	Tubestock	70	0	14	*1*	
Grevillea pteridifolia	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	60	0	8	*2*	Remaining uncertainty regarding long-term suitability on waste-rock
Hakea arborescens	Tree	Low density in surrounding ecosystem	0	1	0	Tubestock	75	0	1	*0*	
Jacksonia dilatata	Shrub	Patchy abundance in surrounding ecosystem	0	1	0	Tubestock	75	0	1	*0*	

Species	Growth form	Reference	Target stems[1] (min)	Target stems[1] (max)	Target stems[1] (ave)	Proposed Establishment Method	Expected survival at 2-years post-planting (%)	Initial planting density[1] (min)	Initial planting density[1] (max)	Initial planting density[1] (ave)	Comment
Jasminum molle	Shrub	Low density in surrounding ecosystem	0	1	0	Tubestock	20	0	5	*0*	Remaining uncertainty regarding suitability on waste-rock
Livistona humilis	Palm	Patchy coverage (fire affected?) in reference sites, identified cultural species	0	280	40	Tubestock	65	0	431	*62*	
Livistona inermis	Palm	Previous successes, present on rocky country in surrounding ecosystem	0	1	0	Tubestock	90	0	1	*0*	
Owenia vernicosa	Tree	Sparse in reference sites, identified cultural species	0	5	1	Direct seeding	N/A	N/A	N/A	*N/A*	Direct seed in clusters near rock piles and ridgelines, seed potentially germinated following fire
Pandanus spiralis	Palm	Sparse, patchy in reference sites, identified cultural species	0	10	5	Direct seeding	90	N/A	N/A	*N/A*	Direct seed in minor depressions
Persoonia falcata	Shrub	Common in reference sites, identified cultural species	0	60	15	Tubestock	50	0	120	*30*	No reveg experience because unsuccess with propagation/seeding, some limited recruitment in reveg areas
Petalostigma pubescens	Tree	Identified cultural species	0	5	1	Tubestock	40	0	13	*3*	
Planchonella arnhemica	Tree	Sparse in reference sites, identified cultural species	0	10	5	Tubestock	50	0	20	*10*	No reveg experience because unsuccessful with propagation/seeding
Planchonia careya	Tree	Sparse in reference sites, identified cultural species	0	10	2	Tubestock	95	0	11	*2*	Requires fresh seed
Stenocarpus acacioides	Tree	Sparse, patchy in reference sites	0	5	1	Tubestock	40	0	13	*3*	
Sterculia quadrifida	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience. Suitable for dry monsoon sub-community
Syzygium eucalyptoides subsp. bleeseri	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	90	0	6	*1*	Requires fresh seed
Syzygium eucalyptoides subsp. eucalyptoides	Tree	Sparse, patchy in reference sites, identified cultural species	0	10	1	Tubestock	70	0	14	*1*	Requires fresh seed for propagation, suitable for dry monsoon sub-community
Syzygium suborbiculare	Tree	Sparse in reference sites, identified cultural species	0	5	1	Tubestock	75	0	7	*1*	Requires fresh seed
Terminalia carpentariae	Tree	Identified cultural species	0	5	1	Tubestock	70	0	7	*1*	
Terminalia ferdinandiana	Tree	Common in reference sites, identified cultural species	10	70	30	Tubestock	75	13	93	*40*	May be suitable for direct seeding, propagation difficult in cooler months
Terminalia pterocarya	Shrub	Common, patchy in reference sites	0	15	1	Tubestock	75	0	20	*1*	
Vitex glabrata	Tree	Identified cultural species	0	5	1	Tubestock	50	0	10	*2*	No reveg experience
Wrightia saligna	Shrub	Previous successes	0	1	0	Tubestock	75	0	1	*0*	
Xanthostemon paradoxus	Tree	Common in reference sites	0	250	50	Tubestock	70	0	357	*71*	Value from 6-months post planting in one area. Remaining uncertainty regarding suitability for initial planting

1 Stems per hectare (ha)

2 REFERENCES

Brady, C, Christopherson, P & O'Brien, J 2021. Incorporating indigenous knowledge in mine closure: Ranger Uranium Mine. Proceedings of the Royal Society of Victoria 133, pp. 18–22. DOI: 10.1071/RS21003.

Daws, M & Gellert, C 2011. Ongoing (2010) Revegetation monitoring on the trial landform. April 2011.

