

Independent Monitor EIS REVIEW REPORT

MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

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**McArthur River Mine Overburden Management Project
EIS Review
EIS Review Report**



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Table of Contents

Chapters

Executive Summary.....	ES-1
1. Introduction.....	1-1
1.1 Scope.....	1-1
1.2 Risk Assessment	1-2
1.2.1 Introduction.....	1-2
1.2.2 Assessment of Likelihood.....	1-2
1.2.3 Key Project Risks	1-3
1.2.4 What Must be Addressed in the EIS Supplement	1-6
1.3 References.....	1-6
2. Geochemistry	2-1
2.1 Is the Information in the EIS Sufficient?	2-1
2.1.1 Comparison with Terms of Reference	2-1
2.1.2 Context	2-2
2.1.3 Overburden Geochemical Testing and Classification.....	2-3
2.1.4 Overburden Segregation and Handling	2-4
2.1.5 Current and Future Geochemical Hazards of OEFs.....	2-6
2.1.6 NOEF Management.....	2-9
2.1.7 SOEF, EOEF and WOEF Management	2-19
2.1.8 Tailings Storage Facility	2-19
2.1.9 Open Cut	2-21
2.1.10 Water Resource Impact Assessment	2-23
2.2 What Must be Addressed in the EIS Supplement?	2-23
3. Geotechnical.....	3-1
3.1 Is the Information in the EIS Sufficient?	3-1
3.1.1 Terms of Reference.....	3-1

3.1.2	General Discussion	3-1
3.1.3	Tailings Design and Management.....	3-2
3.1.4	OEF Design and Management.....	3-5
3.1.5	Tailings and OEF Borrow Areas	3-9
3.1.6	In Pit Dumping – Appendix N	3-10
3.1.7	Conclusion.....	3-10
3.2	What Must be Addressed in the EIS Supplement?	3-12
3.3	References.....	3-12
4.	Groundwater Management	4-1
4.1	Is the Information in the EIS Sufficient?	4-1
4.1.1	Groundwater Modelling Guidelines	4-2
4.1.2	EIS Terms of Reference	4-11
4.1.3	Final NOEF Cover and Flood Management Performance.....	4-12
4.1.4	Groundwater Inflows to the Underground Mine.....	4-13
4.1.5	Groundwater Interaction with the Pit Lake.....	4-13
4.1.6	Reduced Metals Attenuation	4-14
4.2	What Must be Addressed in the EIS Supplement?	4-14
4.3	References.....	4-15
5.	Surface Water Quality Management.....	5-1
5.1	Is the Information in the EIS Sufficient?	5-1
5.1.1	Terms of Reference.....	5-1
5.1.2	Further Comments.....	5-3
5.2	What Must be Addressed in the EIS Supplement?	5-10
5.3	References.....	5-11
6.	Mine Site Water Balance.....	6-1
6.1	Is the Information in the EIS Sufficient?	6-1
6.1.1	Adopted Design Flood Standards.....	6-1

6.1.2	Mitigation Measures Adopted in the Risk Assessment	6-5
6.1.3	Inadequate Risk Assessment of the McArthur River Levee	6-5
6.1.4	Assessment of Climate Change Impacts upon Design Flood Standards	6-6
6.1.5	Margin of Safety in the On-site Water Storage Capacity to Allow for Model Uncertainties	6-7
6.1.6	Water Balance Model	6-8
6.1.7	Details of How/Where Additional Storage will be Created	6-10
6.1.8	EIS Surface Water Commitments	6-11
6.2	What Must be Addressed in the EIS Supplement?	6-11
6.3	References	6-12
7.	Terrestrial Ecology	7-1
7.1	Is the Information in the EIS Sufficient?	7-1
7.1.1	Terms of Reference	7-1
7.1.2	Additional Comments	7-1
7.2	What Must be Addressed in the EIS Supplement?	7-4
7.3	References	7-5
8.	Freshwater Aquatic Ecology	8-1
8.1	Is the Information in the EIS Sufficient?	8-1
8.1.1	Terms of Reference	8-1
8.1.2	Additional Comments	8-1
8.2	What Must be Addressed in the EIS Supplement?	8-9
8.3	References	8-11
9.	Mine Closure	9-1
9.1	Introduction	9-1
9.2	Is the Information in the EIS Sufficient?	9-1
9.2.1	Terms of Reference	9-1
9.2.2	Decommissioning, Rehabilitation and Closure	9-3

9.2.3 Adaptive Management	9-8
9.3 What Must be Addressed in the EIS Supplement?	9-9

Tables

Table 1.1 – Inconsistences Between Likelihood and Consequence	1-2
Table 1.2 – Definition of Unlikely and Possible	1-5
Table 4.1 – General Compliance Checklist.....	4-3
Table 4.2 – Detailed Compliance Checklist	4-3
Table 4.3 – Groundwater EIS Terms of Reference	4-11
Table 4.4 – Summary of Groundwater Model Uncertainties	4-14
Table 6.1 – Examples of Inadequate Mitigation Measures in the Risk Assessment.....	6-5
Table 6.2 – Rainfall AEPs for Current and Climate Change Conditions	6-6
Table 9.1 – EIS Terms of Reference Requirements for a Conceptual Mine Closure Plan.....	9-1
Table 9.2 – Example of Inconsistency in Draft Completion Criteria	9-5
Table 9.3 – Inconsistency Between Modelling and Draft Completion Criteria	9-6

Figures

Figure 6.1 – Flood Frequency Analysis Results for McArthur River at MIM Pump Gauging Station	6-4
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Executive Summary

The McArthur River Mine deposit includes some of the most strongly pyritic materials observed by the Independent Monitor (IM). The IM has previously stated in the annual review performance reports that mine waste geochemistry (and its implications) is the most significant environmental issue for the site. Minimising adverse impacts on the receiving groundwater and surface water environments, and ensuring rehabilitation success, requires a thorough understanding of the acid, metalliferous and saline drainage (AMD) potential of mine materials (including waste rock, tailings, open cut walls/void and stockpiles) and development of appropriate management strategies to mitigate both current mining impacts and future impacts during operations and closure for any future mine development.

There was a major change in the understanding of site geochemistry following the McArthur River Mine Phase 3 approval, when further investigations highlighted that waste rock previously considered benign had the potential to generate saline and metalliferous pH-neutral drainage, with consequent implications for the key mine components, including overburden emplacement facilities (OEF), tailings storage facility (TSF) and open cut. This changed appreciation of AMD potential has required McArthur River Mining (MRM) to re-evaluate the environmental risks from mine materials, instigate numerous studies and investigations to better understand those risks, and develop new approaches to mine materials management.

Geochemistry and Geotechnical

A key aspect of the change in the understanding of the McArthur River Mine geochemistry was the recognition that the previous waste rock classification system did not adequately segregate all problematic materials. The current classification system expands on the previous simple non-acid-forming (NAF) and potentially acid-forming (PAF) criteria, and takes into account the presence of sulfidic NAF materials that have potential for neutral drainage with elevated salinity and/or metals/metalloids concentrations, and highly sulfidic and reactive materials that have potential for self-heating.

A consequence of the previous classification system was that overburden thought to be benign and placed in the various OEFs will include metalliferous and saline NAF. In addition, previous overburden management did not account for the fine-grained and highly reactive nature of the pyrite in the PAF overburden, and convection/advection controls were not implemented. The PAF materials were generally end tipped in lifts of approximately 15 m, resulting in segregation of coarse and fine materials and creation of chimney structures that encourage rapid convective oxidation and acid generation, and spontaneous combustion in the case of PAF (reactive) materials. The existing OEFs on site therefore represent legacy issues that need to be accounted for in AMD management in addition to new materials to be mined.

Although the management approaches described in the Overburden Management Project draft environmental impact statement (EIS) are consistent with best practice, there is considerable uncertainty in regard to successful implementation and the long-term (1,000 years) performance at McArthur River Mine. The key areas of uncertainty are:

- ♦ Given that the northern overburden emplacement facility (NOEF) is a major geochemical hazard for the site, modelled predictions of seepage quality carried out to date should be independently verified.
- ♦ It is doubtful that installation of a contiguous low permeability (1×10^{-9} m/s) compacted clay layer (CCL) over the entire surface of the NOEF is achievable.
- ♦ The integrity of the proposed cover system is obviously critical to long-term performance, but it has not been demonstrated that this can be managed with maintenance and repair for the proposed 1,000-year closure period.
- ♦ The effectiveness of the proposed advection control barriers on the large, heterogeneous and actively convecting system represented by the existing NOEF has not been demonstrated.
- ♦ There is no prediction of differential settlement in the NOEF and its potential impact on the relatively thin infiltration control layer.

The above uncertainties suggest that the modelled geochemical impacts from the NOEF may be optimistic, leading to consequent uncertainties concerning the scale and duration of surface water and groundwater collection and treatment requirements.

Implementing the proposed overburden management strategy depends upon successfully identifying and segregating sufficient low salinity NAF resources, and ensuring sufficient resources of clay. The development of the Woyzbun Quarry appears to address the first of these requirements for current management strategies, as well as providing excess resources not planned to be mined but that could be used if required. Additional borrow pits have been located for the purpose of sourcing clay materials. Laboratory testing indicates that a large portion of the clay is dispersive. The expected volume of potentially dispersive material, such as Emerson class 1 or 2, is not provided in the EIS despite extensive testing. There is uncertainty, therefore, that sufficient material has been sourced to form the required clay barriers. There is no information as to how dispersive soils will be managed in the construction of the clay liners. There is no design control for dispersivity, such as allowable Emerson or pinhole dispersion classes.

The general concepts and principles employed for the design of the NOEF cover zone are considered to be well conceived and consistent with best practice, in that they integrate the mechanisms of i) water shedding, ii) store and release, and iii) infiltration/oxygen barrier. The proposed monitoring system is generally considered to be appropriate but the IM recommends the early establishment of cover test trials allowing for long-term monitoring to evaluate the performance of the conceptual design well in advance of completing the final cover system.

The IM believes that the greatest risk to the long-term performance of the NOEF will be the leaching of oxidation products associated with excessive net percolation and that the final cover systems constructed should ensure the lowest possible flux of liquid water to the foundation of the NOEF. The IM is especially concerned that the required continuous low permeable integrity of the CCL barrier layer over the entire surface of the NOEF will not be achieved, particularly given the 1,000-year period referred to in MRM's Project closure objectives. The high performance offered by ultra low flux covers such as HDPE and bituminous liners should be further evaluated.

Groundwater

The groundwater component of the EIS is based on the results from a site-wide groundwater flow and solute transport model developed by Klohn Crippen Berger. The model includes basal seepage contamination from the TSF, perimeter runoff dams (PRODs) and OEFs, as well as possible sources of contaminants from natural zones of mineralisation, and discharges to the pit, creeks and McArthur River.

The model is based on earlier models and has been updated on the basis of a considerable number of studies undertaken over the last two to three years. These studies have included extensive field investigations around the NOEF and TSF, interpretation of the available geological and hydrogeological datasets, and re-conceptualisation of the hydrogeology of the mine site. They have also included the development of a more detailed groundwater flow and contaminant transport model for the TSF area, which has been structured to allow integration with the site-wide model.

A number of significant uncertainties in MRM's understanding of the processes controlling groundwater flow across the mine site remain, some of which have been identified in the reports provided with the EIS. The presence of these uncertainties is understandable given the following:

- ♦ The deficiencies in some of the earlier hydrogeological studies, including the studies completed for the Stage 3 EIS.
- ♦ The complexity and large scale of the groundwater system.
- ♦ The absence of historical monitoring data, especially prior to the start of open cut mining.
- ♦ The poorly understood impacts from some of the post closure landforms, e.g., the NOEF and pit lake.

The uncertainties are, to some extent, addressed under MRM's adaptive management approach, which allows for ongoing collection of information, assessment of impacts and development of options to manage these impacts.

However, the IM's view is that a number of uncertainties require further investigation due to the severity of the potential impacts upon the groundwater and surface water environment. These relate to the following:

- ♦ The performance of the final NOEF cover over the 1,000-year assessment with respect to:
 - Seepage of contaminated water to the underlying groundwater system.
- ♦ The performance of the NOEF flood management facilities with respect to:
 - Preventing inundation.
 - Generation of AMD.
 - Seepage of contaminated water to the underlying groundwater system.

- ♦ The groundwater inflow mechanisms associated with the underground workings, which are used for the majority of the dewatering effort for the pit via the Evase pumping system. It is assumed that these inflows are due to hydraulic connections to the McArthur River diversion channel, although no major aquifers have been identified during field investigations. Understanding and adequately simulating the physical processes controlling this mechanism is important as it affects the dewatering rate during operations and, more significantly, potential links from the pit lake to McArthur River during and after closure.
- ♦ The interaction of the pit lake and groundwater system after closure. This includes both inflows and outflows, which will affect the:
 - Rate at which the pit lake is flooded.
 - Long-term pit lake level.
 - Potential for discharge of contaminated pit lake water to the downstream groundwater and surface water systems.
- ♦ The potential for reduced attenuation of metals in areas where flow is via discrete pathways rather than a porous medium as simulated in the groundwater flow and contaminant transport model.

Surface Water

The mine has developed a complex and comprehensive water management system that, as described in the EIS, will be adapted as required to allow Project implementation. Surface water quality monitoring data up to October 2015 indicates that adverse impacts on downstream surface waters due to the mine are currently limited, although some effects are noticeable in watercourses within the mine lease boundaries (and this is not unexpected) and some non-compliance with waste discharge site-specific trigger values (SSTVs) due to mine activities has occurred (as discussed in the IM's last annual report).

The EIS also assumes that complying with the WDL trigger values at SW11 will protect all relevant beneficial uses. The IM's position is that, while a focus on water quality trigger levels given in the WDL and water quality at SW11 provides an important first tier of assessment, an EIS that is meant to address the broader issue of impacts on the entire McArthur River system over a 1,000-year period should be supplemented by additional levels of assessment, thereby allowing a more comprehensive assessment of the risk. This should include consideration of total loads of mine-derived metals and suspended solids (and Australian water quality guidelines recommend that load-based guidelines be developed for suspended particulate matter in the context of sedimentation and smothering of benthic organisms (as well as nutrients and biodegradable organic matter)), and more thorough assessment of likely impacts in the downstream environment beyond SW11.

Seepage will mainly be managed through collection and treatment. Modelling and groundwater investigations indicate that seepage would report to the lower Barney Creek, where it would be recovered from two collection sumps to help meet surface water quality commitments at SW11. Collection from the Barney Creek sumps is planned into the closure phase with water treatment

as required, but it is unclear whether there is an expectation that collection from these sumps will continue indefinitely.

The closure objectives include no mention of Barney Creek, Little Barney Creek, Emu Creek or Surprise Creek. In the absence of such references, it appears that protection of the environmental values associated with these streams is not a long-term objective. While the appropriateness of this requires consideration by a range of stakeholders and may be considered questionable, the status of these streams after closure with regard to the relevant environmental values should be explicitly stated in the EIS. This is particularly relevant given that the modelling indicates elevated sulfate concentrations in Barney Creek and Surprise Creek post-closure (i.e., annual average concentrations at BCS2 at the lower end of the Barney Creek diversion) that will be up to six times greater than the WDL SSTV of 341 mg/L.

As currently presented, the implications of poorer water quality upstream of SW11 over a period of possibly decades (or centuries) are not adequately addressed in the EIS.

Flood Management

The EIS has adopted different flood magnitudes as the design flood standards for the various mine site elements. For example:

- ♦ The main McArthur River levee is designed to have a 0.2% (1-in-500) annual exceedance probability (AEP) flood immunity.
- ♦ NOEF drains are designed to contain the 1% (1-in-100) AEP discharge.
- ♦ The NOEF PRODs are designed to have 1% (1-in-100) AEP flood immunity.
- ♦ The power station and rehabilitated WOEF will have a levee to protect it from the 0.2% (1-in-500) AEP flood.

There is no discussion or justification in the EIS for the adoption of the design flood standards (AEPs) for the different design elements (e.g., McArthur River levee, NOEF batter drains). In particular:

- ♦ There is no detailed risk assessment of the adoption of flood magnitudes.
- ♦ There is no justification for the difference in design flood standards for different elements. For example, the design flood standards for the McArthur River levee and the rehabilitated NOEF batter drains are the 0.2% (1-in-500) and 1% (1-in-100) AEP events, respectively. If it is assumed the levee has a design life of (approximately) 50 years (if the flow-through pit is adopted) and the NOEF batter drains have a design life of 1,000 years, then the probability of failure during the design life is 10% and 100%, respectively. The failure of an NOEF batter drain post closure may be catastrophic to the integrity of the NOEF cover (including the CCL).

Water Balance

There are numerous assumptions and uncertainties in the site water balance assessment, many of which are identified and acknowledged in the EIS. Even if the water balance modelling is

correct, it demonstrates that, under some scenarios, many water storages are at or above the maximum operating level for substantial periods of time, sometimes years. If some of the underlying assumptions are incorrect there is little available storage to accommodate extra water.

In summary, the water balance model results show that during the wetter sequences, there can be extended periods of time when the NOEF PRODs are near or at their maximum operating level and full supply volumes.

Freshwater Aquatic Ecology

Contamination of surface waters and fluvial sediments due to operations at McArthur River Mine constitute the greatest threat to freshwater ecosystems of McArthur River. If potential sources of contamination of surface water, groundwater, dust, soil and fluvial sediments are addressed (as outlined in this report and the EIS), then the majority of risks will be greatly reduced. However, a number of residual issues are inadequately covered in the EIS that require further information, as follows:

- ♦ Should water quality in the pit lake be too poor to allow the mine levee to be opened and flow through from McArthur River to occur, there are no details of environmental management or potential impacts from contaminated pit lake water to the aquatic ecosystems of McArthur River. Contaminated water from the pit lake may enter groundwater and seep into McArthur River and its tributaries.
- ♦ Ongoing contamination of Surprise and Barney creeks until 3018 and beyond. While contaminant loads are discussed, there is little discussion of the long-term ecological impacts of the elevated contaminant loads, or impacts on other beneficial uses.
- ♦ Management of protected fauna entering, exiting and residing in the pit lake. The potential issues with protected fauna, including the freshwater sawfish (*Pristis pristis*) and estuarine crocodiles (*Crocodylus porosus*), include injury when entering or exiting the pit lake, the provision of adequate suitable habitat, and the potential contamination of fauna should they become stranded in the pit lake. Further information is needed to fully address these issues.
- ♦ The extent and impacts of drawdown of groundwater as a result of MRM's operations. It is stated that water levels in Djirrinmini Waterhole are expected to drop by 0.7 m. There is negligible discussion of the ecological impacts of the drawdown and whether flow duration and additional permanent waterholes on McArthur River will be affected.
- ♦ Ensuring that natural flow regimes are maintained in McArthur River while the pit lake is filled.

Terrestrial Ecology

The Project has the potential to impact terrestrial flora and fauna through vegetation clearing, inadequate rehabilitation and displacement of fauna. Approximately 20% of the purple-crowned fairy-wrens residing within the MRM lease will be relocated from within the mine levee wall to an area inside a planned expansion of the cattle exclusion fence. There has been no risk assessment conducted detailing the risk associated with attempting this relocation. No details are given as to how the birds will be relocated and how the success of the relocation will be monitored.

Groundwater drawdown has the potential to impact springs and groundwater-dependent ecosystems (GDEs) (including decreasing the size of Djirrinmini Waterhole) and affect the persistence of waterholes along the McArthur River bed in the dry season, thereby causing vegetation stress, a reduction in habitat for riparian birds and reduced drinking water sources for native fauna. The presence of springs and GDEs has not been determined and the risks to these systems have not been adequately addressed.

Mine Closure

The IM has reviewed the draft indicators and completion criteria as outlined in the closure framework developed by MRM. The framework provides a logical progression from high-level goals to specific criteria, which are used to demonstrate achievement of the goals. The closure framework, however, does not clearly link each relevant component. For example, the definition of criteria is not linked to indicators but rather to objectives and the definition for indicators does not specifically relate to objectives. The criteria need to specify how the achievement of the indicator will be demonstrated and subsequently how achievement of the indicator demonstrates achievement of the objective.

