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Option analysis to reduce solute loading to surface water receptors from a Ranger mine tailings storage facility

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Abstract

The Ranger mine above-ground tailings storage facility (TSF) safely held tailings and process water through multiple expansions over more than 40 years. Given that the mine is surrounded by, but separate from, the Kakadu National Park, Energy Resources of Australia (ERA) and stakeholders have sought to understand the migration of TSF-derived groundwater solutes and the risks posed to surface water receptors.

ERA and stakeholders are examining potential impacts to surface water concentrations from the TSF and other mine-related solute sources after mine closure. In 2020, INTERA estimated the predictive uncertainty in post-closure loading from 20 groundwater solutes to surface water through a calibration-constrained groundwater uncertainty analysis. A surface water model used the predicted peak groundwater solute loads at three probability values to predict surface water concentrations, which suggested additional mitigation may be beneficial before closure. Design of the TSF deconstruction and evaluation of mitigation options to reduce post-closure groundwater loading are underway.

A preliminary qualitative assessment of multiple remediations options led to a quantitative assessment of five options using numerical modelling. The modelling work, developed in consultation with stakeholders, provided post-closure solute loads for use in assessing the effectiveness of the five remediation options. The results indicate that the greatest reduction in groundwater loading will most likely be achieved with a clay cap to mitigate the plume in the weathered rock beneath the TSF footprint. Combinations of options will continue to be investigated to better understand the potential for further reducing loads. This study is the first step in ERA's development of mitigation options for reducing surface water concentrations from the TSF and other nearby mine-related sources.

Keywords: *groundwater, tailings, plumes, remediation options*

1 Introduction

The former Ranger uranium mine, owned by Energy Resources of Australia Ltd (ERA), operated from 1980 to 2021. The mine, located 250 km east of Darwin and 11 km east of the township of Jabiru in Australia's Northern Territory, is contained within a lease area called the Ranger Project Area (Figure 1). The Ranger Project Area is separate from and surrounded by Kakadu National Park and is on the traditional lands of the Mirarr people.

The Ranger mine workings comprise Pit 1, Pit 3, the tailings storage facility (TSF), waste rock stockpiles and retention ponds (Figure 2). Mining in Pit 1 occurred from 1980 to 1994 and in Pit 3 from 1997 to 2012.

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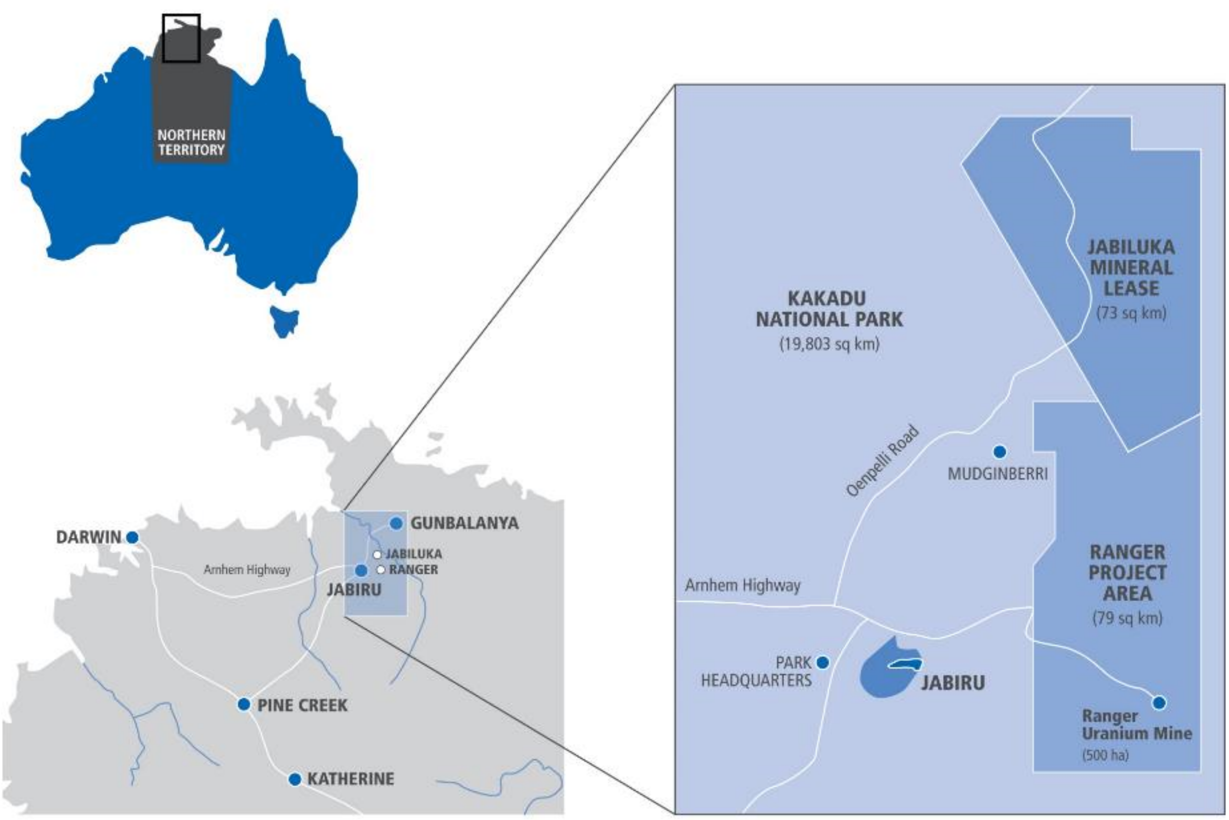