Cook, GD 2021. *Fire resilience for ERA Ranger Mine revegetation.* Arafurica Pty Ltd, Australia.

Freeman M. E., Murphy B. P., Richards A. E., Vesk P. A. & Cook G. D. (2018) Facultative and Obligate Trees in a Mesic Savanna: Fire Effects on Savanna Structure Imply Contrasting Strategies of Eco-Taxonomic Groups. Frontiers in Plant Science 9.

Garde, M 2015. Closure Criteria Development – Cultural. ERA Ranger Integrated Tailings, Water & Closure. Confidential report, Northern Territory. April 2015, p. 160.

Parry, M. L., Bellairs, S. M., & Lu, P. (2022). Improved native understorey establishment in mine waste rock in Australia's wet–dry tropics. Australian Journal of Botany, 70(3), pp. 248–262.

Reddell, P & Zimmermann, A. 2002. An external review of revegetation research at Ranger Mine: Assessment of field trials and their implications for future rehabilitation practice. EWLS/CSIRO (L&W) report to Ranger Mine.

Supervising Scientist (2021). Technical Advice #041: Updated Conceptual Reference Ecosystem data. Provided to ERA 23 August 2021.

Wright, A. 2019a. *Effects of the 2016 prescribed fire on revegetation at the trial landform (2016 and 2018 surveys)*. ERA Report RH220, May 2019.

Wright, A. 2019b. *Trial Landform (laterite mix areas) weed control burn – June 2019*. ERA Technical Memorandum, issued November 2019.

Zimmermann, A 2013. Potential seed provenance for Ranger Mine revegetation. Delineation and recommendations Report by Energy Resources of Australia Ltd, Darwin, NT. November 2013.

Zimmermann, A & Lu, P 2015. A Multilevel Non-genetic Approach to Delineate Provenance Boundaries of Revegetation Species: Ranger Uranium Mine Case Study. In: Proceedings of 3rd Australian Mine Rehabilitation Conference on Innovation in Mine Planning and Rehabilitation workshop, 18–20 August 2015, Adelaide, Australia.

APPENDIX 9.2: VERTEBRATE FAUNA EXPECTED TO RETURN TO THE REHABILITATED SITE

ERA Energy Resources Of Australia

VERTEBRATE FAUNA EXPECTED TO RETURN TO THE REHABILITATED SITE

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Mammals			
Agile Wallaby	*Macropus agilis*		
Antilopine Wallaroo	*Macropus antilopinus*		
Black Flying-Fox	*Pteropus alecto*		
Black-Footed Tree-Rat *	*Mesembriomys gouldii*		
Common Brushtail Possum	*Trichosurus vulpecula*		
Common Wallaroo	*Macropus robustus*		
Dingo	*Canis dingo*		
Fawn Antechinus *	*Antechinus bellus*		
Grassland Melomys	*Melomys burtoni*		
Northern Brown Bandicoot *	*Isoodon macrourus*		
Northern Quoll *	*Dasyurus hallucatus*		
Short-Beaked Echidna	*Tachyglossus aculeatus*		
Sugar Glider	*Petaurus breviceps*		
Birds			
Apostlebird	*Struthidea cinerea*		
Australasian Darter	*Anhinga novae-hollandiae*		
Australasian Figbird	*Sphecotheres vieilloti*	1	
Australian Hobby	*Falco longipennis*		
Australian Owlet-Nightjar	*Aegotheles cristatus*		
Banded Honeyeater	*Cissomela pectoralis*		1
Barking Owl	*Ninox connivens*		
Bar-Shouldered Dove	*Geopelia humeralis*	2	
Black Kite	*Milvus migrans*		
Black-Breasted Buzzard	*Hamirostra melanosternon*		
Black-Faced Cuckoo-Shrike	*Coracina novae-hollandiae*		
Black-Faced Woodswallow	*Artamus cinereus*		
Black-Necked Stork	*Ephippiorhynchus asiaticus*		
Black-Tailed Treecreeper	*Climacteris melanura*		
Blue-Faced Honeyeater	*Entomyzon cyanotis*	2	1
Blue-Winged Kookaburra	*Dacelo leachii*		
Boobook Owl	*Ninox novaeseelandiae*		
Broad-Billed Flycatcher	*Myiagra ruficollis*		
Brown Falcon	*Falco berigora*		