The completion criteria in some instances do not align with the modelling undertaken. For example, the draft completion criterion for the proposed cover on the NOEF is that 5 to 10% of rainfall infiltrates beneath the CCL. However, modelling undertaken by O'Kane Consultants showed that infiltration rates through the cover will range between 4.5 and 5.9% of rainfall.

These model results were used by Klohn Crippen Berger as one of the inputs into the groundwater model. Subsequently, the completion criteria are less conservative than the model results, i.e., the proposed measure of success allows greater infiltration through the cover than the model results that have been used as the basis for the impact assessment. The draft completion criteria need to be linked to the modelling so that any variance from modelling results can be understood in terms of the potential environmental impact and for adaptive management strategies to be implemented.

McArthur River Mining has approval for the construction of a 6 ML/day reverse osmosis water treatment plant with waste (reverse osmosis reject brine) to be used as process feed water. It is stated that seepage management systems will remain in place to collect and treat seepage water from the NOEF until monitoring confirms that it is no longer required. Furthermore, it is stated that these systems will remain in place throughout the adaptive monitoring phase (100 years). The IM could not find any reference to disposal of brine after the cessation of tailings retreatment. Documents supporting the EIS indicate that the water treatment plant will cease production at the conclusion of tailings retreatment in 2047, which is not consistent with the above statement of water treatment continuing throughout the adaptive monitoring phase (100 years). If the brine is to be discharged into the open pit it is not clear if this input has been included in the pit water quality assessment. Clarification is required regarding whether the water treatment plant will continue to operate after the retreatment of tailings has been completed, the expected treatment rate and where the brine will be discharged.

Three options were identified by MRM for the closure of the TSF:

- ♦ Tailings to remain contained within the TSF, with cover system installed.

- ♦ Rehandling tailings back into final void.
- ♦ Reprocessing of tailings then rehandling back into final void.

The preferred option is to reprocess tailings and placement into the final void. It is not clear if reprocessing of tailings is currently technically and financially viable and subsequently clarification is required regarding whether metallurgical testing has demonstrated the feasibility (technical and financial) of this alternative. If this preferred alternative is not currently feasible, clarification is required as to whether MRM's intention is that the alternative of rehandling tailings back into the final void would be implemented. The IM notes that the financial cost to place tailings back into the pit without treatment would have a major impact on company finances.

Three phases of post-closure monitoring and maintenance are described. These phases are appropriate given the size/scale of the operation and the issues being managed. What is unclear is whether MRM intends to manage the site through these three phases or if at the conclusion of the adaptive management phase it is intended that the site be handed back to the Northern Territory government. In the risk assessment, risk ID BB80 states that additional mitigation measures after the EIS include a revised mine closure plan, including cost estimates and details, and that this includes adaptive management and reactive management phases. It is further stated that the ranking basis for the residual risk being reduced from high to low is that the following are implemented:

- ♦ Early monitoring and feedback to estimates continually update closure costs and reduce the risk of unforeseen major costs.
- ♦ Funding mechanisms agreed with regulators to provide for adaptive management and reactive management phases.

It is not clear from the risk assessment whether the revised closure cost for the site now includes costs for the long-term adaptive management and reactive management phases of the Project. It is also unclear if a funding mechanism has actually been agreed with regulators.

There are numerous references throughout the EIS to adaptive management as being a key strategy to be used by MRM should monitoring results indicate that the proposed mitigation strategy is not successful. As a management concept the IM believes that adaptive management is integral to any monitoring program, which should modify management measures based on monitoring results. The EIS outlines the approach to adaptive management and in particular the timeframes. Reference is made to 'plans being developed to assist with the implementation of 'true adaptive management' rather than simply 'monitoring and reacting'. The reference to 'true adaptive management' is confusing and it is not clear to the IM how this differs from adaptive management, hence the IM recommends that this term be explained so that stakeholders are appropriately informed as to MRM's intentions.

The EIS identifies alternatives that may be used should ongoing optimisation and performance monitoring identify a requirement or opportunity to apply adaptive management strategies. What is not clear is the trigger that would indicate that alternative strategies are required. The IM considers this to be particularly important given the concerns about the long-term effectiveness of the NOEF cover system. While MRM has identified a number of alternatives, it is not clear which

would remain an option once the preferred option as outlined in the EIS is implemented or is in the process of being implemented, i.e., in undertaking the preferred option does this then exclude other alternatives from being implemented.

Reference is made in the EIS to collecting and treating water in the event that mitigation measures do not meet results predicted by modelling. It is not clear, however, if MRM is committing (as a last resort) to collect and treat for 1,000 years. The IM believes that it is important to understand what the final mitigation strategy is if other strategies do not meet expectations.

EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

1. Introduction

1.1 Scope

ERIAS Group was appointed as the Independent Monitor (IM) for the McArthur River Mine in December 2013 for a period of five years. Since being appointed ERIAS Group has prepared three annual reports covering the following periods:

- ♦ 2012 – 2013.
- ♦ 2014.
- ♦ 2015.

The main role of the IM is to assess the environmental performance of the McArthur River Mine by reviewing and reporting on environmental assessments and monitoring activities undertaken by McArthur River Mining Pty Ltd (MRM), and environmental assessments and audits undertaken by the Department of Mines and Energy (DME) (now Department of Primary Industry and Resources (DPIR)), with respect to the environmental performance of the mine and Bing Bong Loading Facility.

The IM has reviewed the Overburden Management Project draft environmental impact statement (EIS) and provided comment in the following sections of this report. The IM's review of the EIS focused on the following key areas:

- ♦ Surface water.
- ♦ Water balance.
- ♦ Groundwater.
- ♦ Geochemistry.
- ♦ Geotechnical.
- ♦ Terrestrial ecology.
- ♦ Freshwater aquatic ecology.
- ♦ Mine closure.

In reviewing the EIS, the IM has commented on the EIS and its main deficiencies and outlined areas that MRM should address in the supplementary EIS. Safety, social, economic and cultural heritage matters are outside the IM's scope of work.

1.2 Risk Assessment

1.2.1 Introduction

Discussion on risk assessment is contained in a number of chapters and appendices. The following discussion focuses on EIS Chapter 7, Appendix F (Failure Modes and Effects Analysis Report) and Appendix G (Final Risk Assessment Workshop Report), and selected examples of specific risks. The IM notes that there is inconsistency between the likelihood and consequence tables in Chapter 7, Appendix F and Appendix G. These inconsistencies are outlined in Table 1.1.

Table 1.1 – Inconsistencies Between Likelihood and Consequence

	EIS Chapter 7	Appendix F	Appendix G	Comment
Likelihood	5 categories: Rare, Unlikely, Possible, Likely and Almost Certain	5 categories: Not Likely, Low, Moderate, High, Expected	5 categories: Rare, Unlikely, Possible, Likely and Almost Certain	The description of likelihood in EIS Chapter 7 is different to that in Appendix F which contains both a qualitative and quantitative description
Consequence	5 categories with 5 descriptors for each category: Health & Safety, Environment, Financial Impact, Image & Reputation/ community and Legal & Compliance	5 categories with 5 descriptors for each category (Environmental Impact, Regulatory Compliance and Approval, Consequence Costs, Community & Stakeholders, Safety)	5 categories with 4 descriptors for each category (Health & Safety, Environment, Community and Legal).	<ul style="list-style-type: none"> ♦ The description of consequence in EIS Chapter 7 is different to that in Appendix F. As an example a catastrophic consequence in Chapter 7 is environmental damage > 10 years whereas in Appendix F a major consequence is an impact over 5 to 20 years ♦ Appendix F describes the cost in dollars whereas Chapter 7 provides description related to financial impact on company without dollars ♦ Appendix G does not include a descriptor for cost. The text for each descriptor is different for some descriptors.

These inconsistencies make it difficult and confusing when reviewing the various risk assessments and in understanding the linkages between the three documents.

1.2.2 Assessment of Likelihood

How likelihood is determined and, specifically, if likelihood is determined based on the hazard occurring or likelihood of a consequence occurring from the hazard is unclear. The description of the hazard does not in all cases clearly articulate the hazard but is general in nature. The IM believes that this has caused confusion in determining the likelihood and consequence.

In EIS Table 7-1 the definitions for the consequence categories indicate that likelihood is assessed based on the impact occurring. In contrast, Section 7.2.2.2 indicates from the statement below that likelihood is assessed based on the event or hazard occurring:

A combination of likelihood of occurrence and consequences of failure was considered for each risk event.

Standards Australia/Standards New Zealand has prepared a handbook titled Managing Environment-related Risk (Standards Australia 2012). Section 3.5.3.3 of the handbook notes the following regarding assessment of likelihood:

Analysing likelihood involves estimating the likelihood that a particular consequence or level of consequence will occur. It may also involve exposure assessment. Establishing the likelihood does not depend only on the likelihood of an underlying event, but the distribution of consequences flowing from such an event.

The approach outlined in Standards Australia (2012) is consistent with that described in Standards Australia (2009), with Section 5.4.3 of the latter stating that:

Risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur.

In reviewing the risk assessment, it is unclear to the IM how likelihood has been assessed; however, it appears that likelihood has been determined based on the likelihood of the hazard or event occurring rather than the likelihood of a particular consequence as outlined in Standards Australia (2009) and Standards Australia (2012). To improve the clarity the IM believes that a review of the risk assessment is required and in particular the following aspects:

- ♦ Review and revise the hazard so that the risk is clear.
- ♦ Review and revise the impact to clearly articulate the consequence.
- ♦ Assess likelihood in accordance with Standards Australia 2009 and 2012.

In the discussion in Section 1.2.2 below, the IM has assumed that likelihood is based on assessment of the hazard occurring.

1.2.3 Key Project Risks

Key project risks are outlined in EIS Chapter 7, Table 7-4 with ten of these being specific to the NOEF. The residual score for all risks specific to the NOEF has been determined to be moderate. What is unclear is that the description of each risk as it relates to the NOEF is not always specific with regard to the failure mechanism. For example, risk BB97 in Table 7-5 states the following as being the hazard:

- ♦ Seepage from NOEF including PAF material giving risk to acid and metalliferous drainage.

There is no explanation regarding the mechanism or pathway that has resulted in acid and metalliferous drainage (AMD), i.e., is the AMD due to poor construction, clay properties inconsistent with design or a particular rainfall event(s). The risk ranking prior to the mitigation measures outlined in the EIS was high with the likelihood considered possible and consequence considered major. Following the additional mitigation measures outlined in the EIS, the risk was reduced to moderate with the likelihood considered unlikely and the consequence moderate. Five 'new' mitigation measures were identified as evidence to support the reduced risk. Of these measures:

- ♦ Two related to monitoring of surface water and groundwater.

- ♦ One was a commitment to install other mitigation measures if required, i.e., interceptor drains or recovery bores.
- ♦ One was to install a sump in Barney Creek to capture seepage.
- ♦ One was the design of the final cover system.

Only the design of the final cover strategy has the potential to reduce the likelihood of the hazard from occurring. The other mitigation strategies are focused on either identifying that an impact is or is not occurring or collecting seepage. It is unclear therefore why the likelihood has been decreased from possible (C) to unlikely (D) when the only change to prevent the hazard from occurring has been the design of the final cover strategy. To assess the risk of failure of the cover the IM believes that this needs to be undertaken by assessing specific failure modes rather than generically.

In the Executive Summary of Appendix G (Final Risk Assessment Workshop Report), reference is made to the risk assessment team highlighting a number of risks including the following:

NOEF performance impaired – and similarly leading to an inability to establish the ‘flow through’ site due to not achieving design performance (quality and quantity of sediment and other contaminants).

This is further expanded in Table 2 of Appendix G (Final Risk Assessment Workshop Report), which lists priority issues with risk BB79 as being:

Hazard

Due to closure cover system not meeting water transport requirements, further oxidation products being developed within the NOEF.

Impact

Higher than acceptable geochemical loading from facility.

The controls prior to the additional controls identified in the EIS include:

- ♦ Source controls
 - MRM Dump Management Plan.
 - Inspection and monitoring of emplacement performance.
- ♦ Transport controls
 - MRM Water Management System.

The risk ranking for this hazard was determined as:

- ♦ Probability (or Likelihood) = D (Unlikely)

- ♦ Consequence = Environment (3 – Moderate) and Regulatory¹ (4 – Major)

The overall risk ranking before additional controls identified in the EIS was ranked as Medium.

In reviewing this risk the IM believes that the assessment of likelihood is incorrect for the hazard. Table 1.2 outlines the definition for unlikely and possible as described in Table 7-1.

Table 1.2 – Definition of Unlikely and Possible

	Unlikely	Possible
Likelihood	Could occur about once during a lifetime, more likely NOT to occur than to occur, has occurred at least once in the broader worldwide industry	Could occur more than once during a lifetime, as likely to occur as not to occur, has occurred at least once in the mining/commodities trading industries

The Rum Jungle site near Bachelor is an example of where a cover design has failed and subsequently the IM believes that the likelihood should be possible rather than unlikely. Further evidence is required from MRM providing examples of mine sites where cover systems have been successfully constructed in similar climatic settings and monitoring undertaken which demonstrates the success of the cover system to justify that it is unlikely that the cover will not perform as expected.

The consequence of this hazard was determined as moderate before the additional controls and low after the additional controls outlined in the EIS. The hazard, however, is that the controls are not effective. If the controls are not effective, the IM believes that the consequence should be major or potentially catastrophic.

If the likelihood was classified as possible and consequence major, then this would be a high risk.

Within the additional post EIS controls outlined in risk BB79 the following was stated: 'Geotechnical analysis of proposed NOEF design indicates similar geotechnical performances to existing NOEF – some minor differential settlement is possible'. Differential settlement is identified as a hazard (BB77) with the impact on cover system integrity and performance. The likelihood is assessed as unlikely while the consequence is: environment (2 – Minor) and Regulatory² (3 – Moderate). When the additional controls identified in the EIS are included the likelihood remains the same; however, the consequence is reduced to negligible for both environment and regulatory categories. As MRM has acknowledged that differential settlement is possible, it is unclear why the likelihood is ranked unlikely and not possible. Furthermore, there appears to be an assumption that monitoring identifies any differential settlement at an early stage and that repair is undertaken quickly. No monitoring for differential settlement was outlined in Appendix O (NOEF Closure Monitoring System Report). It is therefore unclear how MRM will identify if the cover system integrity and performance has been impacted as a result of differential settlement within a reasonable timeframe.

¹ Note that in the consequence table (Table 3, Appendix G) there is no category for regulatory. There is, however, a legal category and the IM has assumed that where regulatory is stated this means legal.

² Note that in the consequence table (Table 3, Appendix G) there is no category for regulatory. There is, however, a legal category and the IM has assumed that where regulatory is stated this means legal.

Section 9 of Appendix J (NOEF Cover System and Landform Design Report) and Appendix F of Appendix J detail a series of failure modes specific to the cover design and landform and concludes that these risks are manageable. One of the risks discussed is differential settlement with the risk to the final cover system ranked as low or moderate with the level of confidence considered high. The risk of differential settlement impacting on cover performance is also noted in Appendix F, Table B.3 where in the comments section it states 'No accurate surveys of current dump surface to pick up on settlement rates' and that 'most primary settlement happens during operations. Not much once cover is in place. Settlement could be as high as 5-6% during construction, 0.5% creep following construction (25cm)'. Settlement of 5% for a dump that is 140 m high equates to 7 m. This is further discussed in Section 2.1.6 of this report; however, it would appear that the information provided is conflicting and the IM is unclear about the extent to which differential settlement could compromise cover performance.

1.2.4 What Must be Addressed in the EIS Supplement

A review of the risk assessment is required to clearly articulate the pathways that could result in failure to achieve the closure objectives. Specifically, the risk assessment should document each risk that could result in failure of the cover system and provide further information regarding how the likelihood and consequences were determined. To improve the clarity of the risk assessment the IM believes that a review of the risk assessment is required and in particular the following aspects:

- ◆ Review and revise the hazard so that the risk is clear.
- ◆ Review and revise the impact to clearly articulate the consequence.
- ◆ Assess likelihood in accordance with Standards Australia 2009 and 2012.

The EIS supplement should also provide further information regarding the experience at other mine sites in relation to the long-term performance (i.e., decades) of cover systems and, in particular, comment on whether the cover performance is expected to be maintained for the 1,000 years as modelled. This issue is further discussed in Section 2.1.6.1 and 3.4. The risk assessment has not addressed the long-term performance of the cover system.

1.3 References

Standards Australia. 2012. HB 203:2012. Handbook – Managing environment-related risk. Fourth edition. Standards Australia/New Zealand. Sydney.

Standards Australia. 2009. AS/NZS ISO 31000:2009. Risk management – Principles and guidelines. Standards Australia/New Zealand. Sydney.

2. Geochemistry

2.1 Is the Information in the EIS Sufficient?

2.1.1 Comparison with Terms of Reference

Sections 4.2 and 4.3 of the EIS Terms of Reference (TOR) prepared by the Northern Territory Environment Protection Authority (NTEPA) lists a broad range of geochemical aspects that MRM were required to address in the EIS. In summary these include the following:

- ♦ Assess and address the significant risks posed by NOEF, mine pit, TSF and other waste rock dumps that will contain problematic materials, including: contamination of groundwater and surface water from these sources and consequent downstream impacts; spontaneous combustion of highly reactive potentially acid-forming (PAF) materials; inadequate design of the NOEF leading to stability issues and significant AMD generation; and insufficient benign materials for encapsulation of problematic waste.
- ♦ Provide a description of the potential for AMD generation from waste rock and other project infrastructure, including: geochemical characteristics using static and kinetic testing, with details on sample selection, waste classes and quantities; field identification and segregation methods; and estimates of quantities of benign materials required to encapsulate non-benign materials, and plans showing sources of benign materials to meet requirements.
- ♦ Provide details on AMD strategies to mitigate and manage AMD (such as avoidance of disturbance, dry covers, underwater storage, neutralisation, and collection and treatment), with specific details on: site water balance modelling accounting for all potential contaminant sources; treatment of ongoing AMD; block model of waste rock classes to assist management; and design alternatives for management of non-benign materials, including:
 - Base/cover systems to limit AMD.
 - Encapsulation cell designs that can cope with high temperatures and gasses from reactive PAF materials.
 - Treatment options for reactive PAF materials.
 - Designs that account for potential void creation caused by combustion of reaction PAF and consequent slumping.
 - Designs based on worst case waste rock compositions.
- ♦ Detail a geochemical monitoring program to measure performance of AMD management strategies.

The EIS largely addresses the above requirements, with many investigations and studies commissioned by MRM used to support the predicted geochemical behaviour of the various potential contaminate sources and proposed management strategies. However, there remain a number of uncertainties and knowledge gaps, which are addressed in the following sections. The TOR also refers specifically to design alternatives that address issues associated with reactive

PAF materials, including high temperature (and convecting) systems, and void creation, which relates particularly to the existing NOEF with end tipped PAF materials that are showing active convective oxidation. The EIS includes discussion of reactive PAF materials, but does not clearly consider the effects if these reactive PAF issues are not controlled with the proposed advection barriers. Again more detail on this is provided in the following sections.

2.1.2 Context

The McArthur River Mine deposit includes some of the most strongly pyritic materials observed by the IM, and mine waste geochemistry (and its implications) is the most significant environmental issue for the site. Preventing adverse impacts on the receiving groundwater and surface water environments, and ensuring rehabilitation success, requires a thorough understanding of the acid, metalliferous and saline drainage (AMD) potential of mine materials (including waste rock, tailings, open cut walls/void and stockpiles) and development of appropriate management strategies to mitigate current mining impacts, and future impacts during operations and closure for any future mine development.

There was a major change in the understanding of site geochemistry following the McArthur River Mine Phase 3 EIS approval, when further investigations highlighted the highly sulfidic nature and high AMD potential of much of the waste rock, ore and tailings, with consequent implications for the key mine components, including OEFs, TSF and open cut. This changed appreciation of AMD potential has required MRM to reevaluate the environmental risks from mine materials, instigate numerous studies and investigations to better understand those risks, and develop new approaches to mine materials management. These changes were also the main trigger for the requirement of the current EIS.