Figure 1 Ranger mine location

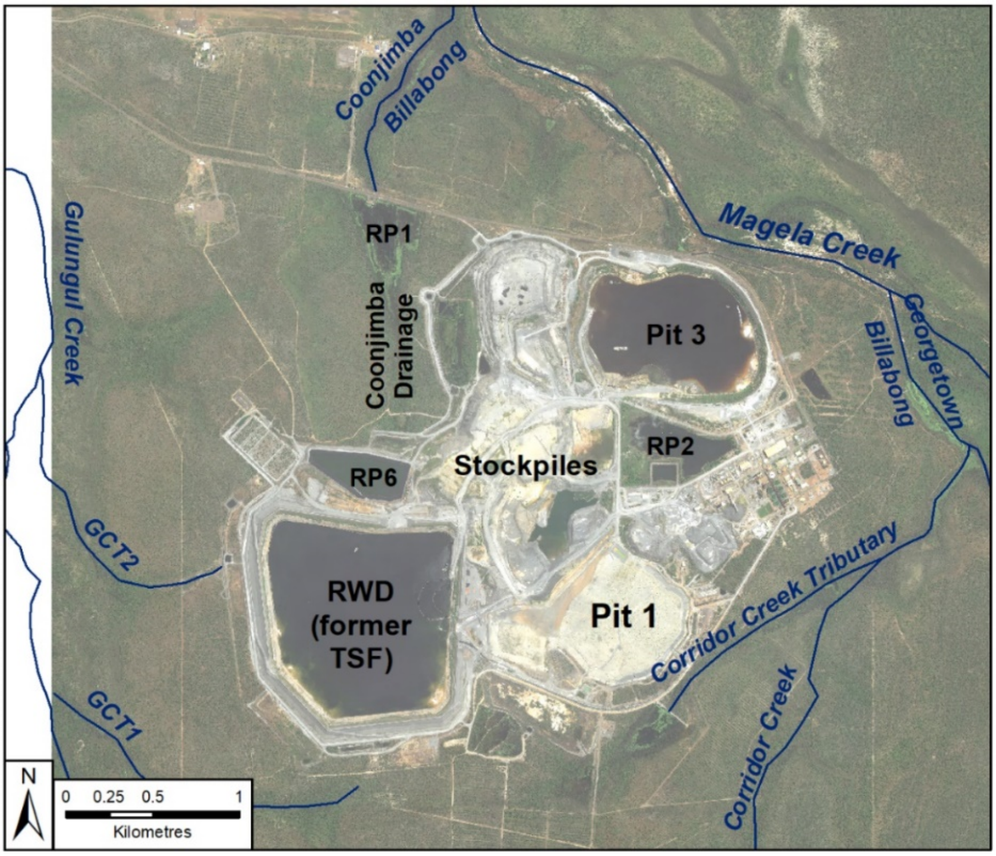


Figure 2 Location of the Ranger water dam at the Ranger mine

The above-ground TSF was used for interim tailings and periodic process water storage during mine operations. All tailings have been transferred to the pits for final disposal. Water management during site decommissioning includes process water storage in the former TSF, now renamed the Ranger water dam (RWD). The mine area is drained by Magela Creek and its tributaries (Gulungul and Corridor Creeks) and the Coonjimba drainage down historic Coonjimba Creek (Figure 2). Other surface waters include Coonjimba and Georgetown billabongs, along with minor Gulungul Creek tributaries GCT1 and GCT2 on the western and southern sides of the RWD.

ERA is currently decommissioning and rehabilitating the Ranger mine, which includes conducting work to secure regulatory approvals for RWD deconstruction and construction of the final landform. Incorporated into the approval applications are environmental assessments consistent with ERA's rehabilitation objective as outlined in the Environmental Requirements governing the Ranger Project Area. The Environmental Requirement specific to overall mine rehabilitation states:

> *'... the company must rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park…' (Commonwealth of Australia 1999, s 41).*

In 2020 the predictive uncertainty in post-closure loading from mine groundwater solutes to surface water was estimated through a calibration-constrained groundwater uncertainty analysis (INTERA 2021). A surface water model used predicted peak groundwater loads from the uncertainty analysis at three probability values to predict surface water concentrations for the 20 Ranger constituents of potential concern (COPCs) (Water Solutions 2021). A subsequent aquatic risk assessment (Iles & Rissik 2021) using the predicted surface water concentrations identified several COPCs, primarily magnesium (Mg) and sulphate (SO_4), that pose a risk to surface water receptors in the Coonjimba catchment (Figure 3).

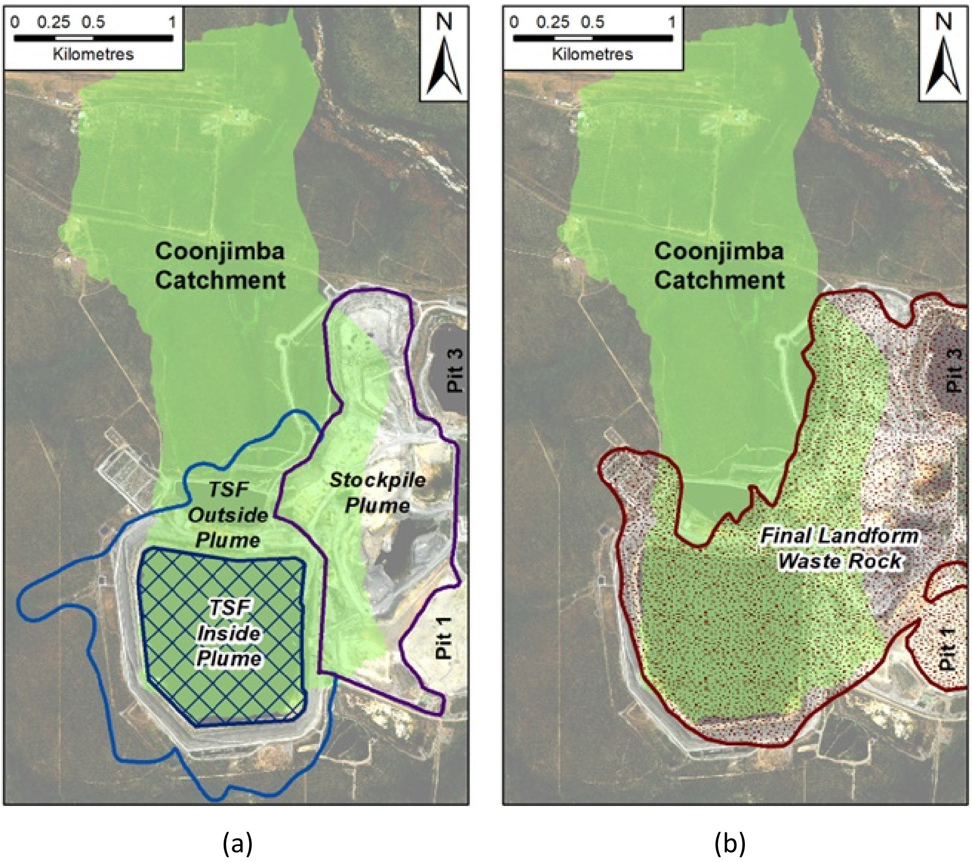


Figure 3 Coonjimba catchment (green shaded polygon) and location of the: (a) Upstream plume sources; (b) Binal landform waste rock with the vadose zone waste rock leachate and saturated zone waste rock upstream sources

Consistent with the rehabilitation objectives, ERA's decommissioning and closing of the RWD involves evaluating options to improve environmental impacts to surface water. The overarching closure objectives for the Ranger mine include that waters leaving the project area do not compromise achievement of the primary environmental objectives related to protection of the people, ecosystem, and World Heritage and Ramsar values of the surrounds, and that impacts within the project area are as low as reasonably achievable (Commonwealth of Australia 1999, s 41).

The primary contributor to surface water concentrations are COPCs in groundwater discharging to surface water bodies. Therefore, surface water impacts can be reduced by reducing COPC loads in the discharging groundwater. This study identified and evaluated potential remediation options to reduce groundwater loads to, and risk for downstream water bodies from, the RWD and other upstream sources in the Coonjimba catchment.

The upstream sources include the TSF plume in the weathered rock created by seepage of tailings porewater from the TSF and water seepage from the RWD, the plume underlying the historic stockpiles, leachate from the vadose zone in the landform waste rock (VZ WR leachate) and solutes in the saturated zone of the landform waste rock (SZ WR) (Figure 3). The TSF plume is divided into a TSF inside plume located beneath the RWD footprint and a TSF outside plume located outside of the footprint, resulting in a total of five upstream sources. Of these sources, only the VZ WR leachate is a constant source expected to persist for a long time.