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Brown Goshawk	*Accipiter fasciatus*		
Brown Honeyeater	*Lichmera indistincta*		1
Brown Quail	*Coturnix ypsilophora*		
Brush Cuckoo	*Cacomantis variolosus*		
Bush Stone-Curlew	*Burhinus grallarius*		
Channel-Billed Cuckoo	*Scythrops novaehollandiae*	1	
Chestnut-Backed Button-Quail	*Turnix castanota*		
Cicadabird	*Coracina tenuirostris*		
Crimson Finch	*Neochmia phaeton*		
Diamond Dove	*Geopelia cuneata*		
Dollarbird	*Eurystomus orientalis*		
Double-Barred Finch	*Taeniopygia bichenovii*		
Dusky Moorhen	*Gallinula tenebrosa*		
Dusky Honeyeater	*Myzomela obscura*		1
Eastern Koel	*Eudynamys orientalis*	1	
Forest Kingfisher	*Todiramphus macleayii*		
Galah	*Eolophus roseicapilla*		
Golden-Headed Cisticola	*Cisticola exilis*		
Great Bowerbird	*Phalacrocorax carbo*	2	
Green-Backed Gerygone	*Gerygone chloronota*		
Grey Shrike-Thrush	*Colluricincla harmonica*		
Grey-Crowned Babbler	*Pomatostomus temporalis*		
Helmeted Friarbird	*Philemon buceroides*	2	1
Large-Tailed Nightjar	*Caprimulgus macrurus*		
Leaden Flycatcher	*Myiagra rubecula*		
Lemon-Bellied Flycatcher	*Microeca flavigaster*		
Little Bronze-Cuckoo	*Chrysococcyx minutillus*		
Little Corella	*Cacatua sanguinea*		
Little Friarbird	*Philemon citreogularis*	2	1
Little Shrike-Thrush	*Colluricincla megarhyncha*	2	
Little Woodswallow	*Artamus minor*		
Long-Tailed Finch	*Poephila acuticauda*		
Magpie Lark	*Grallina cyanoleuca*		

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Masked Finch	*Poephila personata*		
Masked Owl	*Tyto novaehollandiae*		
Mistletoebird	*Dicaeum hirundinaceum*	1	
Nankeen Kestrel	*Falco cenchroides*		
Northern Fantail	*Rhipidura rufiventris*		
Northern Rosella	*Platycercus venustus*	2	
Olive-Backed Oriole	*Oriolus sagittatus*	2	
Orange-Footed Scrubfowl	*Megapodius reinwardt*		
Owlet Nightjar	*Aegotheles chrisoptus*		
Partridge Pigeon *	*Geophaps smithii*		
Peaceful Dove	*Geopelia striata*		
Pheasant Coucal	*Centropus phasianinus*		
Pied Butcherbird	*Cracticus nigrogularis*		
Rainbow Bee-Eater	*Merops ornatus*		
Rainbow Pitta	*Pitta iris*		
Red-Backed Fairywren	*Malurus melanocephalus*		
Red-Collared Lorikeet	*Trichoglossus haematodus*	2	1
Red-Tailed Black Cockatoo	*Calyptorhynchus banksii*		
Red-Winged Parrot	*Aprosmictus erythropterus*	2	2
Rose-Crowned Fruit-Dove	*Ptilinopus regina*	1	
Royal Spoonbill	*Platalea regia*		
Rufous Fantail	*Rhipidura dryas*		
Rufous Whistler	*Pachycephala rufiventris*		
Rufous-Banded Honeyeater	*Conopophila albogularis*		1
Rufous-Throated Honeyeater	*Conopophila rufogularis*		
Sacred Kingfisher	*Todiramphus sanctus*		
Shining Flycatcher	*Myiagra alecto*		
Silver-Crowned Friarbird	*Philemon argenticeps*	2	1
Southern Boobook	*Ninox boobook*		
Spangled Drongo	*Dicrurus bracteatus*	2	
Spotted Harrier	*Circus assimilis*		
Spotted Nightjar	*Eurostopodus argus*		
Straw-Necked Ibis	*Threskiornis spinicollis*		
Striated Pardalote	*Pardalotus striatus*		

