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Risk-based contaminant management: Ranger Mine case study

M Iles *BMT, Australia*

D Rissik *BMT, Australia*

Abstract

The Ranger Mine, operated by Energy Resources of Australia Ltd (ERA), is in a sensitive area in Australia's Northern Territory. It is surrounded by (but separate from) Kakadu National Park (KNP) World Heritage Place and Ramsar wetland. Closure requirements include protecting the KNP values and health of the local people. Impacts from water and tailings contaminants must be as low as reasonably achievable and cause no detrimental impact to the biodiversity or ecological processes of the region. The Indigenous landowners, the Mirarr people, wish to resume cultural activities, including sourcing food, at the site after closure.

A source-pathway-receptors approach and a deep dive into environmental exposures and consequences were used to assess the risks from multiple contaminant sources and water pathways for up to 10,000 years after closure. The most hazardous contaminants were identified by comparing measured and modelled water and sediment concentrations against multiple guidelines for human health and ecosystem endpoints reflecting the regulatory environmental requirements for closure and the aspirations of ERA and its stakeholders.

Prioritised actions were identified to manage contaminant sources, including a review of key modelling assumptions influencing outcomes, targets for process water treatment and decommissioning plans for plumes and contaminated soils around the tailings storage facility.

The assessment used evidence from monitoring, ecological response studies and modelling. Risk descriptors were developed to match the evidence types and frequencies at which guideline values might be exceeded, giving a deep insight into impacts. This case study shows how to modify standard risk assessment tools to match different types of evidence, including probabilistic outcomes solute transport models. The water quality discussed in this report is not that expected after closure. The process discussed here has driven actions to improve water quality on, and downstream of, Ranger Mine after closure. The process can be applied iteratively to revise contaminant management plans thus improving water quality following closure.

Keywords: *risk assessment, ecological vulnerability, as low as reasonably achievable (ALARA), closure criteria*

1 Introduction

The Ranger Mine in the Northern Territory (NT) is operated by Energy Resources of Australia Ltd (ERA). Uranium was mined from two open cut pits between 1980 and 2012 and milling of stockpiled ore was completed in January 2021. The mine has now entered the closure phase.

The Ranger Project Area (RPA) is surrounded by, but separate to, Kakadu National Park (KNP) which is a World Heritage Place and Ramsar wetland site (Figure 1).

Water at and leaving the mine site following closure has the potential to impact community values on and off the RPA after closure if not properly managed. High level environmental requirements (ERs) for the protection of people and the environment during and after mining at Ranger have been set by the Australian Government (Commonwealth of Australia 2000). Those relevant to water quality specify that:

- Waters leaving the RPA do not compromise the achievement of the primary environmental objectives related to protection of the people, ecosystem (biodiversity and ecological processes), and World Heritage and Ramsar values of the surrounds. This applies for 10,000 years for contaminants from tailings.

- Impacts on the RPA are as low as reasonably achievable (ALARA).

The Mirarr Indigenous landowners source food and drinking water up and downstream of the mine and wish to resume these, and other cultural activities, on the site after closure. Studies have been conducted for over 40 years to understand the contaminants on and leaving Ranger Mine and the potential impacts they pose to the health of the ecosystem and people. Water quality guideline values (GV) for multiple contaminants for drinking and recreational water were considered in assessing the risk to human health. Site-specific and national default (ANZG 2018) water and sediment quality GVs were considered for protecting the aquatic ecosystem.

This paper discusses how information from: (i) quantitative solute transport modelling, (ii) water, sediment and ecological monitoring, and (iii) site-specific and literature-based GV were used in a modified version of the Rio Tinto risk assessment template to assess the risks to people and the environment exposed to water on and leaving the mine site after closure.

The water quality reported here is not now expected after closure. The assessment triggered a review of closure plans to improve water quality after closure. The approach used here can be applied iteratively to develop a final plan that achieves water quality objectives. A separate paper (Iles 2022) discusses how the risk assessment outputs are used in the stakeholder decision-making processes on water quality.