The purpose of this study was to develop potential options for reducing groundwater loading, conduct a high-level assessment of all options, select the options most likely to be successful, and conduct numerical modelling to quantify the reduction in groundwater loading for the selected options. The results from this study were provided to ERA to assist in the decision-making process for designing and implementing remediation strategies to reduce surface water concentrations from upstream sources in the Coonjimba catchment to as low as reasonably achievable.

2 Methodology

The first step in this study consisted of developing potential remediation options to reduce groundwater loading from upstream sources in the Coonjimba catchment. An understanding of groundwater flow, transport and source terms, in the catchment provided the information needed to develop 10 potential remediation options. The options were selected based on expected reduction in loading from the three primary upstream sources: the TSF inside plume, the TSF outside plume and the VZ WR leachate. Options addressing the remaining two sources, the stockpile plume and SZ WR, were not developed because previous modelling of the site indicated that groundwater loading from these sources is minor.

Assessment of the remediation options consisted of a two-phase approach. Phase 1 consisted of a high-level evaluation of all potential options and Phase 2 involved a detailed evaluation of the options identified with Phase 1 as the most likely to be successful. The assessment focused on comparing reduction in the peak total load from all upstream sources combined and the results used as part of the technical performance assessment of each option.

Phase 1 consisted of a qualitative evaluation of each option's ability to reduce loading from the upstream sources. Insights from years of modelling the mine site along with preliminary modelling for several options facilitated the Phase 1 assessment. A matrix of option effectiveness on reducing the peak load from each source individually and all sources combined was developed. The purpose of Phase 1 was to qualitatively assess multiple potential remediation options without conducting detailed numerical modelling for each of the options. The results of this analysis were then inputted to a wider options evaluation process that assessed each option against multiple criteria beyond merely the ability of the option to reduce loading.

Phase 2 consisted of a quantitative assessment conducted for four options and one combination of options using numerical modelling. The selection of options for Phase 2 was based on the results of the Phase 1 evaluation as well as input from stakeholders. Five individual groundwater models were constructed to predict peak total COPC loads for each of the remediation options, along with a model simulating the conditions for no remediation. The purpose of Phase 2 was to provide quantitative data to ERA for further assessment of the options identified in Phase 1 as being the most effective.

3 Potential remediation options development

The potential remediation options considered were evaluated against their ability to reduce the peak total load from the upstream sources. Predictions of Mg loading from the 2020 site-wide numerical model (INTERA 2021) show the contributions of the different sources to the peak total Mg load. From highest to lowest, these are the TSF inside plume, the VZ WR leachate, the TSF outside plume, the stockpile plume and the SZ WR (Figure 4). Loading from the VZ WR leachate continues to increase with time because it is a long-term source. Loading from the other sources naturally decreases with time as they are depleted. Based on this breakdown, the list focused on remediation options that would target the three primary contributors to the peak total load: the TSF inside plume, the VZ WR leachate and the TSF outside plume. Remediation of the VZ WR leachate source, which will be constant for a long time, focused on flattening the loading curve or delaying the start of loading from this source. Option effectiveness on reducing the peak total load was also a primary consideration. Due to the small contributions to the peak total load from the stockpile plume and SZ WR sources, options specifically targeting only these two sources were not developed.

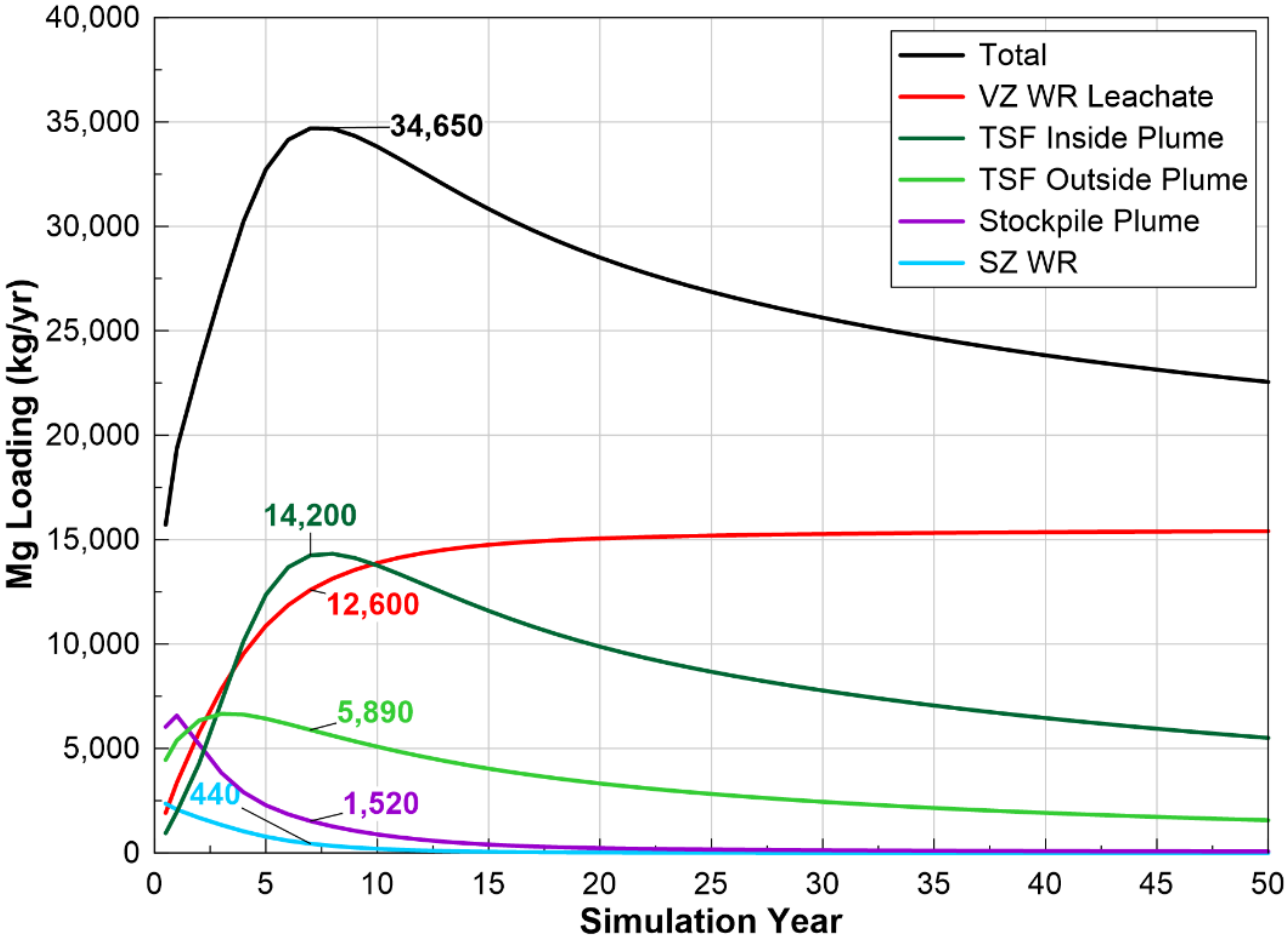


Figure 4 Magnesium loading from the upstream sources predicted by the 2020 Ranger site-wide groundwater model, with loads at the time of the peak posted