The key geochemical considerations used in reviewing the EIS are as follows:

- ♦ Are the geochemical properties of mine materials well defined (e.g., adequate testing, range of testing?), including acid, metalliferous and saline drainage potential and long-term leaching characteristics/kinetics?
- ♦ Is there a reliable classification system that captures the key hazards based on the above to allow selective handling of materials?
- ♦ Does the system of materials segregation, handling and checks ensure correct placement of materials?
- ♦ Are the hazards of current potential mine sources of AMD (e.g., OEFs, TSF, open cut) understood?
- ♦ Are the hazards of future potential mine sources of AMD understood?
- ♦ How is the long-term geochemical behaviour of AMD sources determined and how reliable are the predictions?
- ♦ Will mine materials management systems adequately address AMD issues during operations, at closure, and into the long term?

These geochemical considerations are discussed below, split into the main potential AMD materials and sources.

2.1.3 Overburden Geochemical Testing and Classification

A key aspect of the change in the understanding of the McArthur River Mine geochemistry was the recognition that the previous waste rock classification system did not adequately segregate all problematic materials. The current classification system expands on the previous simple non-acid-forming (NAF) and potentially acid-forming (PAF) criteria, and takes into account the presence of sulfidic NAF materials that have potential for neutral drainage with elevated salinity and/or metals/metalloids, and highly sulfidic and reactive materials that have potential for self-heating. The EIS details five current classes of overburden (EIS Section 6.1.3.1):

- ♦ Low salinity non-acid-forming (high capacity) (LS-NAF(HC)).
- ♦ Metalliferous saline non-acid-forming (high capacity) (MS-NAF(HC)).
- ♦ Metalliferous saline non-acid-forming (low capacity) (MS-NAF(LC)).
- ♦ Potentially acid-forming (high capacity) (PAF(HC)).
- ♦ Potentially acid-forming (reactive) (PAF(RE)).

An additional term, i.e., PAF hanging wall (PAF(HW)), is used for operational purposes to describe a high S PAF unit in the open cut hanging wall, but in terms of geochemical classification this is a high S subset of PAF(HC) that corresponds to a particular lithostratigraphic unit.

The changes in classification were based on review of previous static and kinetic geochemistry results and additional testing arranged by KCB (EIS Appendix M). The test suite used to help define the different classes was an appropriate combination of standard and specialised static tests. The criteria for each class use a combination of neutralisation potential ratio (NPR), S and key metals content. Selection of cut-off values for each class was based on standard classification criteria, KCB experience and geological observation. A detailed justification for the current criteria is outlined in EIS Section 6.4.2. Overall, the criteria appear to be appropriate given the information available and the nature of the geology. Kinetic testing is being used to help validate these criteria (EIS Appendix L), which uses appropriate methods including humidity cells, leach columns and barrel tests.

The criteria for the LS-NAF material are key, since this is the only material considered benign on site, and are defined as follows:

LS-NAF(HC): $\text{NPR} \geq 2$ and $\text{S} < 1\%$ and $\text{Zn} < 0.4\%$ and $\text{Pb} < 0.04\%$ and $\text{Cu} < 0.07\%$

The LS-NAF criteria appear to be conservative (high NPR ratio and reasonably low S content) and appropriate based on the experience of the IM. This is supported by the distribution of S in typically NAF units with less than 1% S shown in Figure 6-8 of the EIS (page 6-26), in which approximately 90% of samples have a S value less than 0.5% S. The metal criteria were based on shake flask and NAG solution analysis, and hence were preliminary, pending kinetic test results.

New criteria are proposed in the EIS for LS-NAF (Section 6.4.3), which utilises the same NPR and S cut offs but a different suite of metals and cut offs:

LS-NAF(HC): $\text{NPR} \geq 2$ and $\text{S} < 1\%$ and $\text{Zn} < 0.12\%$ and $\text{Pb} < 0.04\%$ and $\text{As} < 40 \text{ ppm}$ and $\text{Cd} < 10 \text{ ppm}$

This change is based on results of kinetic testing, and a change in priority metal contaminants of concern (COC). The revised criteria appear justified and conservative based on results presented.

The PAF(RE) criteria are also key, since this material requires special handling to prevent self heating (spontaneous combustion). The current criteria distinguish PAF(RE) from PAF(HC) based only on a total S cut-off of 10%S, which is not clearly justified. There are also proposed revised criteria for PAF(RE) (EIS Section 6.4.3.2.7), which introduces a lithological parameter as follows:

PAF(RE): Black Bituminous Shale and $\text{S} > 10\%$

Restricting the PAF(RE) to the Black Bituminous Shale is appropriate, since the organic carbon component is a crucial contributor to the spontaneous combustion reaction. However, the reason for selection of the 10%S cut off is not given. The use of combined Black Bituminous Shale and $\text{S} > 10\%$ criteria is justified on the basis of matching block model distributions with observed evidence of spontaneous combustion, but this is not demonstrated in the text (EIS Section 6.4.3.2.7). While the PAF(RE) criteria appear to be reasonable, further justification is required.

The sulfate trends from kinetic testing (EIS Appendix L) to date are consistent with the geochemical leaching characteristics expected from the various material types, with LS-NAF samples producing the lowest SO_4 concentrations and PAF(RE) showing the highest. All NAF samples produced circum-neutral pH leachates, supporting the classification. Most of the PAF samples also typically produced circum-neutral pH leachates (apart from one PAF(RE) sample), reflecting a lag period due to high ANC contents. The kinetic testing results support the classification system in general, but long lag times in the order of years to decades can be expected and long-term operation of the kinetic tests would be required to confirm the criteria.

Overburden classes have also been linked back to geological units (EIS Section 6.6) based on the geochemical datasets available, including ABA analysis of over 4000 samples. The clear lithostratigraphic controls on the distribution of pyrite and carbonate (EIS Section 6.2.2) improves the confidence in application of classification criteria.

The geochemical testing and investigations carried out for overburden materials include a comprehensive dataset with an appropriate suite of static and kinetic tests. The IM considers that the geochemical properties of overburden materials at the mine are well understood, and that the classification system is generally well justified and is expected to be reliable. The main exception is that the validity of the PAF(RE) cut-off value of 10%S should be better demonstrated.

2.1.4 Overburden Segregation and Handling

The process of overburden segregation and handling is described in EIS Sections 6.5 to 6.7.

Block modelling from 2005 to 2013 used a %Fe proxy to segregate PAF and NAF, which did not account for MS-NAF materials. The current criteria (from 2014) uses a %S proxy to represent the five current overburden classes. The EIS proposes improved block model criteria using total S, ANC and Zn and Pb. The addition of the ANC better matches the class definitions detailed in EIS Sections 6.4.2 and 6.4.3. The number of samples tested for total S and ANC and used in the

block model is not explicitly stated, but it is assumed to be approximately 10,000 for total S and approximately 4,000 for ANC, based on the description of the drill hole database in EIS Section 6.3.3.1. Spread over the whole deposit, this data set appears to be insufficient to create a reliable block model. However, the lithostratigraphic controls would add more certainty to the block model interpretation. Reference is made to how overburden classes predicted from block modelling often match particular lithostratigraphic units (EIS Section 6.5.2.1), but it is not clear to what extent the geology is used to refine the predicted distribution of overburden classes in the resource block model.

In-pit grade control is carried out with a portable XRF (pXRF) to check block model classifications. The pXRF classification is based on using Ca and Mg as a proxy for ANC, together with S and metals/metalloids to include the same set of parameters as the block model. The use of Ca and Mg as a suitable proxy for ANC was demonstrated for ICP results (EIS Figure 6-40) but not XRF results. The validity of using a pXRF for reconciliation of the resource block model is not clearly demonstrated.

The in-pit grade control results are used to produce a map of overburden classes for production plans. The overburden class descriptions in EIS Section 6.6 provide clarification on how the lithostratigraphy is used to refine the boundaries of the different classes, with a degree of conservatism applied so that only those units known to be consistently benign (based on geology and test work) are mined as LS-NAF(HC), comprising Quaternary Alluvium, Upper Breccia, W-Fold Shale and Teena Dolomite.

Global positioning systems are used to track placement, and quality control checks are carried out monthly, comprising around 250 samples a year. The quality control sampling density is proportional to the amount of material moved based on international guidelines. Note that in EIS Figure 6-45 the sampling frequency for NAF samples either has a misplaced comma, or is missing a 0, and it is uncertain whether samples of NAF materials are collected every 10,000 t or 100,000 t. While use of guidelines is a reasonable starting point, sampling densities need to consider site-specific geological variation and key concerns. Additional monitoring is carried out for PAF(RE) materials, comprising thermal monitoring in-pit, and visual, thermal and gas monitoring at the OEFs. The quality control approach appears suitable, but there is no information on performance and feedback into, for example, suitability of sampling density. There is mention in EIS Section 3.4.4.2.3.2 that PAF(RE) material was misplaced in the SOEF, which did not appear to be detected until obvious signs of spontaneous combustions were observed.

Overall, the system of materials segregation and handling appears appropriate; however, more information is required on:

- ♦ How lithostratigraphic controls are used in the resource block model.
- ♦ Calibration of pXRF testing for grade control.
- ♦ Performance and variation of quality control checks and suitability of the sample density for the site geological/geochemical variation.

2.1.5 Current and Future Geochemical Hazards of OEFs

A consequence of the previous classification system was that overburden thought to be NAF and placed in the various OEFs will include MS-NAF. In addition, previous overburden management did not account for the fine grained and highly reactive nature of the pyrite in the PAF overburden, and convection/advection controls were not implemented. The PAF materials were generally end tipped in lifts of approximately 15 m, resulting in segregation of coarse and fine materials and creation of chimney structures that encourage rapid convective oxidation and acid generation, and spontaneous combustion in the case of PAF(RE) materials. The existing OEFs on site therefore represent legacy issues that need to be accounted for in AMD management in addition to new materials to be mined.

There are currently three main OEFs, i.e., the southern (SOEF), western (WOEF) and northern (NOEF).

The SOEF is temporary, with the non-benign overburden planned to be re-handled and placed back into the open cut for closure. The existing SOEF is described in EIS Section 3.4.4.2.3, and comprises a base of alluvial materials mined from the open cut and placed between 2010 and 2011, with mixed MS-NAF and LS-NAF (prior to revised classification) placed in 2013, and mainly MS-NAF from 2015. A small portion of PAF(RE) material was also accidentally dumped there in 2015. EIS Table 3-9 shows a breakdown of overburden types placed in 2015, which indicates that the composition of the SOEF is well defined, presumably based on tracking of materials dispatch. McArthur River Mining has assumed that the SOEF is MS-NAF for management purposes, which is appropriate, with the main geochemical hazard being the leaching of pH neutral saline and metalliferous drainage. Groundwater monitoring has confirmed this, with elevated sulfate and Zn concentrations measured below the SOEF (EIS Section 3.4.4.2.3.3). The identified hot spots of PAF(RE) are acknowledged as a hazard requiring separate management for control of temperature and gas issues, but are unlikely to greatly affect the overall leaching characteristics of the SOEF.

Further limited placement of MS-NAF at the SOEF is expected during operations, which will change the volume of material but is unlikely to substantially change the current geochemical hazard.

Groundwater investigations discussed in EIS Section 3.4.4.2.3.3 indicate that any seepage from the SOEF will tend to flow towards the open cut.

The geochemical hazards of the SOEF generally appear well defined and the primary pathways of seepage understood. The pH neutral saline and metalliferous leachate is the main potential issue, which is expected to mainly drain to the open cut during operations. For closure, the SOEF MS-NAF materials (and hence leaching hazard) will be primarily transferred to the open cut, with some MS-NAF used at the WOEf for re-shaping. The alluvial materials are assumed to be benign and would be used in cover construction of the WOEf. Confirmation of the LS-NAF nature of the alluvial materials is not provided, and should be obtained before use in the WOEf cover.

The WOEf is described in EIS Section 3.4.4.2.4, which was developed in 2005 to 2008 at the start of open cut mining. It is planned to be a permanent OEF, but no additional overburden will be placed there during operations, and it will continue to be used for workshops, offices and ROM

pad. There is a general description of materials placed in the WOEF, comprising a NAF base (mixed LS-NAF and MS-NAF), with a PAF cell (presumably mixed PAF(HC) and PAF(RE)) encapsulated in clay, and with more NAF placed on the outside. The PAF appears to have been mainly end tipped in 2 lifts to 20 m high. Although the general nature of the overburden and construction configuration are described, there is no detail provided on the geochemical characteristics and the nature and performance of the existing cover. Conceptual modelling indicates that most seepage from the WOEF will drain eastwards to the open cut, with a small portion draining north to the Barney Creek Channel. The geochemical hazard represented by the WOEF appears to be understood in a general sense, but further work would be required to define the geochemical characteristics and hydrology, to better understand the suitability of proposed management during operations and closure.

The NOEF is described in EIS Section 3.4.4.3. The NOEF is the largest dump at McArthur River Mine, currently holding approximately 200 Mt of overburden and covering an area of 228 ha. The NOEF would hold over 750 Mt of overburden at the end of the proposed mining in 2032 and cover an area of approximately 525 ha.

The existing NOEF has been used for overburden placement since 2008, and was largely constructed prior to the change in classification and appreciation of the extent of site geochemical issues. The dump comprises an undifferentiated NAF base to the 100 year flood level, undifferentiated PAF cells end tipped in 15 m lifts, a 20 m thick undifferentiated NAF overburden outer zone, and interim clay layers between PAF and NAF materials. This design did not account for the presence of MS-NAF materials in the NAF zone, and the end tip placement encourages rapid oxidation of PAF(HC) and PAF(RE) materials, with spontaneous combustion effects readily observed from the facility. Appendix H of the EIS outlines investigations carried out to better understand the geochemistry and distribution of overburden classes in the existing NOEF, which involved:

- ♦ Using historical survey records, mining production data, and geological block model to reconstruct the placement of overburden classes in the NOEF as a block model.
- ♦ Drilling into the NOEF to obtain in situ geological and geochemical information to calibrate the NOEF block model and provide a visual measure of the degree of oxidation in overburden materials.
- ♦ Measuring temperature and gas compositions in drill holes to better understand internal dump oxidation conditions and reactions.
- ♦ Installing groundwater monitoring bores to better understand NOEF hydrology and groundwater quality below the NOEF.

Results of the NOEF block model reconstruction indicate that PAF(HC) makes up 13% of the NOEF and PAF(RE) 5%, lower than that expected based on historical volumes reported due to past conservatism in PAF classification. Results also confirm that the NOEF NAF base has both LS-NAF and MS-NAF, but is dominated by MS-NAF at 60%. Gas and temperature monitoring confirmed that advective oxidation is occurring. There is a comment in Appendix H (pages. 52 and 64) that the low oxygen measured in the NOEF means that oxygen is limited in the interior, resulting in control of oxidation rates and preventing run-away self-heating and combustion of the

PAF. While the low oxygen concentrations do show that the rate of oxidation exceeds oxygen supply, the results alone do not confirm anything about air movement or oxidation rates, and any assumptions about limited oxidation in the dump interior and controls on spontaneous combustion require other evidence. The temperature profiles discussed in EIS Appendix H (Figures 33, 34 and 37) show high temperatures at various depths, indicating rapid and convective oxidation within at least portions of the interior of the dump. Note also that the while background temperatures of 65°C do not indicate spontaneous combustion, they are indicative of convective oxidation and rapid AMD generation rates. The elevated temperatures measured throughout the PAF cells indicate high rates of oxidation, and do not support the concept of limited oxygen in the dump interior.

Chapter 4.6 of EIS Appendix T discusses the main pathways for seepage and water flow for the NOEF, which identifies the key migration pathways of any seepage, with the main receptors being Surprise Creek to the southeast and Barney Creek diversion channel to the south and southeast.

The approach taken to better define the geochemical hazards and key seepage/flow pathways of the existing NOEF is considered appropriate by the IM. However, there was no incorporation of water quality results for groundwater underneath the NOEF, and the implications for interpretation of AMD processes and seepage currently occurring. Figure 8-11 of the EIS shows clear evidence of high sulfate in this groundwater.

The future geochemical hazards of the NOEF will depend on the breakdown of overburden classes to be mined, which are linked to the block modelling discussed in EIS Chapter 6. A new schedule has been produced for the LOM split by overburden class (EIS Figure 3-28 and Table 3-8), which the IM expects to be reliable for the purposes of long-term planning based on the information provided.

An eastern OEF (EOEF) is proposed in addition to the three existing OEFS, which will be used for temporary storage of various materials types (alluvial materials, low grade ore, PAF(HW)), with non-benign materials in the EOEF being placed back in the open cut once mining ceases. Drainage would be directed to the open cut. The geochemical hazards of the EOEF are considered to be well defined.

The current and future geochemical hazards of the OEFs are generally well defined, except for the following:

- ♦ Testing should be carried out on the SOEF alluvial materials to confirm the LS-NAF nature since it will be used in the WOEF final cover.
- ♦ Further information should be provided to better define the geochemical characteristics and hydrology of the WOEF, which are currently described in a general sense only.
- ♦ The suggestion that oxidation is limited in the interior of the NOEF based on low oxygen concentrations should be re-assessed.
- ♦ Water quality results for groundwater underneath the NOEF should be incorporated into interpretation of AMD processes and seepage currently occurring in the NOEF.

2.1.6 NOEF Management

The long-term management of the NOEF is paramount to controlling geochemical impacts on the receiving environment at MacArthur River Mine, and this OEF is appropriately the main focus of investigation in the EIS. Significant effort has been made by MRM to better understand the mechanisms and rates of pyrite oxidation, resulting seepage water quality, and transportation pathways to help formulate management strategies during operations and into the long term.

Section 3.4.4.3 of the EIS summarises the proposed management of the NOEF and supporting investigations. Long-term management involves construction of stable landforms that minimise advection within the facility and placement of a cover system to control infiltration and oxidation. Management during operations is focussed on collection and treatment of seepage and runoff. As noted previously, much of the existing NOEF was constructed in a manner that promotes advective oxidation, and these zones will not be modified, relying on the future construction and cover system to control geochemical impacts from historic materials. Although the management approaches described in the EIS are consistent with best practice, there is considerable uncertainty in successful implementation and the long-term (1,000 years) performance at McArthur River Mine, which is described in more detail in the following sections. The key areas of uncertainty are:

- ♦ Given that the NOEF is a major geochemical hazard for the site, modelled predictions of seepage quality carried out to date should be independently verified.
- ♦ It is doubtful that installation of a contiguous low permeable (1×10^{-9} m/s) CCL barrier layer over the entire surface of the NOEF is achievable.
- ♦ The integrity of the proposed cover system is obviously critical to long-term performance, but it has not been demonstrated that this can be managed with maintenance and repair for the proposed 1,000-year closure period.
- ♦ The effectiveness of the proposed advection control barriers on the large, heterogeneous and actively convecting system represented by the existing NOEF has not been demonstrated.
- ♦ There is no prediction of differential settlement in the NOEF and its potential impact on the relatively thin infiltration control layer.
- ♦ The above uncertainties suggest that the modelled geochemical impacts from the NOEF may be optimistic, leading to consequent uncertainties concerning the scale and duration of surface water and groundwater collection and treatment requirements.

2.1.6.1 NOEF Cover System

The NOEF design concept presented in EIS Section 3.4.4.3.3 and illustrated in Figure 3-47 is a valid approach to managing AMD from pyritic materials and consistent with best practice, along with the concept of reducing the footprint by increasing the final elevation of the NOEF. The trilinear concave batters to be used around the perimeter of the final landform are similar to the surrounding topography and are expected to limit erosion.

The key conceptual findings of modelling work summarised in Section 3.4.4.3.3 (p. 124) listed below are considered valid:

- ♦ Infiltrating waters in the NOEF travel largely in a vertical direction towards the foundation. Internal sloped compacted clay covers (CCLs) result in only minor deflections of the seepage pathways due to the limited permeability contrast between the CCL and rock, and limited slope angles.
- ♦ Geochemical modelling indicates that concentrations of many elements in the moisture within the NOEF are likely to be solubility controlled, therefore seepage will have relatively constant values (concentrations) for a long time. This means that loadings from the NOEF will be directly related to the rate of water flow through the NOEF as infiltration.
- ♦ Net percolation (NP) through the outer protective cover of the NOEF is the main potential inflow of water into the NOEF in the long term. This is proportional to the NOEF footprint area. Therefore, for the same cover system specifications, a reduced footprint will result in smaller loadings to seepage.
- ♦ The McArthur River Mine overburden is characterised by a very high acid consumption capacity, and even PAF lithologies contain a high intrinsic buffering capacity. The principal water quality related issues to manage over time are likely to be saline and neutral metalliferous drainage with elevated sulfate and Zn levels in seepage waters.
- ♦ Due to the height of the NOEF, the seasonal response of seepage movement towards the foundation is muted, with the increased wet season infiltration rates observed more as relatively constant seepage rates over a whole year at the foundation.