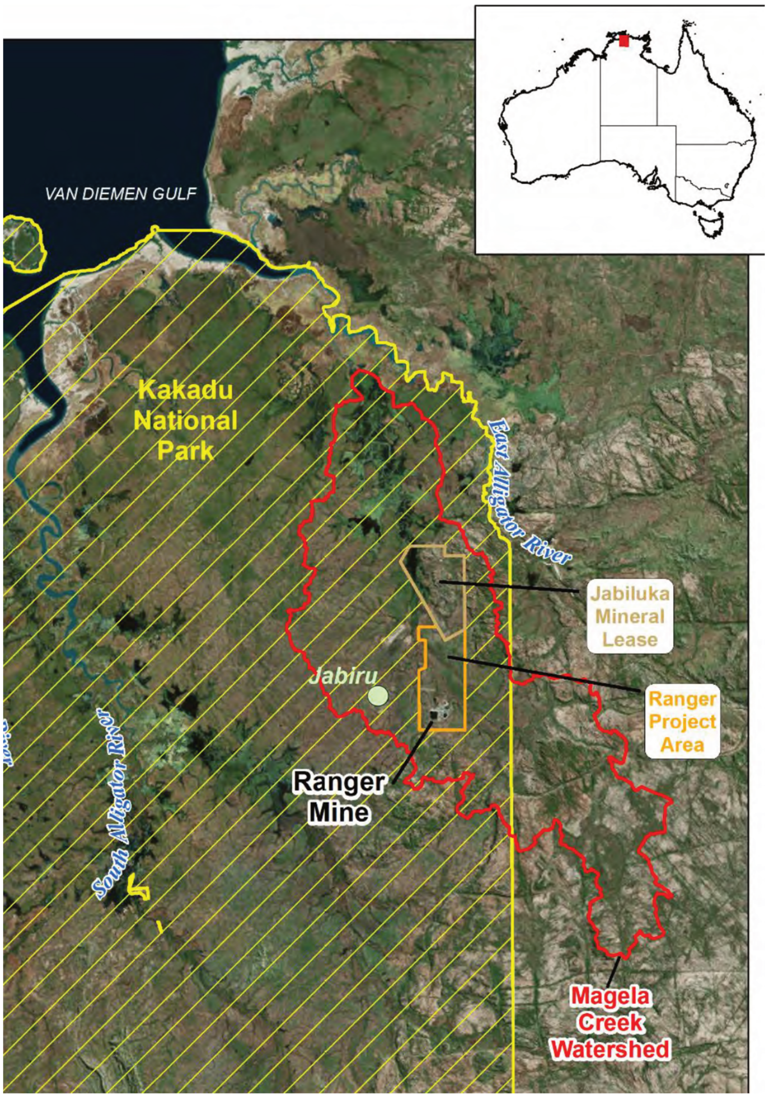

Figure 1 Ranger Project Area and mine site location (Iles & Rissik 2021)

2 Methodology

Numerous studies have been completed to understand what contamination exists now and is expected on the RPA following closure, how these contaminants are transported, and the sensitivity of the aquatic environment and human health to these contaminants in the surface water. The results of these studies, particularly those measuring or predicting contaminant concentrations in surface water and sediment and the effect of those concentrations in surface water to the ecosystem and human health form the evidence base for this risk assessment.

The standard Rio Tinto risk assessment spreadsheet, including consequence descriptors and scoring matrices, were altered (in consultation with the Supervising Scientist Branch (SSB)) to match the various types of evidence used.

The proposed approach was tested in a stakeholder workshop in early 2020 and areas for improvement were identified. Representatives from ERA, BMT and SSB were present with a Northern Land Council representative observing. Risk scoring was completed by ERA and BMT following the workshop with consultation with SSB on improvements to descriptors and evidence interpretation. The assessment approach was to:

- Use conceptual model to identify endpoints requiring protection.
- Identify a set of GV and develop consequence descriptors for those endpoints.
- Compare water and sediment quality (measured and predicted) to endpoints (discussed in results section).
- Use the Rio Tinto modified risk register template to classify and rank risks to receptors off the RPA and in four sub-catchments on the RPA (discussed in results section).
- Identify contaminant sources and contaminant of potential concern (COPC) responsible for impacts (discussed in results section).
- Assess risk from sources and to receptors in five areas; four sub-catchments on the mine site and offsite receptor sites on Magela and Gulugul Creek using the likelihood and consequence descriptors described below and the standard Rio Tinto risk classification matrix.

2.1 Source-pathway-receptor conceptual model

The conceptual underpinning was derived from a range of previous conceptual models for various solute pathways that were developed over decades of environmental research and refined during the more recent stakeholder ecological risk assessment for mine closure (Pollino et al. 2013; Bartolo et al. 2013). While those models were developed to identify assessment end points and knowledge gaps, the focus of the integrated conceptual model for this assessment was the influence of the contaminant sources on values.