Understanding how solute mass exits the groundwater system in the numerical model also guided development of the potential remediation options. Boundary conditions are used in the model to represent locations of groundwater and mass discharge to surface water, groundwater evapotranspiration and groundwater exfiltration (discharge at ground surface). The RWD is a ring dam with a clay core in the walls and clay keyed into the underlying weathered rock. The portion of the walls remaining in the final landform will create a bathtub effect for groundwater within the RWD footprint area. Groundwater is recharged in the topographic high areas at the south end of the RWD and discharges via exfiltration at the topographic low area at the north end (Figure 5). Migration of the TSF inside plume is primarily upward into the overlying waste rock where it then exfiltrates in the low area inside the RWD. About half of the mass from the VZ WR leachate contributing to loading also exfiltrates in this same area. Outside of the RWD, the large contrast in permeability (four orders of magnitude) between the final landform waste rock and the underlying weathered rock results in groundwater exfiltration along the margin of the final landform (Figure 5). Most of the mass that discharges at this margin is sourced from the TSF outside and stockpile plumes, SZ WR and VZ WR leachate. All mass exiting boundary conditions, including that by groundwater exfiltration, is assumed to immediately discharge to surface water bodies in the calculation of mass loading.

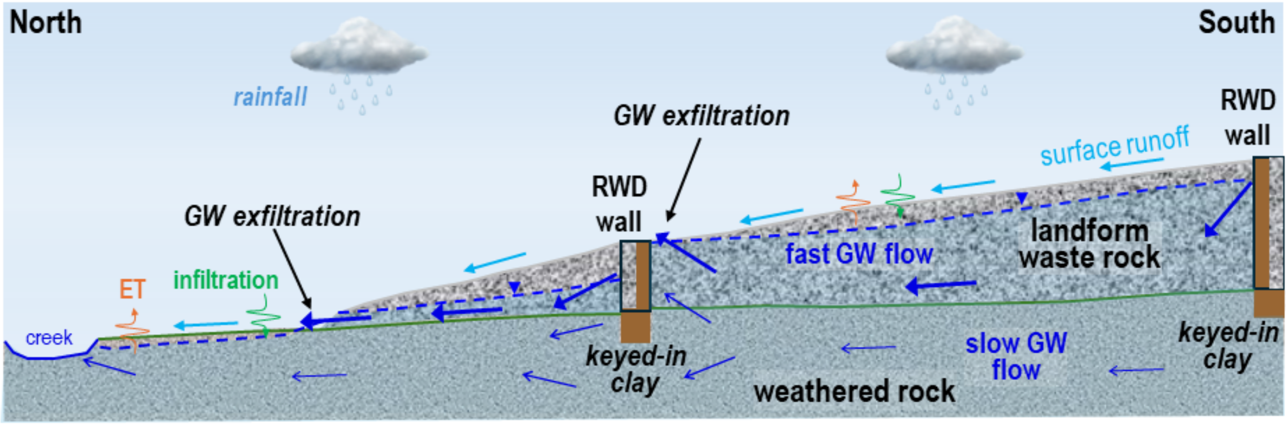


Figure 5 Schematic cross-section with vertical exaggeration showing areas of groundwater exfiltration at the north Ranger water dam (RWD) wall and toe of the final landform north of the RWD (ET = evapotranspiration; GW = groundwater)

Ten potential remediation options were identified and broadly divided into type B (waste rock movement or treatment), type C (groundwater capture and treatment) and type D (groundwater movement) (Table 1). Bolded options in the table were carried through to the Phase 2 assessment. The condition of no remediation was used as a baseline to gauge the effectiveness of the remediation options.

Table 1 Potential remediation options

Option	Option description
B1	**Install a 1 m-thick clay cap on the Ranger water dam (RWD) footprint (Figure 6a) using material from the deconstructed RWD walls**
	Target restricting upward groundwater flow and constituents of potential concern (COPCs) migration from the tailings storage facility (TSF) inside plume
B2	Reduce the hydraulic conductivity (K) of the saturated landform waste rock in the vicinity of the RWD (Figure 6b) by mixing clay material from the deconstructed RWD walls into the waste rock
	Target slowing of solute migration in the waste rock to flatten the loading curves from the vadose zone in the landform waste rock (VZ WR) leachate and TSF inside plume sources
B3	Decrease the vadose zone thickness in the landform waste rock in the vicinity of the RWD (Figure 6b)
	Target decreasing of concentrations by reducing residence time in the VZ WR and loadings from the VZ WR leachate source term
B4	Reduce groundwater recharge in the landform waste rock in the vicinity of the RWD (Figure 6b) by a factor of 10
	Target reducing the amount of groundwater recharge in the final landform waste rock that quickly discharges as groundwater exfiltration to flatten the loading curves from the VZ WR leachate and TSF inside plume
C1	**Capture groundwater from the saturated landform waste rock inside the RWD footprint (Figure 6c)**
	Target capturing groundwater to reduce exfiltration at the north RWD wall (dark blue T zone depicted in Figure 6c) to delay loading from both the VZ WR leachate and TSF inside plume sources
C2	**Capture groundwater in higher-K hydrogeologic units north of the RWD (Figure 6c)**
	Target reducing loading from the TSF outside
C3	Capture shallow groundwater using the Sed2B sump (Figure 6c)
	Target intercepting shallow groundwater north of the RWD to capture COPCs in the TSF outside plume
C4	**Construct an interception system north of the RWD connecting existing interception systems (Figure 6c)**
	Target interception of groundwater to reduce loading from all sources
D1	Remove the clay core in a portion of the north RWD wall (Figure 6d)
	Target eliminating the bathtub effect and reducing groundwater exfiltration within the RWD to flatten the loading curve for the VZ WR leachate and TSF inside plume source terms
D2	Remove a portion of the keyed-in clay core below the north RWD wall (Figure 6d)
	Target increasing horizontal and decreasing vertical flow and transport from the TSF inside plume to reduce loading from this source