The NOEF design focuses on two key aspects: the control of advective oxygen transport to PAF(RE) cells and the core PAF(HC) + MS-NAF zone to reduce pyrite oxidation rates and generation of AMD and limit spontaneous combustion from PAF(RE) materials; and control of net percolation to reduce seepage rates and contaminant loadings. However, the IM believes that there are significant performance uncertainties in regard to the proposed design for both of these aspects, and particularly in relation to the long-term (1,000 years) sustainability. Further information, including field testing programs, is required to measure and demonstrate acceptable in situ performance for the proposed advection barriers and final cover zone.

NAF Base Layer

The base of the existing NOEF comprises an undifferentiated NAF base and was designed to keep overlying PAF and low grade stockpiles above the 1:100 flood level. Block modelling showed that this NAF layer is mainly comprised of MS-NAF materials. The new portions of the NAF base layer will also mainly comprise MS-NAF, with LS-NAF materials reserved for the outer cover zone. This departs from the previous design concept of only benign materials being placed in this layer, but is justified in the EIS on the basis of the planned implementation of additional flood protection measures, including encapsulation of the entire base zone in the cover system and 100 year flood protection barriers keyed into the basal clay layer. The reasoning is supported by the IM, particularly since the principal impacts from the NOEF are likely to be through seepage from PAF materials into the groundwater system.

In newly-developed areas of the NOEF, the foundation layer for the NAF base layer will be compacted to direct any seepage passing through the NOEF towards an appropriate Perimeter Runoff Dam (PROD). The foundations under much of the existing NOEF do not have a basal compacted layer, and any seepage from the existing NOEF (expected to contain elevated sulfate and metals) is expected to report to Surprise Creek to the southeast and Barney Creek diversion channel to the south and southeast.

PAF Cell Construction and Advection Barriers

In EIS Section 3.4.4.3.3.2, it is stated that the storage of high pyrite PAF(HC) and PAF(RE) in a low oxygen environment to limit the generation of oxidation products may be achieved with the placement of materials in low lifts followed by compaction and encapsulation with fine-grain advection barriers. It is understood that fine-grained alluvial advection barriers are being installed around existing end-tipped PAF materials. Gas monitoring in the cell indicates that very low oxygen levels exist and it is suggested that the compacted clay layer underlying the PAF materials is providing a barrier to advection (EIS Section 3.4.4.3.1). In addition, it also stated that the advection barriers will shut down reactions over time.

Section 3.4.4.3.3.2 states that the core of the NOEF will be constructed with oxygen advection limiting techniques, including:

- ♦ Constructing thin lifts of 2 m thickness or less to limit particle segregation and enable consistent compaction through the rock matrix. and/or
- ♦ Constructing lifts up to 7.5 m high with regular advection barriers composed of suitably compacted and moisture-conditioned fine-grained materials.
- ♦ Incorporating advection barriers into each inter-stage face that will be exposed for over six months (refer to EIS Figure 3-68).

Section 3.4.4.3.3.4 of the EIS states the following in relation to the PAF(RE) cells:

- ♦ PAF(RE) will be placed in 2 m lifts or paddock dumps with heavy compaction. Prior to each wet season, an advection barrier layer will be placed to seal the material off from oxygen, followed by a low lift of MS-NAF to further limit gas diffusion and water infiltration, and reduce erosion of the advection barriers. These techniques have been used effectively in 2016 for managing the placement of PAF(RE).
- ♦ Scheduling guidelines to limit the mining of PAF(RE) during the wet season will be used to reduce the volume of PAF(RE) that is exposed to wetting, which is a known trigger of enhanced oxidation.

The concepts and design of the NOEF PAF cells and advection controls summarised above are an appropriate approach; however, field trials must be carefully designed and executed to test the proposed control measures and confirm that advection can be successfully managed. Failure of the advective barriers would lead to continued high oxidation rates and contaminant release during operations, and high temperatures in the NOEF. This is particularly important for the existing end-tipped PAF portions of the NOEF in which convective oxidation is already occurring.

A conceptual model for air and water movement through the NOEF is presented in EIS Section 3.4.4.3.3.1, which forms the basis of predicting seepage quality from the NOEF. That section is a summary of DumpSim modelling work carried out O'Kane Consultants (OKC), with more detail contained in EIS Appendix P. The DumpSim model is a one dimensional analytical model and an OKC proprietary tool. It comprises a number of modules to model heat generation, gas flux, water flux, AMD load generation and pore water quality. The main model inputs include the overburden class distribution (existing and over the LOM), physical/hydrological properties of the various materials, climatic data, temperature profiles, and results of kinetic test work. The key water quality outputs produced by the modelling were sulfate, Zn, Pb, Cd, As concentrations, and pH and redox potential.

Overall, the IM finds Section 3.4.4.3.3.1 to be confusing, and it is unclear how the various DumpSim modules interact to produce the predicted outputs. Further explanation is required on whether the acid generation predicted is solely a function of air permeability/gas flux, and how this links with pore water quality prediction derived from kinetic testing. In addition, Figures 3–50 and 3-51 are poorly explained, as is the relationship between these two figures. Figure 3–50 appears to be based on the 1D DumpSim model while the gas fluxes presented in Figure 3–51 were generated by the TEMP/W and AIR/W models. Figure 3-53 is also very difficult to interpret, and a legend would be most helpful.

While the approach used by OKC appears appropriate, the model is complex and it is difficult to judge the validity of the model seepage water quality predictions without an in-depth assessment of the data and assumptions, and a clearer explanation of how the various modules interact. It is recommended that consideration be given to independently reviewing these model results using other industry standard models such as ToughAMD or SULFIDOX, and including consideration of the effects of compromised final cover performance and higher seepage rates on the receiving environment.

Although the overall balance of PAF and NAF materials in the NOEF indicates that seepage would mainly represent a saline and neutral metalliferous drainage issue, given the highly pyritic nature of these materials and lack of data on lag times and long-term neutralisation effectiveness, assessment of potential down-gradient impacts should consider the effects of acidic leachate from portions of the dump. There may be situations in which PAF materials produce acid drainage that does not directly interact with NAF materials and hence is not neutralised before reaching the underlying groundwater system. This is particularly relevant to the existing end-tipped PAF cells in the NOEF, where convective oxidation and rapid rates of AMD generation are occurring.

The results of a drilling program completed for the existing end tipped PAF materials in EIS Section 3.4.4.3.2.2 generally show very low volumetric water contents, with no seepage or liquid water found above the foundation CCL. The IM agrees this is most likely due to the high internal temperatures (background of 65°C with very high temperatures of 100 to 200°C in portions of the NOEF), which promote rapid vaporisation. An additional effect is the potential for high water vapour partial pressure, which is likely to further drive advection processes. As noted in Section 2.1.3 of this report, gas measurements showed very low oxygen levels, i.e., below 1%, but the conclusion that oxygen is consumed and that the low oxygen levels significantly reduce oxidation rates is not supported by the observed high temperatures. The IM does not believe that the gas transport properties of the NOEF under the current high temperatures are fully understood. The

hypothesis that external advective oxygen barriers will shut down reactions over time (EIS Section 3.4.4.3.1) needs to be verified with comprehensive field testing and monitoring programs. While the proposed advection barriers are an appropriate approach, the effectiveness of these barriers on a large, heterogeneous and actively convecting system has not been demonstrated in the EIS.

Appendix I of the EIS discusses advection control modelling that has formed the basis of the proposed 7.5 m lifts for PAF(HC) materials in the LOM NOEF, with each lift comprising a 2 m paddock dump at the base and a 5.5 m high tip head over it. The modelling utilised the DumpSim Model and various dumping scenarios, and assumed that advection barriers were constructed with alluvial materials. Again, while the modelling is a valid tool for assessment, trials are essential to confirm that such a design will appropriately limit oxidation in these highly pyritic PAF materials. There is a comment in Section 6.1.1 of Appendix P that McArthur River Mine overburden materials appear to have a high propensity to segregate even along relatively short tip heads, and modelling showed that paddock dumping of PAF materials resulted in significantly lower predicted rates of contaminant release than 5 m end tipping (Section 9), suggesting that the risk of advection from these 7.5 m PAF(HC) lifts requires further investigation. Details such as the methods of construction, frequency of advection control layers, and cell dimensions for these PAF(HC) and PAF(RE) materials are not clear from the description in EIS Section 3.4.4.3, which also makes it difficult to judge the likely performance of the proposed designs.

The principle of adaptive management based on a period of scheduled periodic inspection and maintenance to rectify performance problems as the landform is constructed is strongly supported. Time frames in the order of 50 years after rehabilitation are mentioned. However, in the case of using advection barriers for the PAF(HC) and PAF(RE) cells, performance needs to be evaluated in the short term well before they are encapsulated by halo embankment. Construction of full-scale trial dumps may need to be considered to assess behaviour of the various waste rock materials, as was completed at the Grasberg Mine in Indonesia as well as the Antamina Mine in Peru.

Section 3.4.4.3.2.2 of the report states that 'ongoing monitoring of temperatures and gas composition will allow MacArthur River Mining to determine the effectiveness of implemented controls on aspects of convection and air movement within the NOEF'. Furthermore, it is stated that 'the data gathered through the back-analysis of the existing NOEF has been used in both modifying the development of the NOEF in the pre-EIS period, and in developing the post-EIS NOEF conceptual model and mitigation solutions'. Such monitoring and back analysis is most strongly supported and encouraged.

The Cover Zone

Section 3.4.4.3.3.6 of the EIS states that:

The role of the Cover zone is to restrict oxygen ingress, store water to promote plant growth, and shed excess water down purpose-built drains in higher intensity rain events whilst resisting erosion. It works together with the landform (overall size and shape) to achieve these goals. It must have a high degree of constructability, using skills, methods, equipment and materials readily available and at a rate consistent with the needs of the mining schedule. The materials used in oxygen and water management controls must be resilient or easily renewed/replaced considering the life of the facility.

A critical component of the cover system is the continuous CCL barrier layer meant to reduce water infiltration and oxygen ingress to the NOEF. The CCL barrier layer extends from the top of the facility to below ground level to integrate with the barrier layer in the foundation.

The IM considers the proposed design to be generally consistent with best practice, but site conditions will make implementation and long-term (1,000 years) performance challenging. The design of the cover system is multimodal in that it combines water shedding, store and release, and barrier mechanisms. Nevertheless, the proposed cover system may not adequately diminish net percolation. A crucial requirement for the cover zone will be to obtain a contiguous low permeable CCL barrier layer over the entire surface of the NOEF and that this may prove to be very difficult to achieve given the large area and the low infiltration target (1×10^{-9} m/s). Alternate infiltration control layers such as HDPE and bituminous geomembranes should be evaluated.

A key to proposed overburden management is successfully identifying and segregating sufficient resources of LS-NAF, and ensuring sufficient resources of clay. The development of the Woyzbun Quarry appears to ensure that there are sufficient LS-NAF resources for current management strategies, plus excess resources not planned to be mined but that could be used if required (EIS Table 3-11). Development of the open cut and preparation of the NOEF foundations will also produce excess clay.

It is understood that the maximum height of the NOEF would be increased to 140 m so that the facility can provide the necessary storage capacity within a smaller footprint. The use of the trilinear concave batters in the NOEF as summarised below to manage runoff and erosion is supported:

Lower-slope section: 0 to 55 m elevation; batter angle 1V:4.5H.

Mid-slope section: 55 to 100 m elevation; batter angle 1V:3.5H.

Upper-slope section: 100 to 140 m elevation; batter angle 1V:2.5H.

The total surface area of the NOEF will be 525 ha with approximately 128 ha (25%) creating the upper plateau and about 397 ha (75%) forming sloping batters. Section 3.4.4.3.3.6 of the EIS states that the NOEF cover system shown in Figure 3-57 will comprise:

- ♦ A barrier layer at the base (nominally a 0.5 m CCL with a maximum saturated permeability of 1×10^{-9} m/s) placed over a thin layer of fine-grained alluvial material rolled into the halo to reduce the risk of piping failure.
- ♦ A 0.5 m thick drainage layer of coarse LS-NAF rock overlying the CCL, linked into the surface drainage system. This is required to convey excess water during intense rainfall events off the barrier layer, reducing ponding and net percolation.
- ♦ A 1.5 m thick alluvium growth media (GM) zone overlying the drainage layer, and 0.1 m of topsoil. The fine-grained GM will enhance plant establishment and evapotranspiration, while coping with the low erosive forces present on the gently sloped plateau. A 0.1 m thick topsoil layer will be placed over this growth media.

- ♦ Separation of the plateau into sub-catchments, with surface water runoff being conveyed down purpose-built drains incorporated into the haul ramps. The drains will include an underlying geomembrane to provide initial stabilisation through the adaptive management phase, with suitably sized coarse durable LS-NAF rock utilised for drain construction.
- ♦ A plateau crest that will be higher than the interior where practicable, to shed water away from, and prevent overtopping of, the crest. Effective drainage around the crest will enhance geotechnical stability of the steeper upper slope section of the NOEF.

The base case batter cover system is defined as:

- ♦ A barrier layer at the base of the cover system, consisting of a 0.5 m thick CCL with a maximum saturated permeability of 1×10^{-9} m/s placed over a thin layer of fine-grained alluvial material rolled into the halo to reduce the risk of piping failure.
- ♦ A 2.0 m thick GM layer comprising coarse LS-NAF(HC) to provide acceptable erosion performance and adequate drainage while balancing the requirements of supporting vegetation and maintaining the saturation of the CCL.
- ♦ A 0.1 m thick topsoil layer, integrated into the GM layer in a manner that controls the potential for excessive topsoil erosion but enables vegetation establishment.
- ♦ Limited vegetation establishment on the upper rocky slopes, particularly the steeper slopes. Vegetation establishment on the lower slopes is anticipated to be successful with an anticipated resultant appearance being consistent with the rocky escarpments and vegetated lower slopes of the surrounding area.
- ♦ Depending on the season and location, possible utilisation of soil stabilisation methods such as hydromulching or erosion matting.

As stated above, the permeability of the 0.5 m thick CCL is considered most critical as it is assumed to have a maximum saturated permeability of 1×10^{-9} m/s. The EIS states that 130 laboratory saturated hydraulic conductivity tests have been completed by MRM and reports a range of saturated permeability values between 1×10^{-11} m/s and 3×10^{-9} m/s. The range of liquid limits and plastic indexes for the CCL materials supports these values of measured permeability. Furthermore, the IM considers reported relationships between dry density, water content and measured laboratory permeability the data for the CCL to be credible.

Section 3.4.4.3.3.7.1 of the EIS describes the landform drainage features for the NOEF and the IM considers the conceptual design to be appropriate.

Section 3.4.4.3.5.4 of the EIS describes instrumentation and monitoring. The proposed monitoring system is generally considered to be appropriate but the IM recommends the early establishment of cover test trials allowing for long-term monitoring to evaluate the performance of the conceptual design well in advance of completing the final cover system.

The general concepts and principles employed for the design of the NOEF cover zone are considered to be well conceived and consistent with best practice, in that they integrate the mechanisms of i) water shedding, ii) store and release, and iii) infiltration/oxygen barrier. While

the proposed monitoring system is supported by the IM, the primary risk is that the monitoring system will be installed after construction is complete, and thus the information gained from the monitoring system will not be obtained in time to modify or improve the design. This is considered a significant risk and it is recommended that MRM starts as early as possible to allow for modifications or improvements in the final cover design.

Achieving a maximum saturated permeability of 1×10^{-9} m/s for the CCL in the field will be challenging. The value of the saturated permeability needs to be verified with the construction of a full-scale lysimeter. Long-term large lysimeter infiltration trials would be most conclusive, especially over periods such as decades. These need to be constructed as soon as possible and not after the cover has been completed. The lysimeters should be used to optimise and provide the final design specifications.

Settlement monitoring employing a combination of surface monument surveying and high precision satellite monitoring is to be conducted upon completion. However, the EIS does not appear to predict how much settlement can be expected for the NOEF, or whether the cover systems as designed will tolerate the expected deformations. Settlements of 1 to 2% are common and in some cases can be as high as 10%, and such settlements can exceed the thickness of the final cover layer, potentially compromising the cover performance. For example, settlements could be large enough to cause the lateral drainage layer to fail resulting in the ponding of water above the CCL with a dramatic increase in net percolations rates. More information and analyses needs to be established in advance of the final design of the cover system.

Quality assurance/quality control (QA/QC) of the cover during construction will be paramount in achieving high quality performance. In general, experience with the mining industry has shown that the construction of high integrity liners and barriers can be difficult. The primary reason may be attributed to the preference for the use of heavy mining equipment as opposed to civil construction equipment for building earthen structures and barriers. In addition to this general trend for the industry, the McArthur River Mine site is subject to both wet seasons and prolonged dry seasons and hence water conditioning to achieve optimum water contents for compaction will be difficult. Furthermore, it is not clear how the compacted CCL will be protected from drying and cracking during construction. Finally, achieving low permeabilities of 1×10^{-9} m/s on the upper steeper slopes of 1V: 2.5 H is expected to be difficult.

The IM believes that the greatest risk to the long-term performance of the NOEF will be the leaching of oxidation products associated with excessive net percolation and that the final cover systems constructed should ensure the lowest possible flux of liquid water to the foundation of the NOEF. The IM is especially concerned that the required continuous low permeable integrity of the CCL barrier layer over the entire surface of the NOEF will not be achieved, particularly given the 1,000-year period referred to in MRM's Project closure objectives. The high performance offered by ultra low flux covers such as HDPE and bituminous liners should be further evaluated.

The EIS presents project alternatives (given in Chapter 5) and describes variations for the base case cover system with a bituminous geomembrane replacing the CCL as a barrier layer. The bituminous geomembrane has a manufactured thickness of 5.6 mm and the physical properties of the barrier are consistent with natural materials. The EIS suggests that the bituminous geomembrane is more robust than thinner geomembranes such as HDPE and that bituminous

membranes are considered to have low rates of degradation in buried environments such as the NOEF and can provide very low installed permeabilities.

While the EIS considers bituminous geomembranes to be suitable for high risk areas such as above the existing NOEF PAF cells, caution must be used to ensure such a cover is isolated from any residual high temperatures so it does not melt. The EIS has not demonstrated that control of the existing convective oxidation is achievable. However, the use of bituminous geomembranes in the NOEF surface cover may prove to be highly desirable. The low degradation characteristics of bituminous geomembranes referred to in the EIS (Section 5.5.3.5.3) are not conclusive and are currently being investigated at Queens University in Canada by Dr. Kerry Rowe.

The effects of temperature from existing PAF cells are also a consideration for compacted clay covers, with temperature effects potentially drying out the layer and affecting performance.

Figure 6.8 in Section 6.4.7 (EIS Appendix J Part 1) shows that net percolation for an HDPE cover increases dramatically from less than 5 mm to 50 mm after about 200 years. However, no information or background for this figure is provided, nor what basis was used for evaluating the performance of HDPE geomembranes at 30°C and 40°C. The IM recommends that this section be updated with an external peer review expert to provide additional insight into the long-term performance that might be expected from both HDPE and bituminous geomembranes.

Section 3.4.4.3.5 of the EIS describes a proposed staged construction, which will allow progressive rehabilitation and reduce the area of non-benign materials exposed. It is stated that the progressive cover placement transitions from a large area of exposed non-benign material to increasing portions of benign material. While this is true, it is also misleading since Figure 3-75 shows the actual area of non-benign materials from 2019 is at least the same or greater than the 2018 area, only reducing close to cessation of mining in 2030. Consideration should be given to options for more active infiltration control during operations.

In summary, a series of large-scale lysimeters to compare the performance of cover systems with a 0.5 m CCL, a HDPE geomembrane, and a bituminous geomembrane should be established immediately in order to provide at least 10 years of observation and monitoring to allow opportunities for modification if required before cessation of mining in 2036. The empirical data provided by such long-term trials will greatly assist in reducing the level of risk associated with seepage and leachate production from the NOEF.