Figure 2 shows the integrated source-pathway-receptor conceptual model for this assessment along with the assessment methods used and what aspects were included or excluded from this risk assessment:

- 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.
- Grey box shows the end points being assessed.
- Solid green boxes show the assess method used (i.e. exposure concentration versus guideline value).
- Boxes outlined in dashes and filled with green stripes show issues that are not included in this assessment.

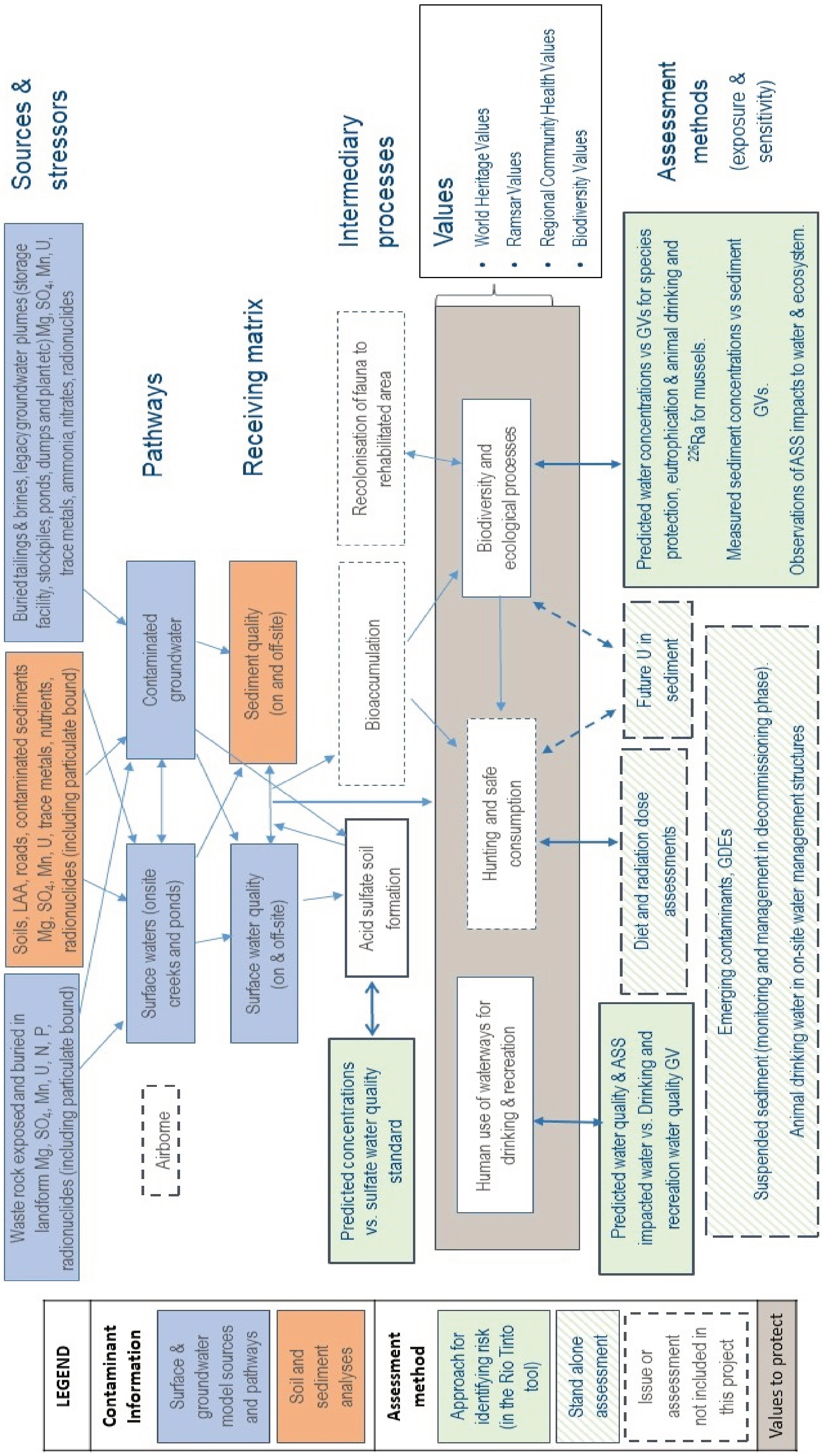

Figure 2 **Aquatic source-pathway-receptor model and risk assessment approach (Iles & Rissik 2021)**

2.2 Exposure evidence

Monitoring data provided evidence of current exposure to contaminants. Future concentrations of 20 COPC are based on a surface water model (SWM; Water Solutions 2021) for the closure strategy described in ERA (2020). The model is conservative with respect to contaminant behaviour, i.e. conservation of mass applies whereas attenuation would occur for reactive elements.