Options in bold were carried to the Phase 2 assessment

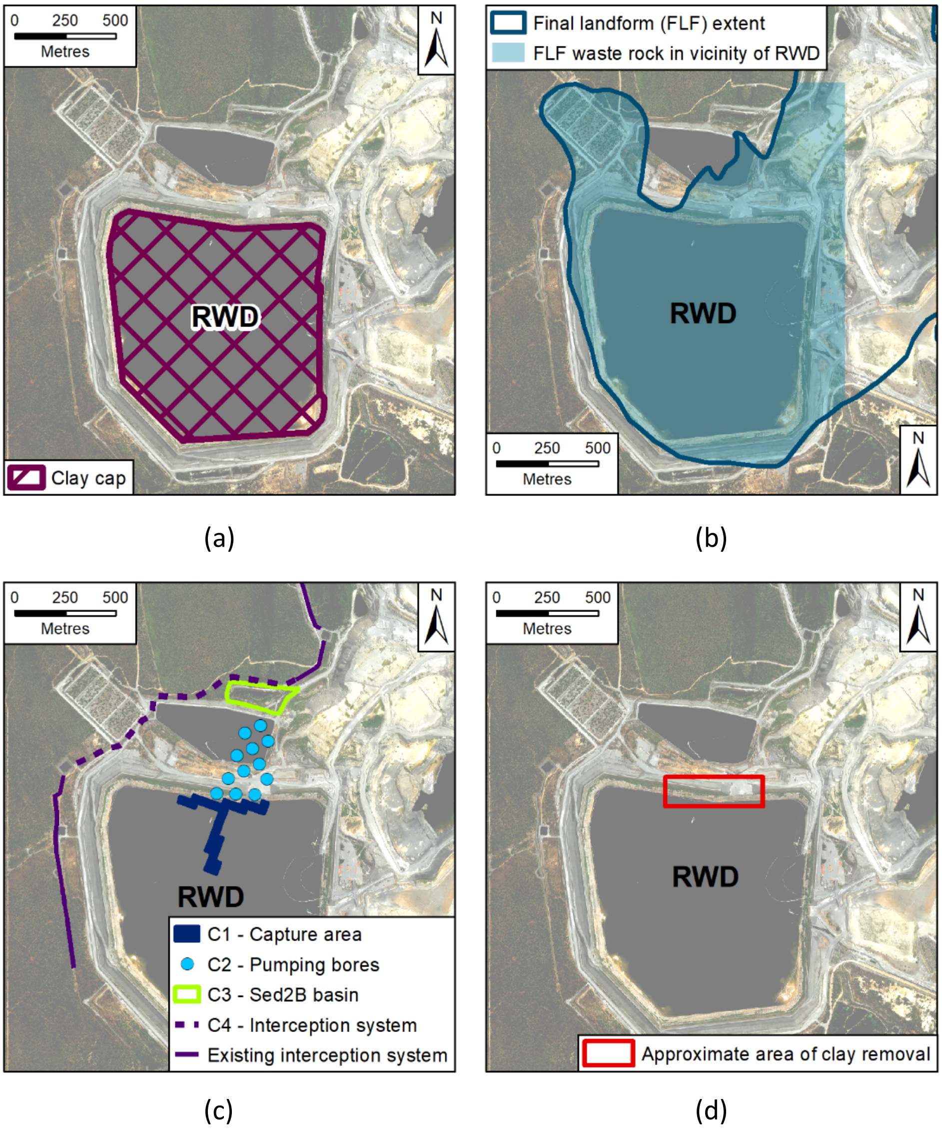


Figure 6 Location of the (a) clay cap for Option B1; (b) areas with changes to the landform waste rock for Options B2 to B4; (c) type C groundwater capture and treatment options; (d) areas with clay removal for the type D options

4 Results

4.1 Phase 1 assessment of remediation options

The objective of the Phase 1 assessment was a high-level evaluation of each option's effectiveness at reducing groundwater loading. This was considered for each upstream source individually and for all sources combined. Preliminary modelling of several options provided additional information to guide the assessment. The overall effectiveness of each option was based on expected reduction in the peak total load and categorised as high, medium, low, negligible or none.

Option effectiveness on reducing the peak total load ranged from negligible to medium. Each option primarily targeting a single source prevented any one option from having a high effectiveness since three of the upstream sources provide a large contribution to the peak total load. The most effective options either: (1) resulted in a large reduction in loading from one of the three major sources but little to no reduction in loading from the other two; (2) resulted in only a small reduction in loading from more than one of the major sources; or (3) increased the time to the peak total load but had little to no impact relative to no remediation on loading at the time of this later peak.

Table 2 shows the relative ranking of the options based on the Phase 1 assessment. Options B1, B3 and B4 ranked the highest, with a medium category. Options B2 and C1 were categorised as medium low and Option C2 as low. The lowest categories of negligible to low or negligible were assigned to Options C3, C4, D1 and D2.

Table 2 Summary of the effectiveness category from the Phase 1 assessment at the time of peak total load for the potential remediation options

Option	Category of option effectiveness at time of peak total load					
	VZ WR leachate[(a)]	TSF inside plume[(b)]	TSF outside plume[(b)]	Stockpile plume[(b)]	SZ WR[(b)]	All sources combined
B1[(c)]	None	High	None	None	None	Medium
B2[(c)]	Low	Medium	Negligible	Low	Negligible	Medium low
B3	High	None	None	None	Slight increase	Medium
B4[(c)]	High	Low	Medium	High	High	Medium
C1[(c)]	None to negligible	None to low	None to negligible	None	None	Medium low[(d)]
C2	None	Negligible	Low to medium	None	None	Low
C3	None	None	Negligible to low	Negligible to low	None	Negligible to low
C4	None	None	Low	Low	None	Negligible to low
D1	Negligible	Negligible	None	None	None	Negligible
D2	None	Negligible	None	None	None	Negligible

[(a)] Constant source for the first several hundred years after mine closure.
[(b)] An initial source at the end of mine closure.
[(c)] Preliminary modelling using the 2020 site-wide groundwater model conducted for this option.
[(d)] Increases the time to the peak, which decreases the peak total load, although the option has little impact on loading from the individual sources relative to no remediation at the time of the later peak.

The high-level assessment indicated that Options B2 and B3 would be just as effective as some of the other options. They were not carried into the Phase 2 evaluation, however, due to low scores against other assessment criteria including construction complexities.

4.2 Phase 2 assessment of remediation options

Review of the Phase 1 assessment results and discussions with ERA and stakeholders informed the selection of four remediation options and one combination of options to carry forward into the Phase 2 quantitative assessment. The selected options were B1 (clay cap), C1 (groundwater capture in the waste rock inside the RWD footprint), C2 (groundwater capture in higher-K units north of the RWD), C4 (interception system), and the combination of options B1 and C1 (referred to as Option F1).