Cover System Integrity

The integrity of the proposed cover system is obviously key to long-term performance, which relies heavily on a relatively thin 0.5 m compacted clay layer to control infiltration. Erosion is a major factor that could influence the cover integrity, which is acknowledged by MRM, and the cover system includes a number measures to reduce erosion, including:

- ♦ A growth medium layer designed to encourage revegetation for surface stability and act as a layer for storage and evapotranspiration of incident rainfall.
- ♦ Inclusion of a 0.5 m drainage layer in the cover on the plateau.
- ♦ Use of trilinear concave batters.

Appendix J of the EIS includes discussion on erosion impacts on the cover system, with modelling indicating that erosion can be reduced to rates that will be manageable with maintenance and repair. What is absent is a discussion of method, resources and equipment requirements to carry out such repair, or elaboration on the implication that the maintenance would be required for the entire 1,000-year period assumed in the closure objectives.

Other factors that could affect the cover integrity include differential movement through normal dump settling (as discussed above), or differential movement that is exacerbated by the effects of temperature differentials and local pressure effects in zones of active convection.

Some discussion on erosion and other potential effects on cover integrity is given in a Table 9.2 of EIS Appendix J and EIS Appendix F detailing results of Failure Modes Effects Analysis (FMEA), but there is no demonstration that the long-term risks to cover integrity (1,000 years) can be managed with maintenance and repair.

2.1.6.2 NOEF Surface Water and Groundwater Collection and Treatment

During operations, the NOEF's surface water management system will continue to direct runoff from non-benign areas to retention ponds called Perimeter Runoff Dams (PRODs) for storage and evaporation or treatment. Four PRODs will be used at the NOEF, the three existing dams, i.e., south PROD (SPROD), southeast PROD (SEPROD) and western PROD (WPROD), plus an additional east PROD (EPROD). Once the NOEF cover system is fully installed, WPROD and EPROD will be removed as long as monitoring does not indicate continued water quality issues (EIS Section 8.5.3.2). Both SPROD and SEPROD would be retained for open cut water management until approximately 2052 (EIS Table 3-7) assuming continued treatment of open cut water is not required.

Section 3.4.4.3.3.7.2 of the EIS indicates that shaping of surface slopes and maintaining drainage would be used to encourage surface runoff on the NOEF, but there is no firm commitment to placement of infiltration control layers to limit seepage prior to the wet season. PAF(RE) materials are the only exception, which would be compacted and have temporary wet season covers (EIS Section 3.4.4.3.1). Expansion of the NOEF footprint and lack of specific wet season controls on infiltration during operations means that AMD will continue reporting to groundwater, extending the period of higher seepage rates until the final cover is installed, and increasing seepage recovery efforts. Consideration should be given to options for more active infiltration control during operations.

Seepage will mainly be managed through collection and treatment. Modelling and groundwater investigations indicate that seepage would report to the lower Barney Creek, where it would be recovered from two collection sumps to help meet surface water quality commitments at SW11. Collection from the Barney Creek sumps is planned into the closure phase with water treatment as required (EIS Table 8-9), but it is unclear whether there is an expectation that collection from these sumps will ever stop.

The contingency for greater seepage recovery effort during operations and post closure for the NOEF is outlined in EIS Appendix Q, with a variety of mitigation options discussed. Given the uncertainties in the cover design and other controls, use of these mitigation options should be assumed, and more detail provided on what resources and equipment would be committed.

2.1.7 SOEF, EOEF and WOEF Management

Management of the smaller OEFs, i.e., SOEF, EOEF and WOEF, generally follows approaches planned for the NOEF. Both the SOEF and EOEF will be temporary OEFs, used for storage of mine materials during operations, but with non-benign materials mainly transferred to the open cut along with any associated geochemical issues. The WOEF will be permanent.

The SOEF contains mainly MS-NAF materials, except for some misplaced PAF(RE) materials. The identified PAF(RE) hot spots will be removed to the PAF(RE) cells in the NOEF. Runoff from non-benign parts of the SOEF would be directed to bunds and sumps for management as part of the contaminated water collection system. Seepage would not be actively managed, as it is expected to report to the open cut and be incorporated into the open cut seepage and groundwater management. Monitoring of groundwater would be carried out adjacent to the SOEF and MacArthur River diversion channel, and additional management carried out (such as infiltration control, seepage capture) if impacts are observed. Once mining ceases, some non-benign materials would be used for re-shaping the WOEF, and the alluvial materials at the base of the SOEF would be used in cover construction at the WOEF. The proposed management of the SOEF is considered appropriate.

The EOEF will include storage of excess alluvial materials, low grade ore and PAF(HW). The EIS states that PAF(HW) materials would be managed in a similar manner as PAF(RE) materials, with low lifts, compaction, advection barriers and erosion control, but no design details are provided. Low grade ore was reported to be a source of significant spontaneous combustion in the NOEF (EIS Appendix H), but no assessment of this and outline of management requirements are provided in EIS Section 3.4.4.2.2. As with the SOEF, surface water will be directed to bunds and sumps. The foundation of the EOEF will be sloped to direct seepage towards the open pit. The overall management approach for the EOEF appears appropriate, but further detail is required on PAF(HW) and low grade ore management.

Management of the WOEF during operations will utilise the current surface drainage system, and no active management of seepage is planned. Seepage is expected to mainly flow towards the pit, but a portion is expected to report to the Barney Creek diversion channel. Monitoring for evidence of seepage from the WOEF into Barney Creek diversion channel will be carried out, and water extracted from Barney Creek sumps as required. Once mining ceases, the WOEF will be re-shaped, using MS-NAF from SOEF as required, and covered as per the NOEF. As mentioned in Section 2.1.3 of this report, the benign nature of the SOEF alluvial materials should be confirmed before placement at the WOEF. While the management approach appears appropriate, more information on the distribution of overburden rock types is required to determine whether there are any material issues with existing convective oxidation or close proximity of PAF materials below the proposed cover.

2.1.8 Tailings Storage Facility

The geochemical test results for tailings are summarised in EIS Section 6.10, which included static testing of 150 monthly composites collected from 2009 and 5 in situ tailings samples collected to support the EIS, and humidity cell testing of 2 samples. The summary results indicate a general consistency in the tailings, with all samples classified PAF(HC), but with significant lag times (possibly years) expected due to high ANC contents of over 100 kg H₂SO₄/t. While the

duration and amount of testing carried out and the consistency of results described suggest that the tailings geochemical properties are well defined and the overall classification is reliable, the summary is brief and does not include the data that supports these conclusions. Figure 6-50 of the EIS, for example, is a plot of NAPP value versus NAGpH, but does not explain what tailings sample set was used, which appears to be much less than the 150 composite samples mentioned. Several tailings geochemical assessment reports are listed in Section 6.10, and inclusion of some of this information would help demonstrate the validity of the tailings AMD properties and classification presented. In addition, there is mention of tailings lag times being calculated for the tailings to demonstrate that the tailings are not likely to produce acid during the operations phase (EIS Appendix R, page 22) but no details are provided.

With the tailings planned to be re-processed and disposed in the open cut after mining, the key management issues for the TSF will be during operations, with any residual geochemical issues in the tailings after processing transferred to the open cut.

The EIS provides an overview of the LOM management for the TSF in Section 3.4.4.4 and 3.4.5, with more detail in Appendix R. Management of the TSF during operations will involve continuation of Cell 2 tailings disposal until approvals are obtained for a combined deposition in Cells 1 and 2. Cell 3 will continue to be used for water management, and Cell 4 will no longer be required. Once mining ceases, the tailings will be hydraulically mined and re-processed.

During operations, the main geochemical impacts on the receiving environment will be related to effects of seepage of tailings oxidation products and process water. The EIS notes that an Independent Tailings Review Board (ITRB) review in 2016 indicated that the existing elevated sulfate and metals impacts on Surprise Creek are more likely related to process water than tailings oxidation effects (Section 3.4.4.4.3.2). The reference is not cited in Chapter 16, and no details are provided regarding the reasoning except that the large volumes of water stored in Cell 2 until 2014 would have driven significant seepage. Cell 1 is adjacent to Surprise Creek, and given Cell 1 is not active, it is unlikely that the tailings contained therein are saturated. Kinetic testing reported in EIS Section 6.10.3 indicates that unsaturated tailings are likely to be oxidising at very high rates ($3 \text{ to } 4 \times 10^{-8} \text{ kg O}_2/\text{kg/s}$), and flushing of Cell 1 during the wet season would be expected to mobilise accumulated salts. It appears likely that the impacts on Surprise Creek are a combination of Cell 1 seepage of oxidation products and Cell 2 process water. Further justification would be required to support the suggested lack of impact from pyrite oxidation in tailings. However, during operations, management of infiltration will be key to minimising impacts on adjacent drainage, regardless of whether the source is process water or flushing of sulfide oxidation products.

Operations management of the TSF is detailed in EIS Appendix R, which involves encouraging beaching and maintaining a small decant pond, which will reduce seepage rates as well as provide greater stability. In addition, an interception trench is planned along the north wall of the TSF to control seepage into Surprise Creek, with pumping from sumps in Barney Creek in low flow periods. It is mentioned that the interception trench could be extended further around the eastern and southern perimeter of the TSF as required, but no trigger is mentioned as to when that would be considered.

Although the tailings are beached, results of testing 3 locations shows that the tailings still retain relatively high moisture (EIS Appendix R, Section 5.1), with moisture saturation to 150 mm depth ranging from 87 to 95%. Oxidation rates were measured in tailings at moisture saturations of 70%, 80% and 90% (EIS Appendix R, Section 5.2), which indicate low oxidation rates can be achieved in tailings if moisture saturations are maintained at 80% or more, which is put forward as a minimum target. Placement of these fresh tailings with saturation of 80% or more over Cell 1 is likely to greatly reduce any oxidation currently occurring. The need for monitoring surface tailings saturation is mentioned, but details are not provided, which should include field confirmation of the oxidation controls (e.g., pH, pore water quality) indicated by test work.

Overall, the TSF management actions appear appropriate during operations, and seem likely to minimise both seepage and oxidation, with seepage collection used to control direct impacts on receiving drainage.

The following further information should be provided to better demonstrate the tailings geochemical hazards outline and support the proposed management approaches:

- ♦ Provide more detail on tailings geochemical characteristics to demonstrate the validity of the tailings AMD properties and classifications, including estimation of lag times before acid production from tailings.
- ♦ Expand on the reasoning and data supporting the suggestion that elevated sulfate and metals impacts on Surprise Creek are more likely related to process water than tailings oxidation effects.
- ♦ Outline the situation or trigger whereby interception trenches would be extended further around the eastern and southern perimeter of the TSF beyond that currently planned for Surprise Creek.
- ♦ Provide more detail on the monitoring approach that would be used at the TSF to confirm saturation and control of oxidation.

2.1.9 Open Cut

Operations AMD management for the open cut mainly comprises pit dewatering and evaporation or water treatment. PAF(RE) and PAF(HW) in the pit wall are also managed to minimise oxidation and spontaneous combustion risk by avoiding berm development, and using temporary caps of alluvial materials where required, but this is more focused on gas management rather than AMD.

In-pit dumping of waste rock is proposed for the last 6 years of mining, with the in-pit dump (IPD) constructed in 16 m lifts. The IPD will exclude PAF(RE) and PAF(HW) materials to minimise the risk of gas generation, but will include other PAF(HC) materials and MS-NAF. Experience at the existing NOEF shows that end tipping in lifts this high will most certainly cause segregation, advection and high oxidation rates and AMD generation, even if spontaneous combustion is less of a concern. Ultimately, these materials will be inundated, and the advection issues resolved, but the AMD generated will increase the pit water treatment efforts required during operations and pit filling.

Once mining ceases, non-benign materials from the SOEF and EOEF will be backfilled into the pit. Shortly after mining ceases, tailings will start being rehandled, processed and placed into the pit, which is planned to occur over a 10 year period. The pit will be actively de-watered while the tailings are being deposited to limit the depth of water that waste rock and tailings are placed into for operational efficiencies. The materials placed into the open pit will leach AMD products along with sulfidic materials in the pit void, which will be managed with evaporation and water treatment.

Once tailings deposition has ceased, the waste rock and tailings placed in pit and exposed sulfidic wall rock are expected to continue to mobilise AMD products as the pit is filled with water, but oxidation will cease in materials that are inundated. A portion of the pit walls will remain exposed. Rapid filling of the open cut (estimated to occur over five years) from McArthur River is planned once tailings deposition has ceased, and this is expected to minimise oxidation. The pit would be isolated from McArthur River until pit lake water quality is confirmed to be suitable for mixing, at which point the open cut would be gradually incorporated into a secondary channel of the McArthur River, with seasonal flood waters flowing through the pit. McArthur River Mining has assumed that the water quality of the pit will not require treatment, but contingency is made for treatment as required until water quality targets are met (EIS Section 8.5.3.1). No specific time frame is given for treatment, but it is nominally assumed that in 2100 the open cut will have a flow through connection with McArthur River (EIS Table 3-7).

Open cut water quality predictions during operations are based on historic data from 2010 to 2014 (EIS Appendix U, Sections 5.2.3). The representativeness of the contaminant concentrations selected have not been assessed, but appear appropriate based on the nature of the rock types draining into the pit.

Post closure pit water quality was modelled by KCB (Appendix VI of EIS Appendix T), taking into account back fill of overburden (SOEF, EOEF and the last six years of mining) into the IPD and deposition of tailings. The modelling was carried out using GoldSim, a widely used software package that uses a mass balance approach to calculate water qualities. The GoldSim package does not consider pH or solubility constraints when determining water quality, and this was addressed by incorporating PHREEQC and Geochemists Workbench (GWB), which are well known geochemical modelling packages.

The modelling involved assigning contaminant loadings based on kinetic testing to overburden classes in the exposed final pit void, overburden classes in exposed waste rock materials, and exposed tailings, and also taking into account release of tailings pore water with consolidation. The modelling is carried out in time steps to allow for progressive inundation of reactive materials. The validity of the loading rates assigned has not been reviewed. The distribution of overburden classes and waste rock materials mined in the final six years and backfilled is based on the block model, which is expected to be a suitable basis for the modelling.

The uncertainties in the modelling are acknowledged in the report, and the description indicates that an appropriate degree of conservatism is used, including the assumption of no pit lake stratification, the assumption that oxygen extends to 50 m below surface, and no accounting for possible positive effects of blanketing of waste rock and pit floor by low permeability tailings.

The IM agrees that the modelling approach is appropriate and possibly conservative, with results indicating that acceptable pit water quality can be achieved long term. The modelling process is

described in general, and the resulting combined predicted pit lake quality is shown over time (Figures 14 to 22), but additional detail would help in understanding the assumptions, reliability and uncertainties of the modelling. This detail includes:

- ♦ Plots of kinetic test source data for loadings assigned.
- ♦ Loading rates assumed for oxidation of deposited tailings, and the predicted geochemical characteristics of tailings after processing, and water quality/loading rates assumed for tailings pore water.
- ♦ Plots showing the contribution of loadings from the various AMD sources over the simulation time.
- ♦ Some examples showing the process of assigning loadings, calculating mixing and use of PHREEQC/GWB to adjust for thermodynamics.
- ♦ Assess the effects of convective oxidation of PAF materials on loadings and water quality given the planned 16 m tip heads to be used in the IDP.

The overall open cut management strategy appears to be sound, and consolidating the tailings and selected non-benign waste rock into one facility for complete inundation is the most secure long-term management approach for these materials. Current understanding of the long-term geochemical behaviour of the open cut relies solely on the KCB pit water quality modelling. As with the NOEF, given that the open pit represents a major geochemical hazard for the site, the model predictions should be verified by an independent expert with additional sensitivity analysis.

2.1.10 Water Resource Impact Assessment

GoldSim modelling was used to assess the impact of site AMD sources on the receiving surface water system (EIS Section 8.2 and Appendix U Section 8 and 9), comprising a whole-of -site water balance model and a waterways model. This was not reviewed in detail, but the key AMD inputs to the model are from water quality prediction modelling of the NOEF and open cut, already discussed in this report above. The approach used in the modelling appears suitable, but would benefit from an independent review, taking failure modes into account for the two key sources, i.e., the NOEF and open cut. A worst case should also be considered, and the ability to continue collection and treatment of this higher loading for the 1,000-year period demonstrated, since this will be the final contingency if other management options are ineffective.

2.2 What Must be Addressed in the EIS Supplement?

The proposed NOEF represents a major geochemical hazard for the site, covering a large area of 525 ha, comprising a high proportion of highly pyritic overburden, and with existing PAF materials currently undergoing convective oxidation. The IM considers there are challenges in managing geochemical issues for the existing NOEF and ensuring that development does not result in increased liability rather than an improved outcome. The following are key aspects that need to be addressed in the EIS supplement to increase confidence in the proposed management and long-term security of the NOEF:

- ♦ The current predictions of oxygen flux, water flux and seepage quality for the NOEF should be verified by an independent expert against other industry standard models such as

ToughAMD or SULFIDOX, and including consideration of the effects of compromised final cover performance and higher seepage rates on the receiving environment and collection and treatment requirements and duration. A commitment to this should be made in the supplementary EIS with proposed timelines.

- ♦ Given the lack of data on lag times and long-term neutralisation effectiveness, assessment of potential down-gradient impacts should be expanded in the supplementary EIS to consider the effects of acidic leachate from portions of the dump. There may be situations in which PAF materials produce acid drainage that does not directly interact with NAF materials, and hence is not neutralised before reaching the underlying groundwater system. This is particularly relevant to the existing end-tipped PAF cells in the NOEF, where convective oxidation and rapid rates of AMD generation are occurring.
- ♦ The gas transport properties of the PAF cells under the current high temperatures do not appear to be fully understood. While the proposed advection barriers are the appropriate approach, the effectiveness of these barriers on a large, heterogeneous and actively convecting system has not been demonstrated in the EIS. The hypothesis that external advective oxygen barriers will shut down reactions over time needs to be verified with comprehensive field testing and monitoring programs. A commitment should be made to evaluate advection barrier performance for existing and future PAF(HC) and PAF(RE) cells in the short term, well before they are encapsulated by halo embankment.
- ♦ 7.5 m lifts for PAF(HC) materials are proposed for the NOEF based on assessment of advection effects using DumpSim. More detail is required concerning issues such as methods of construction, frequency of advection control layers, and cell dimensions. A commitment should also be made to further investigate the risk of advection from these 7.5 m PAF(HC) lifts, including trials.
- ♦ The IM doubts that the integrity of the required contiguous low permeable (1×10^{-9} m/s) CCL barrier layer will be achieved over the entire surface of the NOEF. Alternate cover profiles such as HDPE and bituminous geomembranes should be evaluated. The IM recommends that commitment be made to engaging an external peer review expert to provide additional insight into the long-term performance that might be expected from various liner options. This should include consideration of the effects of temperature on clay, HDPE and bituminous geomembranes covers in the vicinity of existing convecting NOEF PAF cells.
- ♦ The supplementary EIS should detail the design and timing for setting up a series of large-scale lysimeters to compare the performance of cover systems with a 0.5 m CCL, a HDPE geomembrane, and a bituminous geomembrane. These should be established immediately to provide at least 10 years of observation and monitoring before the construction of the final cover is implemented in 2036. The empirical data provided by such long-term trials will greatly assist in reducing the level of risk associated with seepage and leachate production from the NOEF. This should include verification of the saturated permeability target for the CCL option.
- ♦ The supplementary EIS needs to include an initial prediction of how much settlement can be expected for the NOEF and whether the cover systems as designed will tolerate the

expected deformations, and also a commitment to follow up in more detail as required. Such information needs to be established in advance of the final design of the cover system.

- ♦ The integrity of the proposed cover system is obviously critical to long-term performance, which relies heavily on a relatively thin 0.5 m compacted clay layer to control infiltration. It needs to be demonstrated that the long-term risks to cover integrity can be managed with maintenance and repair, and acknowledged that this would be required for the 1,000-year closure period.
- ♦ Expansion of the NOEF footprint and lack of specific wet season controls on infiltration during operations means that AMD seepage will continue reporting to groundwater, extending the period of higher seepage rates until the final cover is installed, and increasing seepage recovery efforts. Consideration should be given to options for more active infiltration control during operations.
- ♦ The contingency for greater seepage recovery effort during operations and post closure for the NOEF is outlined in EIS Appendix Q, with a variety of mitigation options discussed. Given the uncertainties in the cover design and other controls, use of these mitigation options should be assumed, and more detail provided on what resources and equipment would be committed.