Pit tailings flux (PTF) removal in the model assumes 95% in Pit 3 and 99% in Pit 1. The amount of PTF to be removed has now increased as a response to the findings of this work within the process to reduce impacts to ALARA on the RPA. The process is described in Iles (2022).

Predicted concentrations in surface water are based on surface water inputs and the median (P50) groundwater loads entering the surface water system. The timing and magnitude of the P50 peak loads of magnesium coming from different contaminant sources in each ground-watershed (GWShed) are shown in Figure 3. Columns for each of these major sources, and other minor sources, were added to the risk register spreadsheet so threats could be tagged for applicable source allowing risks to be summarised according to source.

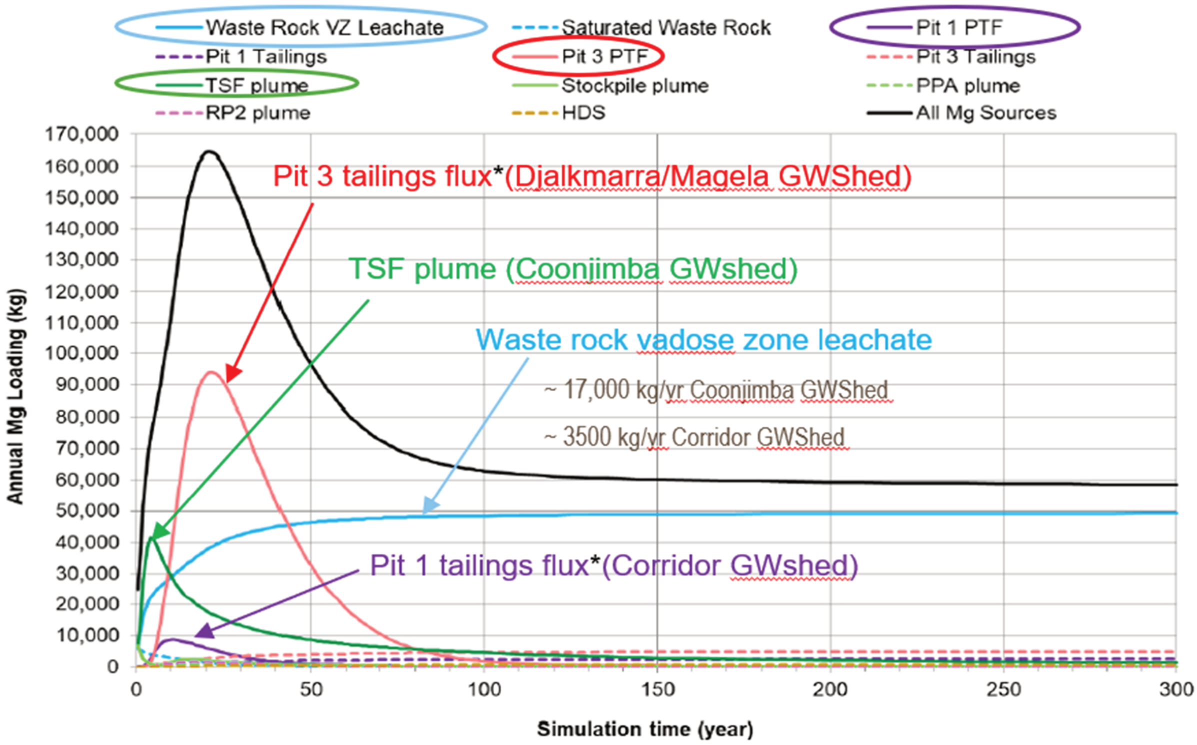

Figure 3 Timing and magnitude of P50 magnesium loads from individual sources across the site (INTERA 2021)

As the SWM scenarios used P50 groundwater loads as model inputs the likelihood of exposure occurring was classified as 'Probable' based on the standard Rio Tinto descriptors for likelihood.

The SWM outputs are probability distribution of future concentrations. An example of an output for concentrations of magnesium (Mg) for a control site and two exposed sites is provided in Figure 4. These were used, along with GV, to provide sliding scale matrix consequence descriptors described below.