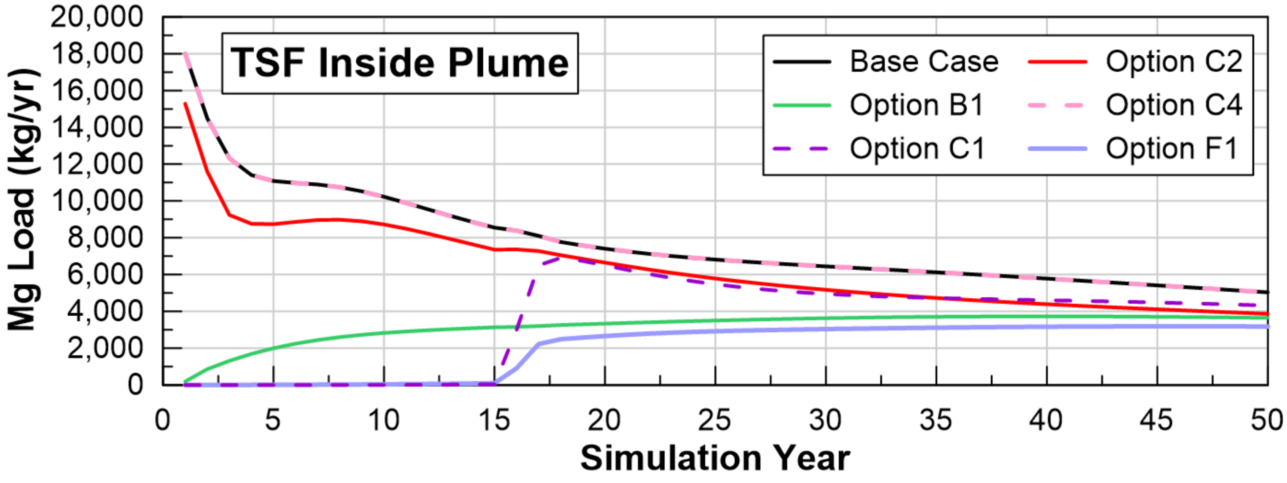
Separate groundwater models were constructed for the base case (no remediation) and for each of the five remediation options. The simulation time for all models was arbitrarily set at 100 years, a period more than sufficient to evaluate the impact of the remediation options on COPC loading. For Options C1, C2, C4 and F1, involving water extraction, 15 years of active remediation was assumed. Steady state flow and transient transport were simulated with the base case model. The option-specific models simulated both transient flow and transient transport.

The primary metric for evaluating option effectiveness was a reduction in the peak total load in the Coonjimba catchment. The peak total load is the maximum load from all upstream sources combined. The percent change in peak total load relative to that with no remediation provided the quantitative measure for assessing each option's effectiveness.

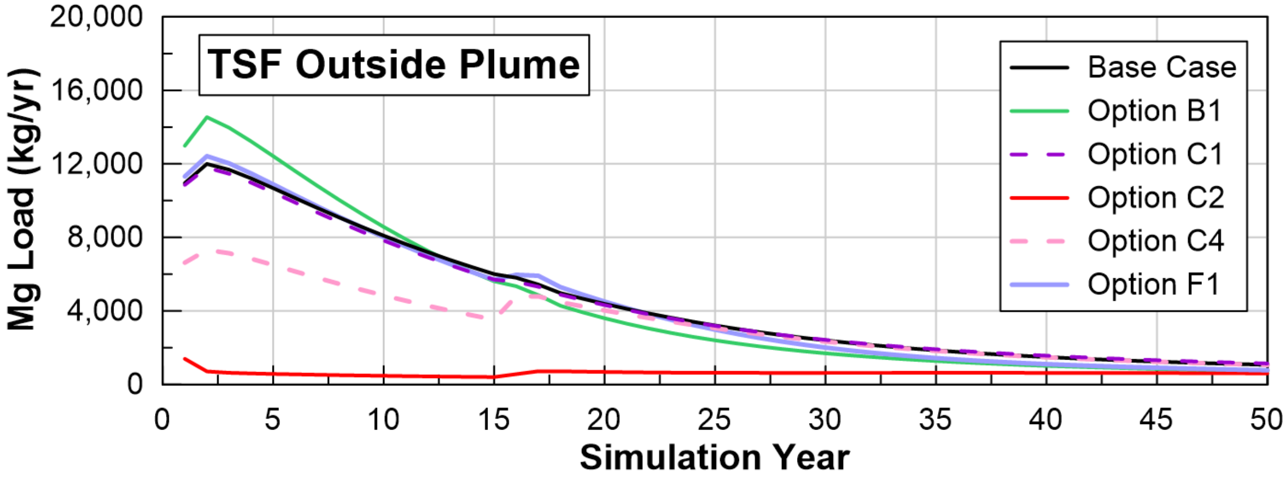
No single remediation option was found to be effective at reducing the COPC load from all upstream sources. As an example, Figure 7 shows the predicted Mg loading for the three primary sources contributing to the peak total load for the base case and each option. Mg loading from the TSF inside plume is most effectively reduced with the options that target this source (Options B1, C1 and F1). Both Options C2 and C4, which target the TSF outside plume, decrease the early time loading from this source. Option C2 provides the greatest reduction in loading from the TSF outside plume and maintains the reduction in the long term, unlike Option C4 that reverts to the base case load once the active treatment period ends. All options except Option B1 target the VZ WR leachate source term during the 15-year period of active remediation. Some decrease in loading from this source is observed for Options C2 and C4, while greater reduction occurs with Options C1 and F1. Once active remediation ends, loading from the VZ WR source term reverts to values consistent with no remediation. For the two upstream sources contributing little to the peak total load for most COPCs, Options C1 and F1 effectively reduced loading from the SZ WR, and a slight decrease in loading from the stockpile plume was achieved with Options C2 and C4.

The predicted total loading from all upstream sources combined over the 100-year simulation period for the base case and five remediation options is shown for Mg and SO_4 in Figure 8. The predicted reduction in peak total load for Mg and SO_4, and most other COPCs, is significant for all options except C4. The peak total load occurs at an early time for the base case. Options B1 and C2 are effective at decreasing this peak total load through slowing COPC migration from the TSF inside plume and removing mass from the TSF outside plume, respectively. The reduction in peak total load with Options C1 and F1 is driven by mass removal during the period of active groundwater capture and an increase in the time to the peak, when loadings from the initial sources are less.

Option C4 has no or little effect on decreasing the peak total load for Mg and SO_4, and most other COPCs, based on the model results. Much of the mass from the VZ WR leachate, TSF outside plume, stockpile plume and SZ WR exfiltrates at the edge of the final landform, represented as flux out of drain boundary conditions prior to reaching the interception system. Transport of the mass after exfiltration is not captured in the groundwater model. Based on the observed effectiveness of existing interception systems used at the mine, such a system north of the RWD will likely be more effective than predicted by the model.



(a)