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Sulphur-Crested Cockatoo	*Cacatua galerita*		
Tawny Frogmouth	*Podargus strigoides*		
Torresian Crow	*Corvus orru*		
Torresian Imperial Pigeon	*Ducula bicolor*	1	
Varied Lorikeet	*Psitteuteles versicolor*		1
Varied Triller	*Lalage leucomela*		
Weebill	*Smicrornis brevirostris*		
Whistling Kite	*Haliastur sphenurus*		
White-Bellied Cuckoo-Shrike	*Coracina papuensis*	2	
White-Bellied Sea-Eagle	*Haliaeetus leucogaster*		
White-Gaped Honeyeater	*Lichenostomus unicolor*	2	1
White-Throated Gerygone	*Gerygone albogularis*		
White-Throated Honeyeater	*Melithreptus albogularis*		1
White-Winged Triller	*Lalage sueurii*		
Willie Wagtail	*Rhipidura leucophrys*		
Yellow Oriole	*Oriolus flavocinctus*	1	
Yellow-Throated Miner	*Manorina flavigula*		2
Zebra Finch	*Taeniopygia guttata*		
Reptiles			
Black-Necked Snake-Lizard	*Delma tincta*		
Black-Tailed Monitor	*Varanus tristis*		
Blind Snake	*Anilios sp.*		
Burton's Legless Lizard	*Lialis burtonis*		
Bynoe's Gecko	*Heteronotia binoei*		
Children's Python	*Antaresia childreni*		
Claw-Snouted Blind Snake	*Ramphotyphlops unguirostris*		
Frilled Lizard	*Chlamydosaurus kingii*		
Gilbert`s Dragon	*Lophognathus gilberti*		
Green Tree Snake	*Dendrelaphis punctulata*		
Grey's Menetia	*Menetia greyii*		
Karl Schmidt's Lerista	*Lerista karlschmidti*		
Lively Ctenotus	*Ctenotus alacer*		
Long-Nosed Water Dragon	*Lophognathus longirostris*		
Marbled Velvet Gecko	*Oedura marmorata*		
Metallic Snake-Eyed Skink	*Cryptoblepharus metallicus*		

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Northern Dtella	*Gehyra australis*		
Northern Dwarf Skink	*Menetia maini*		
Northern Mulch-Skink	*Glaphyromorphus darwinensis*		
Northern Shovel-Nosed Snake	*Brachyurophis roperi*		
Northern Small-Eyed Snake	*Cryptophis pallidiceps*		
Northern Snake-Lizard	*Delma borea*		
Orange-Naped Snake	*Furina ornata*		
Ornate Snake-Eyed Skink	*Notoscincus ornatus*		
Port Essington Ctenotus	*Ctenotus essingtonii*		
Robust Ctenotus	*Ctenotus robustus*		
Scant-Striped Ctenotus	*Ctenotus vertebralis*		
Slender Rainbow Skink	*Carlia gracilis*		
Slender Snake-Eyed Skink	*Proablepharus tenuis*		
Smooth-Tailed Skink	*Glaphyromorphus isolepis*		
Spotted Tree Monitor	*Varanus scalaris*		
Storr's Ctenotus	*Ctenotus storri*		
Storr's Snake-Eyed Skink	*Morethia storri*		
Striped Rainbow Skink	*Carlia mund*		
Swanson's Snake-Eyed Skink	*Cryptoblepharus cygnatus*		
Three-Spined Rainbow Skink	*Carlia triacantha*		
Two-Lined Dragon	*Diporiphora bilineata*		
Two-Spined Rainbow Skink	*Carlia amax*		
Water Python	*Liasis fuscus*		
Zig-Zag Gecko	*Oedura rhombife*		
Amphibians			
Bilingual Frog	*Crinia bilingua*		
Copland's Rock Frog	*Litoria coplandi*		
Giant Frog	*Cyclorana australis*		
Giant Frog	*Litoria australis*		
Green Tree-Frog	*Litoria caerulea*		
Marbled Frog	*Limnodynastes convexiusculus*		
Northern Dwarf Tree Frog	*Litoria bicolor*		
Northern Spadefoot Toad	*Notaden melanoscaphus*		
Northern Territory Frog	*Austrochaperina adelphe*		
Ornate Burrowing Frog	*Platyplectrum ornatus*		
Pale Frog	*Litoria pallida*		

Common Name	Scientific Name	Importance of Fruit	Importance of Nectar
Rocket Frog	*Litoria nasuta*		
Roth's Tree Frog	*Litoria rothii*		
Stonemason Toadlet	*Uperoleia lithomoda*		
Tornier's Frog	*Litoria tornieri*		

* species listed as threatened under the relevant Commonwealth and NT legislation.
1 Indicates that most of the diet is fruit, or nectar.
2 Indicates that fruit, or nectar is important, but other dietary items are more important.