Location	Probability of predicted concentration	Predicted concentrations (mg Mg/L) for various scenarios				
		No Mine scenario	All GWSheds peak	Georgetwon GWShed peak	Coonjimba GWShed peak	10,000 year combined GWSheds
Control site 1	1%	0.81	0.81	0.81	0.81	0.81
	10%	0.81	0.81	0.81	0.81	0.81
	25%	0.80	0.80	0.80	0.80	0.80
	50%	0.75	0.75	0.75	0.75	0.75
	75%	0.39	0.39	0.39	0.39	0.39
	90%	0.27	0.27	0.27	0.27	0.27
	99%	0.20	0.20	0.20	0.20	0.20
Exposed site 1	1%	0.81			1.54	1.13
	10%	0.81			1.41	1.07
	25%	0.80			1.36	1.05
	50%	0.77			0.93	0.80
	75%	0.34			0.46	0.40
	90%	0.25			0.27	0.26
	99%	0.20			0.20	0.20
Exposed site 2	1%	0.90	1.93		1.50	1.06
	10%	0.81	1.48		1.19	0.96
	25%	0.75	1.33		1.14	0.87
	50%	0.62	1.20		1.01	0.73
	75%	0.51	0.73		0.69	0.58
	90%	0.30	0.35		0.34	0.32
	99%	0.19	0.20		0.20	0.19

Figure 4 Example of quantitative predictions of post-closure peak concentrations from the surface water model for five scenarios

2.3 Guideline values and consequence descriptors

GV to compare against concentrations were: (i) site-specific GV (Supervising Scientist 2021a–2021f; Doering et al. 2019), (ii) default GV from ANZG (2018) for sediments and for water, and (iii) national drinking and recreational water GV. Descriptors were developed for consequences to human and environmental health and for extent and duration. The standard Rio Tinto descriptors for community trust, compliance and reputation and likelihood were used. Consequence descriptors for the primary environmental consequences are shown in Table 1.

In assessing the risk posed by the contaminants the frequency of a GV exceedance and the location of the exceedance needed to be considered. An example of consequence descriptors using exceedance frequencies and GV for different levels of species protection for magnesium and uranium is provided in Figure 5. The same approach was used for all COCP for which species protection GV are available.

In keeping with the approach used in the standard Rio Tinto descriptors for environmental consequences, offsite exposures are rated as having higher consequences compared to the same exposure onsite.

Acronyms used in Table 1 for sediment consequence descriptors are default guideline value (DGV), site-specific guideline value (SSGV), high guideline value for sediment (GV-H), lowest observed effects concentration (LOEC). The value for each of these varies depending on the COPC in question and were derived from ANZG (2018) and Supervising Scientist (2021f). Reference to analyte values < X%ile refers to the percentiles of the concentrations in background reference sites (Kumar & Reid 2021). Acidity hazard was determined for soils using the approach of Dear et al. (2014); not reported here.

Table 1 Descriptors for likelihood and primary environmental consequences (Iles & Rissik 2021)

PRIMARY CONSEQUENCES	Very Low	Low	Moderate	High	Very High
Human health & culture consequences: water quality vs drinking and recreational GVs					
Percentage of time water quality restricts use of water body	1%	10% onsite	25% onsite 10% offsite	50% onsite 25% offsite	>50% onsite >25% offsite
Ecosystem consequences*: water quality vs water and sediment quality GVs					
Water - predicted WQ vs species protection level*	Choose from tab "Species consequence descriptors"				
ON-SITE Sediment metals (acidity hazard < medium)	All analytes < DGV or U SSGV	One or more analytes > DGV or U > SSGV (100)	One or more analytes > 2 DGV or U > LOEC (200)	One or more analytes > GV-H or U > low threshold bacterial comm change (400)	One or more analytes > 1.5 GV-H or U > high threshold bacterial comm change (1000)
OFF-SITE Sediment metals (acidity hazard < medium) ON-SITE Sediment metals (acidity hazard ≥ medium)	All analytes < 99.7%ile	All analytes < DGV or U SSGV	One or more analytes > DGV or U > SSGV (100)	One or more analytes > 2 DGV or U > LOEC (200)	One or more analytes > GV-H or U > low threshold bacterial comm change (400)
OFF-SITE Sediment metals (acidity hazard ≥ medium)	All analytes < 95%ile	All analytes < 99.7%ile	All analytes < DGV or U SSGV	One or more analytes > DGV or U > SSGV (100)	One or more analytes > 2 DGV or U > LOEC (200)
Ecosystem based on data types not covered above					
Consequences to environmental values	Negligible impact on environmental values and/or connected waters/ other parts of the environment; no detectable impacts on species	Localised short-term damage to environmental values and/or connected waters/other parts of the environment	Short-term damage to environmental values and/or connected waters/ other parts of the environment; short-term impacts on species	Long-term damage to environmental values and/or connected waters/ other parts of the environment; significant impacts on listed species	Irreversible damage to the environmental values of an aquatic ecosystem and/or connected waters/other parts of the environment; localised species extinction
Extent of contamination and/or impact					
Extent-Sediment/Soil contamination above GVs *(individual results not means)*	Contamination above threshold only in few small locations in catchment	Contamination above threshold is in several small locations throughout catchment	Contamination above threshold is moderate within onsite billabongs/areas close to main creeks on the RPA	Contamination above threshold is extensive within onsite billabongs areas close to main creeks on the RPA. Few occurences off the RPA (pathway from mine not ruled out).	Contamination above threshold several occurences off the RPA (pathway from mine not ruled out)
Extent-Water contamination (eg from ASS events or predicted above GV)	Confined to onsite tributaries	Confined to onsite tributaries and billabongs	Extends beyond confluence of billabong in main creek channel	Extends to RPA boundary sites	Extends to off site billabongs
Duration of poor water quality					
Predicted water quality or ASS driven deterioration	Weeks	Months	Years (CJP scenario)	Decades (AWP and GTP scenarios)	Centuries (A10k scenario)