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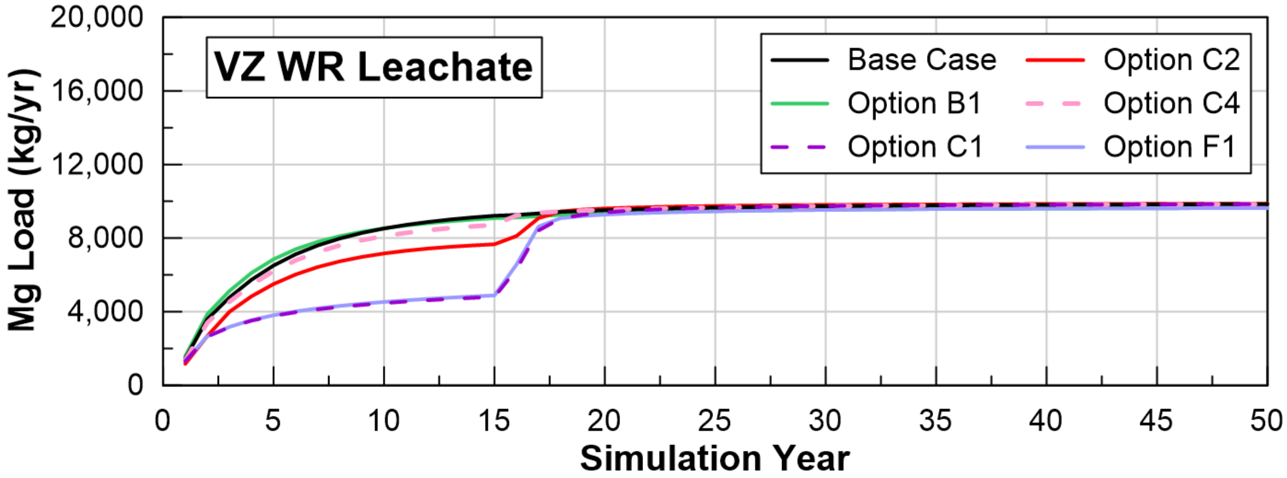
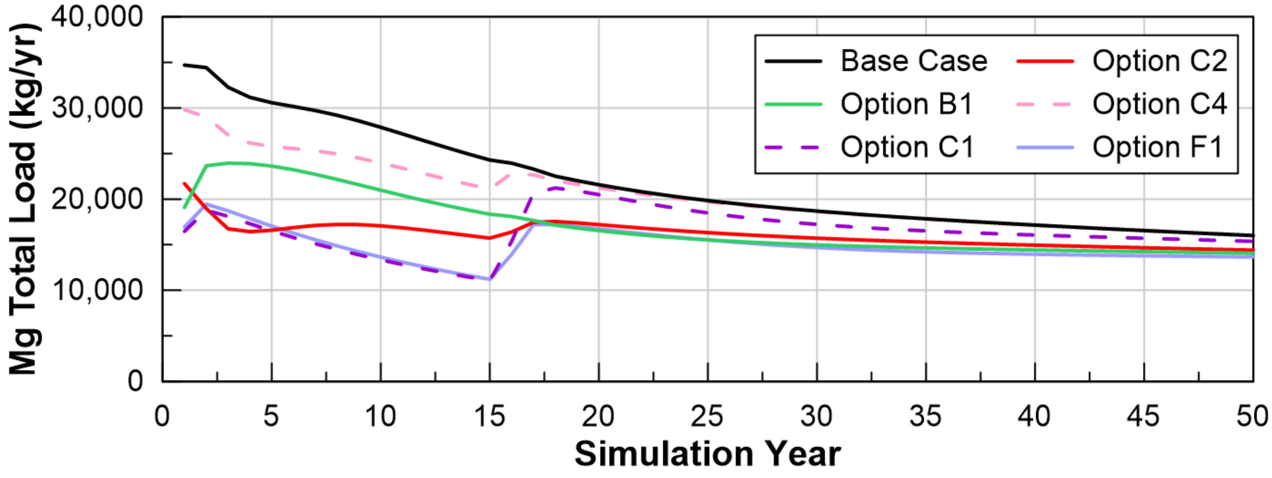
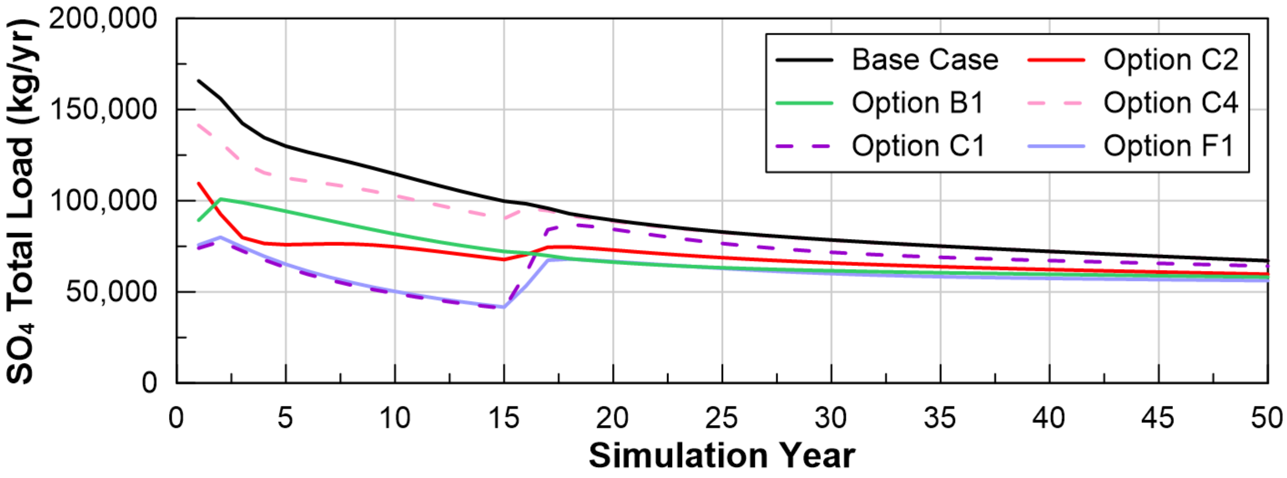


(c)

Figure 7 Magnesium loading from the (a) tailings storage facility (TSF) inside plume; (b) TSF outside plume; (c) vadose zone waste rock leachate for the base case and five remediation options



(a)



(b)

Figure 8 Comparison of (a) magnesium; (b) SO_4 total loading for the base case and five remediation options

At times greater than about 30 years, the total loading for all remediation options begins to converge on that of the base case. Without remediation, total loading declines with time because only the upstream VZ WR leachate is a continuous source. As the COPC mass in the other four sources becomes depleted, later time loading from those sources, and thus the total loading, naturally declines.

The percent change in peak total load in the Coonjimba catchment relative to the base case for each COPC and remediation option was calculated to quantitatively assess the effectiveness of the options (Table 3). In most cases the change is a reduction in peak total load, represented by a positive percentage. For some COPCs and options there is no change, represented by a percentage of zero. Also given in the table is the primary source or sources contributing to the peak total load with no remediation. The largest percent reduction for each COPC is indicated with bold text in Table 3.

The quantitative assessment shows a correlation between remediation option effectiveness at decreasing the peak load and the primary source contributing to the peak (Table 3). Option F1 is most effective for decreasing the peak total load for COPCs with the TSF inside plume as the primary source. Option B1 is equally or nearly as effective as Option F1 for many COPCs. The presence of a clay cap on the RWD footprint with these two options is highly effective at reducing early time loading from the TSF inside plume, which results in a lower peak total load. The most effective option at reducing the peak total load for COPCs with the TSF outside plume as the primary source or the TSF inside and outside plumes equally contributing to the peak total load is Option C2. Loading from the TSF outside plume is substantially reduced by the removal of mass during active groundwater capture and continues to remain low with this option.