The open pit also represents a major geochemical hazard for the site, and commitment should be made for verification of the pit void model predictions by an independent expert.

Commitment should also be made for independent verification of the GoldSim modelling used to assess the impact of site AMD sources on the receiving surface water system, taking failure modes into account for the two key sources, i.e., the NOEF and open cut. It should also be demonstrated in the supplementary EIS that there are sufficient resources to collect and treat worst case AMD loadings for the 1,000-year period as contingency if other management options are ineffective.

The following information and investigations should also be provided in the supplementary EIS to resolve additional uncertainties in the EIS:

- ♦ Better demonstrate the validity of the PAF(RE) sulfur cut off of 10%S.
- ♦ Elaborate on how lithostratigraphic controls are used in the resource block model.
- ♦ Provide more information on calibration of pXRF testing for grade control to demonstrate its validity.
- ♦ The sample density quality control checks are currently based on general guidelines, and more information is required on the performance and variation of the current system to demonstrate their suitability for the site-specific geological/geochemical variation. The current NAF sampling frequency in EIS Figure 6-45 also needs to be clarified.
- ♦ Carry out testing of SOEF alluvial materials to confirm that these materials are benign and suitable for use in the WOEF cover.

- ♦ Provide further information to better define the geochemical characteristics and hydrology of the WOEF, which are currently described in a general sense only.
- ♦ Reassess the suggestion that oxidation is limited in the interior of the NOEF based on low oxygen concentrations, since this is not supported by elevated temperatures throughout the PAF cells.
- ♦ Incorporate groundwater quality results collected from below the NOEF into interpretation of AMD processes and seepage currently occurring.
- ♦ Update information presented in Section 3.4.4.3.3.1 with a clearer explanation of DumpSim modelling to better understand how the various DumpSim modules interact to produce the predicted outputs, including:
 - Whether the acid generation predicted is solely a function of air permeability/gas flux, and how this links with pore water quality prediction derived from kinetic testing.
 - Better explain Figures 3–50 and 3-51 and the relationship between these two figures.
 - Better explain Figure 3-53 and provide a legend.
- ♦ Provide further detail on PAF(HW) and low grade ore management on the EOEF given the spontaneous combustion potential of these materials.
- ♦ Provide more detail on tailings geochemical characteristics to demonstrate the validity of the tailings AMD properties and classifications, including estimation of lag times before acid production from tailings.
- ♦ Expand on the reasoning and data supporting the notion that elevated sulfate and metals impacts on Surprise Creek are more likely related to process water than tailings oxidation effects.
- ♦ Outline the situation or trigger whereby interception trenches would be extended further around the eastern and southern perimeter of the TSF beyond that currently planned for Surprise Creek.
- ♦ Provide more detail on the monitoring approach that would be used at the TSF to confirm saturation and control of oxidation.
- ♦ Provide the following additional detail on open cut modelling to help in understanding the assumptions, reliability and uncertainties:
 - Plots of kinetic test source data for the loadings assigned.
 - Loading rates assumed for oxidation of deposited tailings, and the predicted geochemical characteristics of tailings after processing, and water quality/loading rates assumed for tailings pore water.
 - Plots showing the contribution of loadings from the various AMD sources over the simulation time.

- Some examples showing the process of assigning loadings, calculating mixing and use of PHREEQC/GWB to adjust for thermodynamics.
- Assess the effects of convective oxidation of PAF materials on loadings and water quality given the planned 16 m tip heads to be used in the IDP.

EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

3. Geotechnical

3.1 Is the Information in the EIS Sufficient?

3.1.1 Terms of Reference

The EIS Terms of Reference (TOR) prepared by the NTEPA requires that MRM address the following matters that are specifically related to geotechnical issues:

- ◆ Insufficient quantities of benign material and clay to meet requirements for best practice encapsulation of problematic waste and final closure of waste structures.
- ◆ The availability, sources and volumes of suitable materials required for rehabilitation, revegetation and mine closure (e.g., clay, capping materials).

The extent to which these requirements are addressed is discussed in the following sections, which also discuss other significant areas of geotechnical concern. It should also be noted that the TOR cross-reference table (EIS Appendix B) directs the reader to Table 7-4 of the EIS in relation to the first point listed above. Table 7-4 is a summary of the key Project risks and does not specifically refer to clay or encapsulation. Furthermore, the TOR cross-reference table refers to EIS Sections 3.2.1 and 3.2.2 in terms of providing justification for excluding aspects of Phase 3 activities in the EIS, including (if sufficient suitable clay and benign material are available) construction of water management structures; however, this information is not evident in these sections.

3.1.2 General Discussion

In geotechnical terms, the areas that have been considered as part of this review are:

- ◆ Tailings management in the long and short term, including the TSF and in-pit storage.
- ◆ OEF cover and liner systems, and overall stability of the upper, mid and lower slopes.
- ◆ Revised borrow areas for sourcing suitable materials for the OEFs and TSF.
- ◆ Closure design.

For tailings, the EIS proposes a number of changes to short- and long-term management at the mine. The most critical changes are considered to be:

- ◆ A change in deposition method to promote 'wet' conditions in the TSF and in-pit.
- ◆ The elimination of the proposed TSF Cell 4.
- ◆ The raising of TSF Cell 1 and amalgamation with TSF Cell 2.
- ◆ Reprocessing of tailings and deposition into the final void once open cut operations have ceased.
- ◆ Additional borrow pits in the vicinity of the TSF for construction materials.

The EIS proposes a number of changes to the development and construction of overburden emplacement facilities (OEFs). In summary, these changes are:

- ♦ Increase in the northern overburden emplacement facility (NOEF) height from 80 to 140 m.
- ♦ Internal geometry of the NOEF including an internal and an encompassing compact clay liner (CCL).
- ♦ Development of a 'tri-linear' slope for the NOEF with the following geometry:
 - 2.5H:1V 'Upper' slope with a slope height of 40 m and length of 100 m.
 - 3.5H:1V 'Mid' slope with a slope height of 50 m and length of 175 m.
 - 4.5H:1V 'Lower' slope with a slope height of 50 m and length of 225 m.
- ♦ A revised NOEF footprint with a revised cover design and a reduction in the basal liner thickness from 0.6 to 0.5 m in areas targeted for expansion.
- ♦ A new in-pit dump (IPD).
- ♦ Relocation of the SOEF and EOEF material to the NOEF with some material potentially in the IPD.
- ♦ Additional borrow pits for construction materials.

3.1.3 Tailings Design and Management

3.1.3.1 Re-establishment of Deposition into TSF Cell 1

Currently, the re-establishment of deposition at TSF Cell 1 is proposed as an amendment under the current Mining Management Plan process. Of particular concern is how Cell 1 is to be raised in a safe and stable manner given the uncertain construction practices used in the original construction and the potential for increased seepage due to renewed deposition activities. This potential for increased seepage is considered high priority given the:

- ♦ Significant seepage from TSF Cell 1 that has occurred during previous active deposition into this cell.
- ♦ Ongoing seepage into Surprise Creek despite cessation of deposition in 2007 and construction of an interim cover.
- ♦ Limited ability to ameliorate seepage into Surprise Creek despite a number of targeted remediation campaigns, including injected geopolymer barriers and hydraulic containment.

Notwithstanding these issues, the concept of raising of Cell 1 has merit as this minimises TSF expansion and increases efficiency for proposed hydraulic mining as the tailings are concentrated over a smaller footprint.

Appendix R of the EIS outlines the proposed strategy for reducing seepage impact on Surprise Creek using a seepage collection drain. Two drain configurations are presented in EIS

Appendix T, with these comprising a drain either 1 or 2 m below the base of Surprise Creek. The appendix indicates that neither remedial option is expected to result in a significant benefit, with only around 17% reduction in flows to Surprise Creek when the drain is 1 m below the base of Surprise Creek and around 20% reduction when the drain is 2 m below. These reductions appear to be relatively small given the relatively significant impact known to occur under the base case. In addition, seepage modelling presented in EIS Appendix T shows water tables significantly higher than those shown in stability analyses presented in EIS Appendix R.

3.1.3.2 Change in Deposition to Promote Wet Conditions

Table 3-6 and Section 4.10.3 of the EIS indicate that the amalgamated TSF cells 1 and 2 are to be operated as a conventional wet tailings storage facility. This marks a significant change from the subaerial design promoted by GHD whereby the phreatic surface is kept low to facilitate strength gain at the beach for upstream construction and increased stability due to reduced pore pressures in the embankment.

The change to 'wet' or subaqueous deposition is cited as a means to reduce dust generation. It also presumably facilitates hydraulic mining for relocating tailings to the final void. However, the use of subaqueous deposition will require re-design of the current and future TSF embankments. Appendix R (prepared by GHD) of the EIS is the Life of Mine Plan for the TSF which advocates continued use of subaerial deposition, directly conflicting with the subaqueous design proposed in Section 4.10.3. The IM has assumed for the rest of this review that Appendix R is the relevant guide with respect to tailings management and that the reference to 'wet' or 'subaqueous' deposition in the main report is erroneous.

3.1.3.3 Tailings Drying and Consolidation Modelling

The design and operation of both the existing TSF and proposed storage in the final void relies heavily on the use of sophisticated and novel modelling techniques. Use has been made of the combined desiccation and consolidation model proposed by Li et al. (2012). The IM has reviewed the model and associated material properties. While the use of such a model is commendable, there are a number of errors and limitations in the chosen approach, as summarised below:

- ♦ The quoted exponents that relate void ratio to effective stress (EIS Appendix AC Chapter 6) do not match the consolidation data shown in Figure 1 of Appendix AC. For example, the computed void ratio at an effective stress of 100 kPa is $1.5 \times 100^{-4.2}$ or 0.006 and this is significantly less than any of the measured void ratios. At the same time, the computed void ratio at an effective stress of 0.1 kPa is 24, well above the value of 2 shown in Figure 1 of Appendix AC. This is likely to be a simple typographical error as these parameters do not match the long-term density profiles shown in Figure 8 of the same appendix.
- ♦ The use of a lumped constant consolidation coefficient ' C_v ' parameter in place of varying hydraulic conductivity in the original Gibson et al. (1967) theory is considered a severe limitation of the model. Values of hydraulic conductivity should be derived with variation in effective stress or void ratio. This could have been readily achieved with the same apparatus used to derive C_v but for unknown reasons was not done. In addition, the range of stress change used to measure C_v is very low compared to the actual range of stress expected in the final depth of tailings in the void. The maximum stress range used in testing represents only about 55 m of tailings compared to the proposed depth of around 200 m. It is possible

that the assumption of a constant value of C_v within the testing stress range significantly underestimates the value of hydraulic conductivity at higher stress. Furthermore, the hydraulic conductivity relationship derived from the adopted C_v value and compressibility is of two to three orders of magnitude more than that estimated in the TSF Life of Mine Plan provided in EIS Appendix R. These discrepancies cast doubt on the accuracy of predictions and therefore predictions of consolidation and water liberation may be significantly in error.

- ♦ The drying model used by Li et al. (2012) ignores the effect of gravity. This type of formulation based on moisture content was adopted in the 1950s and earlier because the more correct theory that includes gravity could not be solved by the analytical methods available at the time. The more accepted practice is to account for unsaturated flow using a pore water pressure based theory which includes gravity. This also provides a continuity of the dependent variable across both desiccation and consolidation (see Krizek et al. (1977); Narasimhan and Witherspoon (1977); Lloret and Alonso (1980); Naser Abu-Hejleh and Znidarčić (1995); Swarbrick (1995); Qiu and Sego (2006)).
- ♦ It is unclear whether the 'selected in-pit tailings' curve in Figure 1 of EIS Appendix AC or the 'selected curve for initial consolidation' in Figure 23 of EIS Appendix R (assuming they are the same plot) are measured data or the adopted fitted curve for the void ratio – effective stress relationship. If these curves are supposed to represent the void ratio – effective stress relationship, then they do not concur with the fitted relationship parameters as discussed above.
- ♦ It is unclear why only one settling test result appears to be shown in Figure 1 of EIS Appendix AC and Figure 23 of EIS Appendix R (assuming these to be the same plot). If the assumption is that the 'selected in-pit tailings' and 'selected curve for initial consolidation' represent the adopted fitted void ratio – effective stress relationship as summarised above, then there appears to be little justification in adopting a curve that plots well above almost all consolidation testing but does happen to pass through the single included settlement test result. Settlement test results do not appear to have been provided in the EIS to allow the veracity of this fit to be tested.

3.1.3.4 In-Pit Disposal of Tailings

The EIS proposes to relocate tailings from the TSF into the final void at the cessation of mining. In theory, this approach provides a means whereby tailings and waste rock can be stored in the long term with reduced ability to produce acidic leachate. However, there are some design issues which potentially require further refinement, these being:

- ♦ The water balance presented in EIS Appendix AC assumes the full extent of potential evaporation for all years of deposition. In reality, evaporation will be limited once the potential evaporation exceeds the rate of water expulsion from the surface of the settling tailings solids, this being expected to occur after Year 7. Consideration should be made for an increased make-up water requirement.
- ♦ The use of a single discharge point will almost certainly prevent good control of the decant pond location, particularly within the pit environment. Tight control of the decant pond is required to facilitate access for water reclamation.

- ♦ The subaqueous and rapid nature of proposed deposition (i.e., 96 m in the first year) in the pit will result in very soft tailings that will not be able to support placement of overburden waste onto it, as suggested in Section 9 of EIS Appendix AC. In addition, any placement of waste will increase the final height of material in the void and lessen the likelihood of the tailings surface remaining saturated in the longer term. The issues surrounding waste placement on tailings are, to some degree, acknowledged in EIS Appendix AC whereby additional future studies are flagged.

3.1.4 OEF Design and Management

3.1.4.1 Introduction

The OEF design calls for internal moisture and gas control through engineered barriers, i.e., a traditional liner and cover system. For such systems, the cover design is usually the critical control element as it controls the movement of water and gas into and out of the waste.

The proposed cover at the mine is designed to limit ingress of rainfall and oxygen. This will result in an unsaturated environment with consequent complex transport mechanisms. Such mechanisms are controlled by pore size distribution, particle size and distribution, water retention characteristics, unsaturated fluid flow, heat transport, and wetting and drying history (commonly termed hysteresis). In addition, the system is to remain effective for at least 100 and preferably 1,000 years.

Internal moisture movement within the OEF will be largely, if not entirely, unsaturated if the cover is working effectively. Under these conditions the compacted clay liner (CCL) plays a limited role in moisture control because vertical flow is very low, typically less than the saturated hydraulic conductivity, and lateral flow is largely dependent on a build-up of saturated conditions. Additionally, as the waste wets up over time it will reach field capacity (as will the CCL) and although some water will move laterally due to the CCL grades, a significant proportion is likely to continue moving downward and through the CCL under gravity-driven unsaturated flow. This limited ability of the CCL to control release once water has entered the waste highlights the importance of cover design. The liner is effective, however, at limiting ingress of water from flooding as only a relatively small amount can penetrate during a flood event due to the relatively long lateral flow path.

McArthur River Mining has provided an examination of the expected moisture movements within several cover designs in EIS Appendix J. These studies rely entirely on numerical modelling of moisture movement based on well-established theories and their solution. However, the absence of direct physical testing to examine moisture, gas and heat dynamics puts a strong reliance on the method of solution, properties and other assumptions used to predict cover performance. Each of these components is discussed below.

3.1.4.2 Analysis Method

The majority of analyses of moisture movement for the NOEF were undertaken using SEEP/W by Geoslope. SEEP/W is a single phase (water only) isothermal (no heat flux) finite element package that can predict fluid movement in unsaturated porous media in one and two dimensions. It is a well-developed package that provides reliable predictions given the limitations within its formulation. Some of these limitations, however, may have significance at the NOEF given the

expected low flux and the long timeframes required for predictions. SEEP/W limitations considered potentially important are:

- ♦ No dual-phase flow – movement of fluid through the NOEF is expected to occur as a dual-phase phenomenon involving transport of liquid and gas. When liquid moves it must either displace gas or the gas must flow into the void. Not including the effects of gas transport can effect predictions of infiltration rates, saturation levels (which are partly related to hysteresis below) and oxygen ingress.
- ♦ No heat transport – large thermal gradients are expected within the NOEF cover due to climatic effects. These gradients will have an impact on moisture movement, particularly during prolonged periods of evaporation during which the CCL within the cover is expected to remain near saturation.
- ♦ No hysteresis – the movement of liquid in gas in unsaturated porous media is affected by hysteresis whereby the moisture condition in the wetting path is different to the drying path under the same liquid-gas differential pressure. This means that predicted saturations are likely to be different depending upon the previous wetting or drying history.

These limitations are raised here not because they are known to be significant but because their potential impact has not been addressed within the EIS and is therefore unknown.

3.1.4.3 Material Properties

Unsaturated material properties are difficult to quantify due to the time required to equilibrate samples, limitations in most of the testing methods, limitations in sample size, and hysteresis as described above.

Material properties used for hydraulic analyses of the NOEF cover are provided in EIS Appendix J. Because of testing limitations, it is important to state the method of analysis used (as each has its own inherent errors), the sample size and whether properties were derived on a wetting or drying curve or by some other means. This information is not provided in Appendix J and could not be found elsewhere in the EIS.

In addition, many of the material property parameters outlined in Appendix J are 'estimates' which, it is assumed, are based on characteristics of soils found elsewhere. Such estimates are commonly made by comparing particle size distribution and texture.

In addition to these estimates, the water retention characteristics have been measured for two waste rock samples taken from the mine and tested at the University of Queensland (UQ) (Figure C2.2 EIS Appendix J). The method used to derive these values is not stated, the range of testing is very low (only extending for 100 kPa) and, again, the test path (wetting or drying) has not been stated. It is noted in Appendix J that the samples comprised only of particles less than 4.75 mm. Despite these direct tests on McArthur River Mine materials, the UQ results do not appear to have been used. Material properties appear to be based predominantly on estimates and previous testing. Testing of waste rock unsaturated hydraulic properties is known to be very limited worldwide.

Appendix J makes reference to 'Soil-Plant-Atmosphere' modelling which appears to include capability for unsaturated flow coupled with oxygen diffusion. The details of the model are not provided. This modelling may include some of the limitations present in SEEP/W such as dual-flow and heat transport. However, this appears unlikely given that relevant material properties to facilitate analyses with these capabilities have not been provided.

The EIS proposed construction of a large-scale lysimeter in the cover system of the NOEF in 2022. It is acknowledged in the EIS that this type of physical system will provide more direct evidence of the efficacy of the cover designed and the IM concurs with this assessment. The lysimeter will also address many of the concerns raised here in relation to the potential for other effects such as dual-phase flow and heat transport. However, the timing of the lysimeter construction and associated data collection is largely designed as a one-off event. If the lysimeter and associated instrumentation shows that the cover system is inadequate, the ability to redesign and retest the cover system within the proposed closure timeframe is likely to be severely limited. Therefore, analyses being used to test the robustness of the cover design in the EIS should consider as many potential influences as possible as discussed above.

It is well known that the presence of a lysimeter can affect what it is designed to measure, namely infiltration. Care must be taken to measure profile information such as moisture and temperature within and adjacent to a lysimeter so that an assessment of the potential impacts of the lysimeter can be assessed. The proposed lysimeter and associated instrumentation appears to address this issue in a logical and appropriate manner.

A number of limitations are identified above that should be addressed as part of this holistic design process. This is particularly the case given that the current modelling presented in Appendix E of EIS Appendix J shows that net percolation is at least 4.8% of rainfall for all cases considered and the ability to further reduce this net percolation rate appears to be limited based on the sensitivity testing that has been undertaken.

3.1.4.4 Other Specific NOEF Issues

A significant change to the EIS is the inclusion of a drainage layer in combination with a CCL to cover the NOEF. The purpose of the CCL is to reduce infiltration into the NOEF as well as reduce gas emission while the drainage layer promotes lateral flow. The CCL is proposed to be a minimum of 0.5 m in thickness and be overlain by 0.5 m thick drainage layer comprising a free draining cover breccia. This is then overlain by a 1.5 m growth medium and 0.1 m of topsoil. This configuration is considered likely to be effective over 100 years (pending field verification) as it captures a number of measures to limit water ingress including a barrier system (CCL), a diversion system (drainage layer), and a store and release system (growth media).