Probability of predicted concentration

Site Specific Guideline Values based on ecotoxicity testing of local species

Parameter	Species protection level (%)			
	99	95	90	80
Magnesium (mg/L)	2.9	5.7	9.4	19

Likelihood of exposure			Consequence to species				
Exceedance Probability	OFFSITE	ONSITE	Very Low	Low	Medium	High	Very High
	≤1%	≤1%	No SPL exceedance	1% exceedance any SPL	NA	NA	NA
		>1-10%	0 - 2.9	2.91 - 5.7	5.71 - 9.4	9.41 - 19	>19
	>1-10%	>10-25%	0 - 2.9	NA	2.91 - 5.7	5.71 - 9.4	>9.4
	>10-25%	>25-50%	0 - 2.9	NA	NA	2.91 - 5.7	>5.7
	>25%	>50%	0 - 2.9	NA	NA	NA	>2.9

Higher consequence ranking for equivalent concentrations off the RPA

Predicted URANIUM in water vs 99, 95, 90 and 80% species protection levels of 2.8, 8.3, 13, 23 µg/L.							
Likelihood of exposure			Consequence to species				
SWM Predicted concentration Probability	OFFSITE	ONSITE	Very Low	Low	Medium	High	Very High
	≤1%	≤1%	0 - 2.8	> any SPL	NA	NA	NA
	°	>1-10%	0 - 2.8	2.9 - 8.3	8.4 - 13	14 - 23	>23
	>1-10%	>10-25%	0 - 2.8	NA	2.9 - 8.3	8.4 - 13	>13
	>10-25%	>25-50	0 - 2.8	NA	NA	2.9 - 8.3	>8.3
	≥25%	>50%	0 - 2.8	NA	NA	NA	>2.8

Figure 5 Sliding scale consequence matrix for species protection consequences for magnesium and uranium (Iles & Rissik 2021)

2.4 Risk classification and scores

The risks were classified into four classes using the standard Rio Tinto classification matrix (Table 2). Columns to include extent and duration were added to the risk register template. Likelihood and primary consequence classifications were assigned values of 1 through to 5 for the lowest to the highest classification and after risks were assessed overall scores were determined by multiplying the scores for likelihood with the primary environmental consequences.

Table 2 Rio Tinto risk classification matrix used by ERA

Likelihood	Consequence severity				
	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

3 Results

Using the source-pathway-receptor approach the threats were combined to produce 57 threats and information was available to evaluate 51 of those, 21 of which occur in year 10,000.

The breakdown of the 51 evaluated risks is:

- 29 Class I (low) risks.
- 7 Class II (moderate) risks.
- 5 Class III (high) risks.
- 10 Class IV (critical) risks.

For the 10,000-year assessment there were:

- 19 Class I (low risks).
- 2 Class IV (critical risks).

Low (Class I) risks are those below the risk acceptance threshold and do not require active management. Moderate (Class II) risks are close to acceptance thresholds and require active monitoring to ensure they remain at that level. High risks require proactive management and critical risks are those which require additional treatment.