Table 3 Percent decrease in peak total load in the Coonjimba catchment relative to no remediation

COPC	Percent decrease in peak total load (%)[a]					Primary source(s) without remediation
	Option B1	Option C1	Option C2	Option C4	Option F1	
Aluminium	81	64	14	0	**84**	TSF inside plume
Calcium	15	24	**46**	27	22	TSF outside plume
Cadmium	72	50	15	0	**75**	TSF inside plume
Chromium	80	65	15	0	**84**	TSF inside plume
Copper	81	65	13	0	**84**	TSF inside plume
Iron	**40**	11	34	3	**40**	TSF inside plume
Lead	80	63	14	0	**83**	TSF inside plume
Magnesium	31	39	37	14	**44**	TSF inside plume
Manganese	79	62	17	0	**82**	TSF inside plume
Nickel	**51**	26	36	5	**51**	TSF inside plume
Nitrate-nitrogen	16	13	**42**	3	16	TSF inside/ outside plumes
Total phosphorous	74	54	15	0	**78**	TSF inside plume
Polonium-210	81	65	14	0	**84**	TSF inside plume
Radium-226	16	28	**44**	16	28	TSF outside plume
Selenium	78	59	17	0	**81**	TSF inside plume
SO_4	39	48	34	15	**52**	TSF inside plume
Total ammonia nitrogen	74	56	16	0	**75**	TSF inside plume
Uranium	15	**21**	10	5	**21**	Stockpile plume
Vanadium	50	42	19	5	**55**	TSF inside plume
Zinc	38	42	**51**	17	49	TSF inside/ outside plumes

[a] Maximum percent reduction indicated with bold text

Considering all COPCs together, the reduction in peak total load is only slightly less for Option B1 than for Option F1 for most COPCs. Option C1 is effective at decreasing the peak total load for all COPCs because it removes mass during the period of active groundwater capture and increases the time to the peak when loadings from the initial sources are less. For COPCs where Option C2 results in the greatest reduction in peak total load there is generally a fairly large difference in the effectiveness of this option relative to the other options. The model predicts Option C4 will have little effect on decreasing the peak total load for all COPCs. However, the transport of mass exfiltrating at the north RWD wall and edge of the final landform waste rock to surface water is not captured in the model, resulting in an underestimation of Option C4's performance.

Table 4 summarises the option most effective at decreasing the peak total load for each COPC and the predicted reduction in the peak total load with that option, which is the maximum reduction considering all options. No single remediation option is the most effective for all COPCs. However, the maximum decrease in peak total load is predicted with one of two options (either Option F1 or Option C2). Option F1 is predicted to be most effective at reducing the peak total load for 16 COPCs whereas Option C2 is predicted to be most effective for four COPCs. Option B1 is just as effective as Option F1 at decreasing the peak total load for two COPCs and Options F1 and C1 are equally effective at reducing the peak total load for one COPC.

Table 4 Most effective option and associated maximum percent reduction in the peak total load for each constituent of potential concern

COPC	Most effective option	Predicted maximum reduction (%)
Aluminium	F1	84
Calcium	C2	46
Cadmium	F1	75
Chromium	F1	84
Copper	F1	84
Iron	B1/F1	40
Lead	F1	83
Magnesium	F1	44
Manganese	F1	82
Nickel	B1/F1	51
Nitrate-nitrogen	C2	42
Total phosphorous	F1	78
Polonium-210	F1	84
Radium-226	C2	44
Selenium	F1	81
SO_4	F1	52
Total ammonia nitrogen	F1	75
Uranium	C1/F1	21
Vanadium	F1	55
Zinc	C2	51

The predicted maximum reduction in peak total load is not the same for all COPCs. A high reduction (≥ 75%) is predicted for 10 COPCs, a medium reduction (40 to 60%) is predicted for nine COPCs and a low reduction (≤ 25%) is predicted for one COPC.

5 Conclusion

The benefit of additional mitigation for sources in the Coonjimba catchment was indicated by previous groundwater and surface water modelling, followed by an aquatic risk assessment that identified several COPCs that pose a risk to downstream water bodies. Consistent with rehabilitation objectives, ERA is evaluating options for reducing groundwater load to surface water from upstream sources in the catchment during decommissioning and closing of the RWD to improve the environmental impacts on surface water. The overarching closure objectives of the Ranger mine include that waters leaving the project area do not compromise achievement of the primary environmental objectives related to protection of the people, ecosystem, and World Heritage and Ramsar values of the surrounds, and that impacts within the project area are as low as reasonably achievable (Commonwealth of Australia 1999).

Ten potential remediation options were identified (Table 1) to reduce groundwater loading from upstream sources in the Coonjimba catchment. Development of the options was based on insights from previous modelling, a review of the primary sources contributing to the peak total load, and the locations of groundwater discharge. A Phase 1 high-level assessment indicated option effectiveness at reducing the peak total load ranging from negligible to medium. After discussions with ERA and input from stakeholders, four individual options (B1, C1, C2, and C4) and one combination of options (F1) were selected for a Phase 2 quantitative assessment with groundwater modelling.

Results of the Phase 2 assessment indicated that option effectiveness at decreasing the early time (< 30 year) loading differed for the different upstream sources. Reduction in loading from the TSF inside plume was achieved with Options B1, C1 and F1, and from the TSF outside plume with Options C2 and C4. Less loading from the VZ WR leachate and SZ WR was achieved with Options C1 and F1 during the period of active remediation. Options C2 and C4 slightly decrease loading from the stockpile plume. At late time (> 30 year) the loading for all sources converged near that for no remediation. Most of the sources are initial sources that gradually reduce their contribution to the total load with time and without remediation. One source (the VZ WR leachate) is a long-term constant source. Consequently, the contribution of this source to the total load at later time is not impacted by the remediation options.

The qualitative results from the Phase 1 assessment and quantitative results from the Phase 2 assessment were consistent. The incorporation of preliminary numerical modelling in Phase 1 ensured that the general conclusions on option effectiveness were similar to the specific conclusions from Phase 2. Insights from years of groundwater flow and transport modelling of the site used to guide the Phase 1 assessment also led to consistency in results between the two phases.

The maximum reduction in the peak total load was predicted with one of two options for all COPCs: the clay cap and groundwater capture in the waste rock inside the RWD footprint (Option F1) or groundwater capture in higher-K hydrogeologic units north of the RWD (Option C2). For most COPCs the F1 combination option was only slighter better than the clay cap option by itself (Option B1). These results suggest that the greatest reduction in groundwater loading will most likely be achieved with a clay cap to mitigate the plume in the weathered rock beneath the TSF footprint. Combinations of options will continue to be investigated to better understand how loads can be further reduced.

This study is the first step in ERA's development of mitigation options for reducing surface water concentrations from the TSF and other mine-related sources in the Coonjimba catchment.

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Disclaimer

This paper does not impose on or legally bind ERA to undertake any of the remediation recommendations and outcomes contained in it. Negotiations are underway to govern the ongoing rehabilitation requirements for ERA to rehabilitate, close and relinquish the Ranger Project Area.

References

Commonwealth of Australia 1999, *Atomic Energy Act 1953*.

Iles, M & Rissik, D 2021, *Ranger Closure Aquatic Pathway Receptors Risk Assessment*, Energy Resources of Australia, Darwin.

INTERA 2021, *Final Report: Groundwater Uncertainty Analysis for Ranger Mine Closure*, prepared for Energy Resources of Australia, Austin.

Water Solutions 2021, *Ranger Surface Water Model – Model Upgrade, Water Solutions*, Kenmore.