Sections with either insufficient information or recommended modifications are outlined below. Pages relate to the main report section of the EIS:

- ♦ On Page 6-75 the permeability/hydraulic conductivity of placed clay layer testing frequency is one test per 10,000 m³. The 2015 Environmental Performance report (ERIAS Group, 2016) (Table 4.31) previously recommended the testing frequency be brought back to two tests per 10,000 m³.

- ♦ On Page 6-75 the geotechnical testing specifications (apart from permeability testing) appear to match the 2015 Environmental Performance report recommendations (ERIAS Group, 2016).
- ♦ On Page 6-75 the internal CCL layers are proposed not to be constructed to the same criteria as the final cover CCL. The EIS does not state what criteria the internal CCLs are to be constructed to. This should be specified.
- ♦ On Page 3-130 the CCL cover barrier construction and compaction method is described conceptually; however, no reference to a construction specification is provided. Chapter 6 provides material characterisation and testing specifications. Appendix N – Geotechnical Assessment Report provides outlines of a work program for sampling and testing, CCL construction, post-construction testing and performance assessments.
- ♦ On Page 3-131 the CCL construction method of the 'upper' slopes is proposed to involve horizontal strips. While feasible, this method is likely to require modifications to previous CCL construction and compaction methods/specifications.
- ♦ The basal clay liner is to slope towards the toe of the dump to aid seepage of water to the toe and through the basal layers. Page 3-115 states that:

The geometry and materials of the new foundations will promote reporting of net percolation as toe seepage rather than basal seepage. This will be achieved by confirming an in-situ clay layer or, where no suitable basal layer exists, constructing a sloping low-permeability basal layer. The base will target performance equivalent or better to 0.5 m of CCL with a maximum saturated hydraulic permeability of 10^{-9} metres per second (m/s). Proof rolling and profiling of the base layer will be undertaken, with removal of unsuitable materials that may provide uncontrolled preferential pathways for seepage or geotechnical instability. Unsuitable materials will be replaced with a suitable fine-grained medium to meet the design specifications. The sloped base will have a lined subsoil drainage network incorporated into it, directing collected seepage to specific collection pits at the toe of the NOEF. Refer to **Figure 3-48** and **Figure 3-49** for locations of the drains, and details of the lining and materials used.

It is unclear if proposed subsoil drains mentioned in the paragraph above are above or below the clay liner. The drawing details are for borrow pit drainage which is not entirely applicable to drainage of the foundation.

3.1.4.5 Geotechnical Stability of NOEF – Appendix N

Notes on the geotechnical stability assessment of the NOEF are summarised below:

- ♦ Page 24 – Design Criteria of $FOS > 1.5$ is based on ANCOLD recommendations for tailings storages.
- ♦ Page 25 – Shear strength parameters are based on past geotechnical studies from various consultants and universities. On this basis, and a review of the tabulated strengths in Table 9 (page 29), the strengths appear reasonable and are probably conservative.
- ♦ Page 46 – Sensitivity analysis of the cover system stability indicates that the presence of alluvial material may result in stability conditions not meeting the design criteria. Chapter 3 does not address the potential for not meeting the design criteria if alluvials are used in the

cover system. Page 3-128 does, however, acknowledge the high erosion potential of the alluvials and notes that this has been 'considered' in the design.

3.1.4.6 EOE and SOEF Management

The EOE and SOEF are temporary facilities for storing non-benign waste material. The plan as described in the EIS is to store the material in these facilities and then relocate the material to the open cut in-pit dump. The EOE is completely different to the previous Phase 3 design. The primary change to the SOEF is the removal of the eastern portion to allow for development of the Woyzburn Quarry.

Page 3-93 of the EIS does not provide sufficient information concerning foundation preparation of the SOEF.

Page 3-98 of the EIS does not provide sufficient information on the interaction of the SOEF and the open cut pit walls. Consideration needs to be made as to how the presence of the SOEF may affect the stability of the overall adjacent pit walls.

3.1.4.7 WOEF Design

Page 3-100 of the EIS states that 'the top of the WOEF is heavily trafficked and tightly compacted'. There appears to be insufficient information to confirm this.

3.1.5 Tailings and OEF Borrow Areas

3.1.5.1 General

The EIS proposes the location of a number of borrow pits for the purpose of sourcing benign material for the TSF and OEFs. A key component of the OEFs is the construction of clay liners at the base and cover of the OEFs. This represents a major change and, as a result, additional borrow pits have been located for the purpose of sourcing clay materials. This increase has been offset to some degree by a lessening in final cover requirements for the TSF as the tailings are to be hydraulically mined and relocated to the pit for ultimate storage.

The spacing of testing is approximately 100 to 300 m for a large area of approximately 1600 ha in five areas. The investigation has comprised 750 boreholes/test pits (275 are within borrow pit areas) and laboratory and field testing. These investigations have identified:

- ♦ Five areas within the mine tenement with clay.
- ♦ That the area is underlain by topsoils, clay, clayey sand/sandy clay, extremely weathered rock and bedrock.
- ♦ Two types of clay:
 - Brown clay – medium to high plasticity with some silt.
 - Red/brown clay – majority of clay on site, medium to high plasticity with some gypsum.

Areas of insufficient information are summarised below:

- ♦ Laboratory testing indicates that a large portion of the clay is dispersive. The expected volume of potentially dispersive material, such as Emerson class 1 or 2, is not provided despite extensive testing. There is uncertainty, therefore, that sufficient material has been sourced to form clay barriers.
- ♦ There is no information as to how dispersive soils will be managed in the construction of the clay liners.
- ♦ There is no design control for dispersity, such as allowable Emerson or pinhole dispersion classes.
- ♦ There is no documentation of clay mineralogy (testing or geological assessment). There is documentation (EIS Chapter 6) of mineralogical testing/assessment, however this is not documented in EIS Appendix AH.
- ♦ The assessment of the borrow pit areas and distribution of borrow materials in the EIS does not document the development of the engineering geology or geomorphology model. This forms a key component to understanding the distribution and ultimately the available volumes of borrow materials. This will be especially important for the clay borrow pits given their importance to the OEF designs.

3.1.5.2 Borrow Pit Design Process Guideline – Appendix AG

No specific information is provided concerning geotechnical investigation, testing and analysis for borrow pits. Page 5 of EIS Appendix AG outlines geotechnical analyses to be addressed as part of a borrow pit design.

3.1.6 In Pit Dumping – Appendix N

The in-pit dump (IPD) is proposed to be developed in the open cut mine void in order to reduce the amount of non-benign material to be placed in the NOEF. The IPD is proposed to be developed from the bottom up, which is favourable for dump stability purposes. This method of construction also allows the dump to be keyed into the western wall, thereby buttressing the dump at the toe. Possible insufficiencies in the information include:

- ♦ Page 60 – Stability modelling only considered circular failure. A non-circular failure mechanism with planar sliding along the base and advection layers is recommended to check other potential modes of failure.

3.1.7 Conclusion

Notwithstanding the issues cited above, the level of investigation and analysis is considered largely acceptable for the TSF and OEFs. In particular, the TSF construction sequencing, stormwater design, tailings conditioning trials and liquefaction potential assessment are considered to be of high standard.

However, there are areas where information is lacking in relation to the TSF. Some of these are likely to be misunderstandings or require simple corrections. In other cases, such as resuming disposal in Cell 1 and the level of analysis undertaken for the OEF cover system, highlighted deficiencies are considered to be potentially significant. The full list of issues is as follows:

- ♦ It is understood that justification for deposition into Cell 1, Cell 1 and 2 amalgamation, and future management of Cell 3 for water management is to be part of a separate submission. McArthur River Mining considers this to be already part of their approved management of the TSF. This review finds that this has a number of potential associated environmental impacts and recommends that this submission be provided with the EIS.
- ♦ There is some confusion over whether the TSF is to be operated as a subaerial or subaqueous operation. This should be clarified.
- ♦ The large strain consolidation modelling (EIS Appendix AC) contains material relationships that are either lacking test data (in the case of compressibility) or have been potentially oversimplified (in the case of hydraulic conductivity). The IM suggests that these deficiencies be justified and, preferably, quantified.
- ♦ Settlement data referred to in EIS Appendix AC upon which the consolidation relationship relies has only been provided for one column test. Column test data should be provided so that the suitability of the adopted compressibility test can be verified.
- ♦ Insufficient information has been provided to determine whether the model deficiencies highlighted here, such as the lack of dual-phase flow or coupled heat transport, will have a significant impact on net percolation or saturation levels within the cover system.
- ♦ There is no specific information on the expected volume, distribution and management of dispersive materials to be used in clay barrier (cover and liner) construction.
- ♦ The method and testing path (wetting or drying) of unsaturated material properties has not been provided.

Various specific issues relating to missing or inadequate information relating to the NOEF, SOEF and EOEF as described above include the following:

- ♦ Discrepancies over the CCL hydraulic conductivity testing frequency.
- ♦ The internal CCL compaction specification is not stated.
- ♦ The CCL cover barrier compaction specification is not stated.
- ♦ The location of subsoil drains mentioned in relation to the basal clay layer is not provided.
- ♦ Insufficient information on foundation preparation of the SOEF is provided.
- ♦ No information concerning any potential interaction of the SOEF and the pit is provided.
- ♦ Insufficient information to confirm that 'the top of the WOEF is heavily trafficked and tightly compacted' is provided.
- ♦ Laboratory testing indicates that a large portion of the clay is dispersive. There is no information as to how this will be managed in the construction of the clay liners.

- ♦ No documentation of clay mineralogy (testing or geological assessment) is provided. There is documentation (Chapter 6) of mineralogical testing/assessment; however, this is not documented in the EIS Appendix AH.
- ♦ The assessment of the borrow pit areas and distribution of borrow materials in the EIS does not document the development of the engineering geology or geomorphology model. This forms a key component to understanding the distribution and ultimately the available volumes of borrow materials. This will be especially important for the clay borrow pits given the latter's importance to the OEF designs.

3.2 What Must be Addressed in the EIS Supplement?

The IM considers that the following must be addressed in the EIS supplement:

- ♦ Justification for deposition into Cell 1, and Cell 1 and 2 amalgamation.
- ♦ Explanation of how the large strain properties have been derived and their relationship to settling column testing.
- ♦ An explanation as to the discrepancy in pore water pressures between seepage modelling in EIS Appendix T and stability analyses in EIS Appendix R.
- ♦ A sensitivity analysis of the in-pit tailings consolidation predictions to account for possible variations in C_v (or preferably hydraulic conductivity) at high pressures.
- ♦ A sensitivity analysis of water balance requirements during in-pit tailings disposal based on sensitivity to variations in C_v as described above.
- ♦ An assessment on how dual-phase flow, heat transport and hysteresis may affect the predicted performance of the proposed cover system.
- ♦ A more detailed description on unsaturated hydraulic conductivity testing including the method used to test McArthur River Mine materials and the test path used (wetting or drying).
- ♦ An assessment of SOEF stability with encroachment of the pit.
- ♦ Information on the expected volume, distribution and management of dispersive materials to be used in clay barrier construction.
- ♦ Design limits for clay dispersivity and additional testing if relevant.
- ♦ Contingency plan should the lysimeter demonstrate that the proposed NOEF cover design is inadequate.

3.3 References

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EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

4. Groundwater Management

4.1 Is the Information in the EIS Sufficient?

The groundwater component of the EIS is based on the results from a site-wide groundwater flow and solute transport model developed by Klohn Crippen Berger. The model includes basal seepage contamination from the TSF, PRODs and OEFs, as well as possible sources of contaminants from natural zones of mineralisation, and discharges to the pit, creeks and McArthur River. The model results provide estimates over the life of mine, during closure and post-closure of the following:

- ♦ Groundwater flow regimes.
- ♦ Contaminant transport within the groundwater system.
- ♦ Contaminant discharge to surface water features.

The model is based on earlier models and has been updated on the basis of a considerable number of studies undertaken over the last two to three years. These studies have included extensive field investigations around the NOEF and TSF, interpretation of the available geological and hydrogeological datasets, and re-conceptualisation of the hydrogeology of the mine site. They have also included the development of a more detailed groundwater flow and contaminant transport model for the TSF area, which has been structured to allow integration with the site-wide model.

A number of significant uncertainties in MRM's understanding of the processes controlling groundwater flow across the mine site remain, some of which have been identified in the reports provided with the EIS. The presence of these uncertainties is understandable given the following:

- ♦ The deficiencies in some of the earlier hydrogeological studies, including the studies completed for the Stage 3 EIS.
- ♦ The complexity and large scale of the groundwater system.
- ♦ The absence of historical monitoring data, especially prior to the start of open cut mining.
- ♦ The poorly understood impacts from some of the post closure landforms, e.g., the NOEF and pit lake.

The uncertainties are, to some extent, addressed under MRM's adaptive management approach, which allows for ongoing collection of information, assessment of impacts and development of options to manage these impacts.

However, the IM's view is that a number of uncertainties should be further investigated as part of the EIS supplement due to the severity of the potential impacts upon the groundwater and surface water environment. These relate to the following:

- ♦ The performance of the final NOEF cover over the 1,000-year assessment with respect to:

- Limiting rainfall infiltration.
- Generation of acid mine and saline metalliferous drainage.
- Seepage of contaminated water to the underlying groundwater system.
- ♦ The performance of the NOEF flood management facilities with respect to:
 - Preventing inundation.
 - Generation of acid mine and saline metalliferous drainage.
 - Seepage of contaminated water to the underlying groundwater system.
- ♦ The groundwater inflow mechanisms associated with the underground workings, which are used for the majority of the dewatering effort for the pit via the Evase pumping system. It is assumed that these inflows are due to hydraulic connections to the McArthur River diversion channel, although no major aquifers have been identified during field investigations. Understanding and adequately simulating the physical processes controlling this mechanism is important as it affects the dewatering rate during operations and, more significantly, potential links from the pit lake to McArthur River during and after closure.
- ♦ The interaction of the pit lake and groundwater system after closure. This includes both inflows and outflows, which will affect the:
 - Rate at which the pit lake is flooded.
 - Long-term pit lake level.
 - Potential for discharge of contaminated pit lake water to the downstream groundwater and surface water systems.
- ♦ The potential for reduced attenuation of metals in areas where flow is via discrete pathways rather than a porous medium as simulated in the groundwater flow and contaminant transport model. This would result in much shorter breakthrough times for the CoCs.

The main uncertainties listed above are discussed in more detail in Sections 4.1.1 to 4.1.3 below.

4.1.1 Groundwater Modelling Guidelines

An assessment of the groundwater flow and contaminant transport model, based on the Australian Groundwater Modelling Guidelines (Barnett et al., 2012), was completed as part of the IM review. The review was carried out in accordance with Chapter 9.3 of the guidelines ('Review Checklists'), which comprises a general compliance checklist (provided as Table 4.1) and a detailed compliance checklist (presented as Table 4.2).

Table 4.1 – General Compliance Checklist

Compliance Question	Yes/No
1. Are the model objectives and model confidence level classification clearly stated?	No
2. Are the objectives satisfied?	Yes
3. Is the conceptual model consistent with objectives and confidence level classification?	No
4. Is the conceptual model based on all available data, presented clearly and reviewed by an appropriate reviewer?	Yes
5. Does the model design conform to best practice?	Yes
6. Is the model calibration satisfactory?	Yes
7. Are the calibrated parameter values and estimated fluxes plausible?	Yes
8. Do the model predictions conform to best practice?	Yes
9. Is the uncertainty associated with the predictions reported?	Yes
10. Is the model fit for purpose?	Yes

No confidence level classification was identified in the EIS documentation provided. However, it is recognised that the development of the groundwater flow and contaminant transport model could be considered preliminary, given future updates of the model will be carried out under the adaptive management process. A confidence level classification should be considered in future model updates.

Table 4.2 – Detailed Compliance Checklist

Review Question	Yes/No	Comment
1 Planning		
1.1 Are the project objectives stated?	Yes	Provided in introduction and executive summary
1.2 Are the model objectives stated?	Yes	Section 5.1
1.3 Is it clear how the model will contribute to meeting the project objectives?	Yes	Not described directly, but addressed in executive summary and introduction
1.4 Is a groundwater model the best option to address the project and model objectives?	Yes	Not described directly, but addressed in executive summary and introduction
1.5 Is the target model confidence-level classification stated and justified?	No	No model confidence level classification has been assigned as per modelling
1.6 Are the planned limitations and exclusions of the model stated?	Yes	Section 5.2
2 Conceptualisation		
2.1 Has a literature review been completed, including examination of prior investigations?	Yes	Detailed assessment of previous studies
2.2 Is the aquifer system adequately described?	Yes	Detailed description of aquifer system
2.2.1 Hydrostratigraphy including aquifer type (porous, fractured rock ...)	Yes	Detailed description on aquifer types supported by comprehensive hydraulic testing
2.2.2 Lateral extent, boundaries and significant internal features such as faults and regional folds	Yes	Detailed description of, e.g., lateral model extents, boundaries, geology, faults

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
2 Conceptualisation (cont'd)		
2.2.3 Aquifer geometry including layer elevations and thicknesses	Yes	Including top and bottom surfaces of hydrostratigraphic units
2.2.4 Confined or unconfined flow and the variation of these conditions in space and time?	Yes	Aquifers classified as unconfined and semi-confined
2.3 Have data on groundwater stresses been collected and analysed?	Yes	
2.3.1 Recharge from rainfall, irrigation, floods, lakes	In part	Rainfall recharge zones identified using AWRA-L, but no description of method
2.3.2 River or lake stage heights	No	Creek flow rates, stage heights etc. not assessed although available for Barney and Surprise creeks and McArthur River
2.3.3 Groundwater usage (pumping, returns, etc)	Yes	Historical groundwater use and dewatering graphs supplied
2.3.4 Evapotranspiration	In part	Evapotranspiration zones identified using AWRA-L, but no description of method
2.3.5 Other?	Yes	Foundation seepage from TSF and OEFs determined from external programs
2.4 Have groundwater level observations been collected and analysed?	Yes	Hydrographs for monitoring bores provided
2.4.1 Selection of representative bore hydrographs	In part	Minimal description of why certain hydrographs were used in calibration
2.4.2 Comparison of hydrographs	Yes	
2.4.3 Effect of stresses on hydrographs	Yes	Effect of stresses discussed in report
2.4.4 Water table maps/piezometric surfaces?	Yes	
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	NA	
2.5 Have flow observations been collected and analysed?	No	Limited base flow data available, but not analysed to estimate flow along specific reaches
2.5.1 Base flow in rivers	No	No calibration attempted against estimated base flows to Surprise and Barney creeks and McArthur River
2.5.2 Discharge in springs	NA	No springs identified in the model domain
2.5.3 Location of diffuse discharge areas?	NA	No diffuse discharge areas identified in the model domain
2.6 Is the measurement error or data uncertainty reported?	In part	Potential measurement errors are described in report
2.6.1 Measurement error for directly measured quantities (e.g., piezometric level, concentration, flows)	In part	Potential measurement errors are described in report

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
2 Conceptualisation (cont'd)		
2.6.2 Spatial variability/heterogeneity of parameters	In part	Spatial extents of aquifers provided together with summary of parameters for each aquifer. However, equivalent porous media (EPM) approach used for bedrock while there is potential for short-circuiting via geological structures, etc., which are not fully described in model
2.6.3 Interpolation algorithm(s) and uncertainty of gridded data?	No	Gridding algorithm not supplied in report
2.7 Have consistent data units and geometric datum been used?	Yes	
2.8 Is there a clear description of the conceptual model?	Yes	Conceptual model described in Section 4, supporting information in other chapters
2.8.1 Is there a graphical representation of the conceptual model?	Yes	Representative cross-sections provided
2.8.2 Is the conceptual model based on all available, relevant data?	Yes	Comprehensive characterisation of study area and thorough examination of previous studies
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	In part	There are no base flow data available which would contribute to model conceptualisation
2.9.1 Are the relevant processes identified?	Yes	
2.9.2 Is justification provided for omission or simplification of processes?	NA	Processes are described in detail
2.10 Have alternative conceptual models been investigated?	No	
3 Design and Construction of the Numerical Model		
3.1 Is the design consistent with the conceptual model?	In part	Mostly consistent but some differences between numerical and conceptual model as outlined below
3.2 Is the choice of numerical method and software appropriate?	Yes	
3.2.1 Are the numerical and discretisation methods appropriate?	Yes	
3.2.2 Is the software reputable?	Yes	
3.2.3 Is the software included in the archive or are references to the software provided?	Yes	
3.3 Are the spatial domain and discretisation appropriate?	In part	Rectangular model domain which is inconsistent with hydrogeological domain. Discretisation seems coarse (50 x 50 m) but satisfactory considering large spatial extent of model
3.3.1 1D/2D/3D	Yes	3D
3.3.2 Lateral extent	In part	Most of groundwater outflow is via base flow which is a short distance from sources, but modelled groundwater flow could be affected due to the shape of model domain