Modifications to the risk register spreadsheet enable risks to be viewed in a range of categories including by location, by environmental value and by contaminant source. These are shown in Figure 6–8 with the latter showing the risk classification resulting from exceeding GVs for protection of people and the ecosystem. Information on which COPC are causing the risks is also available (not shown). This level of information allows a thorough understanding of cause and effect which supports decision-making about any resulting management responses. The dominant sources of contamination are identified from the groundwater shed source load plots Figure 3, the timing of these sources entering the surface water system is also known from that plot.

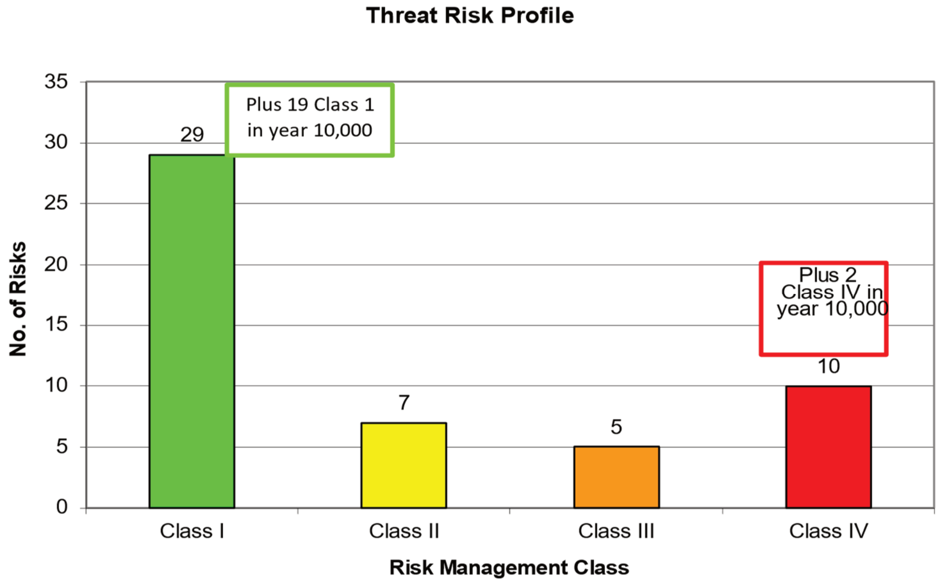

Figure 6 Risks by management class (Iles & Rissik 2021)

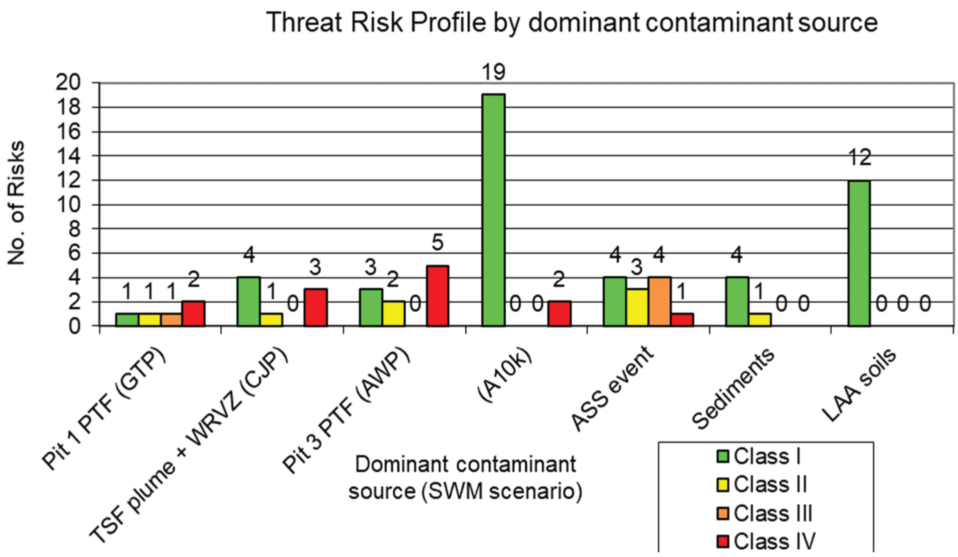

Figure 7 Risks by dominant contaminant source (Iles & Rissik 2021)

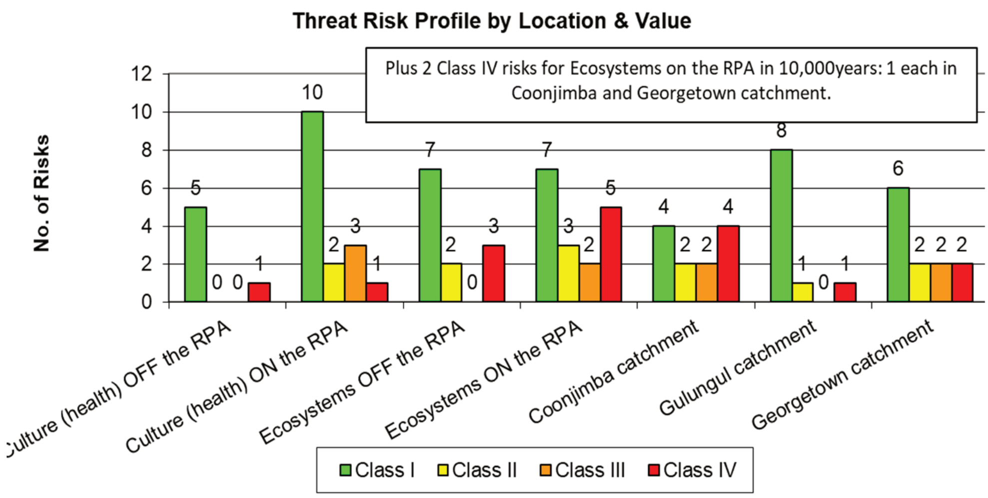

Figure 8 Risks by value and location (risks in each catchment are also counted in the columns for on or off the RPA) (Iles & Rissik 2021)

Actions are triggered for class 3 and class 4 risks. ERA has commenced priority actions to: (i) understand the risks in more detail, (ii) improve confidence in model predictions, (iii) identify, model and assess alternative management scenarios, and (iv) commence major studies on mitigation options for the largest contaminant source. Some of these actions have already resulted in changes to the closure plan to improved water quality coming from the closed mine demonstrating the usefulness of the process.

The risk assessment process and results were reported to stakeholders in 2021 (Iles & Rissik 2021). Through various technical committees ERA is working with, and involving, stakeholders in this process. Feedback on the report is guiding this and will assist improving future risk assessments to evaluate closure plans as they are updated. The role of this risk assessment in the approach to developing water quality closure criteria and triggering consideration of alternative management options is discussed in Iles (2022).

4 Conclusion

Several decades of research, monitoring and modelling has produced information on exposure and sensitivity of the ecosystem and people to current and future contaminants from Ranger Mine. This information was used to tailor likelihood and consequence descriptors to use in a risk assessment to qualify the risk from 20 COPC to community values at locations on and off the RPA.

Using sliding scale matrices of contamination exposure and GV exceedance likelihood for different levels of species protection allowed the consequences and risks to be understood in context of the different requirements for environment protection on and off the RPA. Similar consequence matrices using GV for drinking and recreation water quality and sediment quality provided an understanding of the risk to people and benthic communities.

The source-pathway-receptor framework used allowed the risks at each site to be linked to the responsible contamination source. Drinking, recreation, and species protection GV for several of the 20 COPC assessed were exceeded at locations on and off the RPA at frequencies that resulted in class 3 or 4 risks triggering a review the closure plans for the responsible contaminant sources. The inclusion of descriptors for duration and extent of contamination and impact and a scoring system allowed the risks to be numerically ranked providing more insight than the standard four classes of risk normally used. Thus, the highest priority contaminants and sources which needed alternative management options, or further investigation, were identified and actions developed.

High priority actions identified and commenced included a review of: (i) key modelling assumptions influencing predicted concentrations of those COPC linked to unacceptable risks, (ii) targets for extraction and treatment of process water expressing from buried tailings, and (iii) decommissioning plans for the tailings storage facility.

Additionally, the risk assessment results provide added support and informed the scope for several activities already planned; particularly those aimed at improving confidence in the predictive models used and the understanding of ecosystem vulnerability and sediment contamination.

The water quality reported here does not represent the final water quality expected. Outcomes from model reviews and predictions of contaminants from alternative contaminant management strategies will be assessed iteratively using the same approach discussed here to develop a final closure plan that results in management objectives for water on and off the RPA being achieved.

Acknowledgement

The authors acknowledge the Mirarr people, the Traditional Owners of the land on which the Ranger Mine is situated, and whose quality of reconnection to land and water relies on the successful rehabilitation of the mine site and protection of the surrounding environment.

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