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
3 Design and Construction of the Numerical Model (cont'd)		
3.3.3 Layer geometry?	Yes	Based on conceptual geological model
3.3.4 Is the horizontal discretisation appropriate for the objectives, problem setting, conceptual model and target confidence level classification?	In part	Yes, 50 x 50 m discretisation used throughout model, which seems coarse and could result in errors, e.g., solute transport, but considered satisfactory given the large spatial extent
3.3.5 Is the vertical discretisation appropriate? Are aquitards divided in multiple layers to model time lags of propagation of responses in the vertical direction?	Yes	14 model layers with several layers representing bedrock hydrostratigraphic units
3.4 Are the temporal domain and discretisation appropriate?	Yes	Two periods – model conditioning and calibration
3.4.1 Steady state or transient	Yes	Both
3.4.2 Stress periods	Yes	Monthly stress periods used for calibration period
3.4.3 Time steps?	NS	No information provided on model time-steps
3.5 Are the boundary conditions plausible and sufficiently unrestrictive?	In part	See below
3.5.1 Is the implementation of boundary conditions consistent with the conceptual model?	In part	Most of the boundaries are consistent with conceptual model, apart from: <ul style="list-style-type: none"> ♦ The general head boundary condition used to describe the inflows to the underground at the Evase pumping system ♦ The constant head boundaries used to describe the southeastern corner of the model domain ♦ The no flow boundary used to describe Emu Creek
3.5.2 Are the boundary conditions chosen to have a minimal impact on key model outcomes? How is this ascertained?	In part	River and drain boundaries representing creeks are the main groundwater outflow and therefore impact on the model outcomes
3.5.3 Is the calculation of diffuse recharge consistent with model objectives and confidence level?	Yes	Diffuse recharge calculated by external programs
3.5.4 Are lateral boundaries time-invariant?	Yes	
3.6 Are the initial conditions appropriate?	Yes	Represented by model conditioning period
3.6.1 Are the initial heads based on interpolation or on groundwater modelling?		Groundwater modelling
3.6.2 Is the effect of initial conditions on key model outcomes assessed?	Yes	Initial concentration for sources based on external programs
3.6.3 How is the initial concentration of solutes obtained (when relevant)?	Yes	Initial concentration for sources based on external programs – DumpSim and Tough2
3.7 Is the numerical solution of the model adequate?	Yes	

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
3 Design and Construction of the Numerical Model (cont'd)		
3.7.1 Solution method/solver	NS	No information provided in report on the solution method, convergence criteria and numerical precision
3.7.2 Convergence criteria	NS	No information provided in report on the convergence criteria
3.7.3 Numerical precision	NS	No information provided in report on the numerical precision
4 Calibration and Sensitivity		
4.1 Are all available types of observations used for calibration?	Yes	Calibration mainly based on groundwater levels. Base flow data were unavailable
4.1.1 Groundwater head data	Yes	Large number of groundwater head data used for calibration
4.1.2 Flux observations	In part	Model calibrated to underground mining inflows, but not base flow which were unavailable
4.1.3 Other: environmental tracers, gradients, age, temperature, concentrations, etc.	No	
4.2 Does the calibration method conform to best practice?	In part	Calibration to head data conforms to best practice, although the monitoring period for a number of the hydrographs is relatively short. The model should also be calibrated to base flow data, which is currently unavailable
4.2.1 Parameterisation	Yes	Based on comprehensive characterisation of geology and hydrogeology as outlined in conceptual model
4.2.2 Objective function	In part	Predictions are determined mainly by a qualitative assessment of the base flow characteristics. Measured base flows are unavailable
4.2.3 Identifiability of parameters	Yes	Based on comprehensive characterisation of geology and hydrogeology as outlined in conceptual model
4.2.4 Which method is used for model calibration?	Yes	Trial-and-error
4.3 Is a sensitivity of key model outcomes assessed against?	Yes	No section on sensitivity of model parameters/boundaries (in calibration section), but described in report
4.3.1 Parameters	Yes	Hydraulic conductivity
4.3.2 Boundary conditions	In part	
4.3.3 Initial conditions	Yes	Steady state and model conditioning phase
4.3.4 Stresses	Yes	Calibration include historical mining period
4.4 Have the calibration results been adequately reported?	Yes	Calibration metrics, hydrographs of heads and sulfate concentrations
4.4.1 Are there graphs showing modelled and observed hydrographs at an appropriate scale?	Yes	

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
4 Calibration and Sensitivity (cont'd)		
4.4.2 Is it clear whether observed or assumed vertical head gradients have been replicated by the model?	Yes	Upward and downward gradients are aligned with conceptual model
4.4.3 Are calibration statistics reported and illustrated in a reasonable manner?	Yes	
4.5 Are multiple methods of plotting calibration results used to highlight goodness of fit robustly? Is the model sufficiently calibrated?	Yes	Metrics, hydrographs and sulfate concentrations
4.5.1 Spatially	Yes	There are some data clusters that are not well calibrated but overall acceptable
4.5.2 Temporally	Yes	Model does not adequately simulate seasonal groundwater fluctuations but temporal trends are acceptable Temporal trends for modelled sulfate concentrations are acceptable
4.6 Are the calibrated parameters plausible?	Yes	Mostly within range of expected values
4.7 Are the water volumes and fluxes in the water balance realistic?	Yes	Noted that model outflows (drains, rejected recharge and river leakage) are unknown due to lack of base flow data
4.8 Has the model been verified?	No	The IM understands that the model will be updated as part of adaptive management process.
5 Prediction		
5.1 Are the model predictions designed in a manner that meets the model objectives?	Yes	Graphs showing base flow and water quality predictions
5.2 Is predictive uncertainty acknowledged and addressed?	Yes	See uncertainty section
5.3 Are the assumed climatic stresses appropriate?	Yes	Based on SILO data and considering climate change impacts for long model runs
5.4 Is a null scenario defined?	NA	Mining is already in progress
5.5 Are the scenarios defined in accordance with the model objectives and confidence level classification?	Yes	Graphs showing base flow and water quality predictions (sulfate loads)
5.5.1 Are the pumping stresses similar in magnitude to those of the calibrated model? If not, is there reference to the associated reduction in model confidence?	Yes	Abstraction rates are similar to calibration period, with an allowance for additional dewatering from the pit
5.5.2 Are well losses accounted for when estimating maximum pumping rates per well?	NA	
5.5.3 Is the temporal scale of the predictions commensurate with the calibrated model? If not, is there reference to the associated reduction in model confidence?	In part	Prediction timeframe for life of mine are a similar order to calibration. However, the post-closure modelling is significantly longer
5.5.4 Are the assumed stresses and timescale appropriate for the stated objectives?	Yes	Life of mine and 1,000 years post-closure

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
5 Prediction (cont'd)		
5.6 Do the prediction results meet the stated objectives?	Yes	Base flow and CoC predictions are presented as time-series graphs
5.7 Are the components of the predicted mass balance realistic?	Yes	Based on external programs (Tough2 and DumpSim) for seepage. Inputs and outputs for creeks are realistic
5.7.1 Are the pumping rates assigned in the input files equal to the modelled pumping rates?	NA	
5.7.2 Does predicted seepage to or from a river exceed measured or expected river flow?	No	Within the range of possible creek flows
5.7.3 Are there any anomalous boundary fluxes due to superposition of head dependent sinks (e.g., evapotranspiration) on head-dependent boundary cells (Type 1 or 3 boundary conditions)?	No	Boundary fluxes within expected range
5.7.4 Is diffuse recharge from rainfall smaller than rainfall?	Yes	
5.7.5 Are model storage changes dominated by anomalous head increases in isolated cells that receive recharge?	No	Storage changes dominated by wet and dry rainfall cycles and dewatering from pit
5.8 Has particle tracking been considered as an alternative to solute transport modelling?	Yes	Particle tracking and solute transport are presented
6 Uncertainty		
6.1 Is some qualitative or quantitative measure of uncertainty associated with the prediction reported together with the prediction?	Yes	Detailed sensitivity analysis for base flow and sulfate loads are presented, including Tornado chart indicating sensitive parameters. Monte Carlo outputs also included
6.2 Is the model with minimum prediction-error variance chosen for each prediction?	Yes	
6.3 Are the sources of uncertainty discussed?	Yes	Apart from model parameters, uncertainty analysis also include uncertainty of pathways for mass transport (e.g., for the NOEF)
6.3.1 Measurement of uncertainty of observations and parameters	Yes	Based on prediction sensitivity analysis
6.3.2 structural or model uncertainty	In part	Some aspects of model uncertainty addressed
6.4 Is the approach to estimation of uncertainty described and appropriate?	Yes	Several methods for presenting uncertainty discussed and presented
6.5 Are there useful depictions of uncertainty?	Yes	Sulfate breakthrough, stochastic sulfate concentrations and Tornado sensitivity charts
7 Solute Transport		
7.1 Has all available data on the solute distributions, sources and transport processes been collected and analysed?	Yes	Detailed assessment of solute sources from external programs

Table 4.2 – Detailed Compliance Checklist (cont'd)

	Review Question	Yes/No	Comment
7	<i>Solute Transport (cont'd)</i>		
7.2	Has the appropriate extent of the model domain been delineated and are the adopted solute concentration boundaries defensible?	Yes	Model extent appropriate given short pathways and boundaries based on external programs
7.3	Is the choice of numerical method and software appropriate?	Yes	
7.4	Is the grid design and resolution adequate, and has the effect of the discretisation on the model outcomes been systematically evaluated?	In part	Relatively coarse grid discretisation due to large extent of model domain, but extent of numerical dispersion are negated because of short pathways
7.5	Is there sufficient basis for the description and parameterisation of the solute transport processes?	Yes	Based on detail assessment underlying geology and groundwater flow processes
7.6	Are the solver and its parameters appropriate for the problem under consideration?	NS	No information provided in report on the solver parameters
7.7	Has the relative importance of advection, dispersion and diffusion been assessed?	Yes	Process is dominated by advection and with focus on breakthrough
7.8	Has an assessment been made of the need to consider variable density conditions?	NA	
7.9	Is the initial solute concentration distribution sufficiently well-known for transient problems and consistent with the initial conditions for head/pressure?	Yes	Solute concentration sources derived from external programs and background concentrations from monitoring
7.10	Is the initial solute concentration distribution stable and in equilibrium with the solute boundary conditions and stresses?	NA	Main focus of study is source-pathway-receptor assessment
7.11	Is the calibration based on meaningful metrics?	Yes	Calibrated to time-series sulfate concentrations
7.12	Has the effect of spatial and temporal discretisation and solution method taken into account in the sensitivity analysis?	No	See 7.4
7.13	Has the effect of flow parameters on solute concentration predictions been evaluated, or have solute concentrations been used to constrain flow parameters?	In part	Solute concentrations used to constrain base flow parameters due to absence of base flow data
7.14	Does the uncertainty analysis consider the effect of solute transport parameter uncertainty, grid design and solver selection/settings?	NA	Relatively unimportant due to short pathways
7.15	Does the report address the role of geologic heterogeneity on solute concentration distributions?	Yes	Addressed in particle flow component
8	<i>Surface Water–Groundwater Interaction</i>		
8.1	Is the conceptualisation of surface water–groundwater interaction in accordance with the model objectives?	Yes	Surface water interaction presented by drains, river boundaries and 'rejected recharge' (outflow due to ponding)

Table 4.2 – Detailed Compliance Checklist (cont'd)

Review Question	Yes/No	Comment
8 Surface Water–Groundwater Interaction (cont'd)		
8.2 Is the implementation of surface water–groundwater interaction appropriate?	Yes	Crucial to meeting model objectives
8.3 Is the groundwater model coupled with a surface water model?	No	Coupling with surface water model should be considered if base flow data becomes available
8.3.1 Is the adopted approach appropriate?	NA	
8.3.2 Have appropriate time steps and stress periods been adopted?	NA	
8.3.3 Are the interface fluxes consistent between the groundwater and surface water models?	NA	

Note: NA = not applicable; NS = not stated.

Generally, the model conforms to the guidelines, although a number of deficiencies were identified and are presented in Tables 4.1 and 4.2. The calibration to surface water base flow data was not undertaken, which is considered significant, even though flow and stage height data are available for two stations on the McArthur River, located upstream of the mine and at SW11, and stations on Barney Creek and Surprise Creek. This calibration would provide significantly more confidence in the simulation of key model parameter including recharge, evapotranspiration and groundwater-surface water interaction, and should be undertaken as part of the EIS supplement.

In terms of complexity and adequacy, the current groundwater flow and transport model is judged to be a Class 2 level model, as defined under the Australian modelling guidelines. This is primarily due to the lack of base flow data and, to a lesser extent, because of the short duration of some of the groundwater level datasets used for calibration. However, under the adaptive management process the IM would expect further development and validation to elevate the model to a Class 3 model to provide sufficient reliability to adequately assess the impacts to the groundwater system.

4.1.2 EIS Terms of Reference

A review of the groundwater study was completed against the final terms of reference for the EIS (EIS Appendix A), which is summarised in Table 4.3.

Table 4.3 – Groundwater EIS Terms of Reference

Criteria	Requirement	Comment
Environmental objectives	Ensure that ground and surface water resources and quality are protected both now and in the future	This objective has not been met, primarily due to uncertainties in the groundwater flow and contaminant transport model. A number of key uncertainties have been identified (discussed in Sections 4.13 to 4.16) which should be addressed as part of the EIS supplement, along with model calibration to base flow data. Additional uncertainties have also been identified. However, these could be addressed as part of the adaptive management approach
Information requirements	Provide a hydrogeological site description including aquifer locations and	Hydrogeological descriptions have been provided in the EIS. However, there are significant uncertainties in the locations and properties of some of the hydrostratigraphic units identified. These include high permeability aquifers

Table 4.3 – Groundwater EIS Terms of Reference (cont'd)

Criteria	Requirement	Comment
Information requirements (cont'd)	qualities, faults, palaeochannels or other preferential pathways for groundwater and their interactions with surface water	associated with interpreted fault zones and between the underground mine and the McArthur River diversion channel. The later should be simulated appropriately in the groundwater flow and contaminant transport model to investigate impacts on the dewatering requirement and pit lake after closure as part of the EIS supplement
Assessment of risk	Identify and assess the risks associated with the formation, leakage, seepage and surface expression of AMD including uncontrolled or unplanned releases of environmental contaminants	The risk from uncontrolled/unplanned seepage is recognised in the EIS. However, the groundwater flow modelling has not been used to adequately assess these risks. In particular, the risks from uncontrolled/unplanned seepage from the NOEF as a result of cover failure or flood inundation. This risk should be assessed as part of the EIS supplement
	Identify and assess the risks associated with groundwater drawdown (cone of depression) and its impacts on other groundwater users, existing springs and groundwater dependent ecosystems	No third party groundwater users were identified in the drawdown zones around the main pumping centres (e.g., pit, borefield). The presence of groundwater dependent ecosystems and springs was not discussed in the groundwater section of the EIS and should be included in the EIS supplement
Mitigation	Provide design alternatives for the effective management of non-benign material to minimise the potential for AMD seepage	Options to manage AMD seepage were presented in the EIS, with detailed assessment of an interception drain at Surprise Creek
Monitoring	Detail a monitoring program to ensure the waste rock dumps are performing in accordance with design specifications	The monitoring requirements presented in the EIS are based on maintaining the current program, which will be expanded as necessary under the adaptive management approach. The EIS also recommends a number of future monitoring and investigation programs to improve the understanding of the source-pathway-receptor processes, which should be committed to by MRM

4.1.3 Final NOEF Cover and Flood Management Performance

Total seepage from the NOEF was applied as a recharge term using seepage rates and source concentrations estimated using other models (DumpSim and Tough2). It is interpreted by the IM that these rates were based on the expected performance of the NOEF cover and did not include seepage generated as a result of flood inundation.

The NOEF represents a major risk to the groundwater system, particularly after closure and following the removal/rehabilitation of seepage management facilities (e.g., drains and PRODs).

After this time the control of seepage impacts is mainly reliant on the performance of the final cover and flood protection measures. If the performance of these controls is worse than predicted or should the cover fail in some areas, then the contaminant loading to the groundwater system will increase. This would result in increased loading to Barney Creek and McArthur River, which is the main environmental receptor for the mine.

It is noted that the risks from increased seepage due to poor performance or failure of the cover, or inundation, are identified in the EIS risk assessment.

4.1.4 Groundwater Inflows to the Underground Mine

Dewatering of the underground mine is simulated in the groundwater flow and contaminant transport model using MODFLOW's drain package, which was linked to a general head boundary condition at the location of the Evase pumping system. The general head boundary condition provides a means of allowing inflows to the model domain, which were then removed via the drain cells.

This approach is based on attempting to match historic trends rather than a physical understanding of the mechanisms associated with flows into the underground mine. Therefore, extrapolation of future underground dewatering rates as mining progresses will be unreliable. This could impact on future water management predictions during operational phases, given that the underground discharge is a major inflow to the mine site (140 L/s during 2016) and comprises Class 5 (poor quality) water, which requires either treatment or on site management.

Understanding the underground inflow mechanisms will also be important in assessing the options to manage the pit lake during and after closure. The presence of a high permeability pathway to the McArthur River diversion channel will impact upon the groundwater inflow and outflow rates to the pit lake for all options under consideration. This could, in turn, affect movement of contaminated pit lake water into the groundwater system. In addition, a deep flow path would provide a connection between the highly contaminated water within the lower parts of the pit lake and the groundwater system and (possibly) McArthur River, should pit lake levels exceed the ambient groundwater level (although the likelihood of this is not known).

4.1.5 Groundwater Interaction with the Pit Lake

The pit lake was modelled using a time-variant constant head boundary condition, which was taken from the pit lake water balance results. In reality, the pit lake level and interaction with the groundwater system are interdependent. This requires some form of coupling between the groundwater flow and contaminant transport model and the pit lake water balance to provide reliable predictions.

This could be significant in estimating the long-term pit lake level, especially during high stress periods, e.g., during the wet season when groundwater recharge rates and surface water flows are highest. During these periods there is the greatest risk of environmental discharge of pit lake water to the environment, either to the groundwater system and then either the McArthur River or Barney Creek, or directly to the surface water system under the through flow or backflow pit lake closure options.

4.1.6 Reduced Metals Attenuation

The groundwater flow and contaminant transport model is based on the EPM approach, which is acceptable when simulating average advective groundwater flow. However, when simulating contaminant flow where fractured rock or karstic conditions are known to exist, allowances should be made for these rapid flow pathways which can short circuit the intergranular flow process, reducing travel times and interaction with the rockmass. This will in turn reduce the attenuation of soluble metals, resulting in more rapid migration of the CoCs.

4.2 What Must be Addressed in the EIS Supplement?

A summary of the groundwater related uncertainties identified in the EIS review is provided in Table 4.4.

Table 4.4 – Summary of Groundwater Model Uncertainties

Uncertainty	Comments and Recommendations
The monitoring data collected for dewatering of the mine, indicates the presence of a major conduit(s) hydraulically linking the underground mine to the McArthur River diversion. However, there is minimal information supporting this assumption	The presence of a major hydraulic connection between the underground mine and McArthur River will likely have a major impact on the dewatering requirement and pit lake inflows and outflows. Further field investigations are required to identify this connection and estimate the aquifer properties
The simulation of the assumed major hydraulic link between McArthur River and underground mine has been modelled without consideration of actual physical processes. This impacts upon the reliability of the predictions	The presence of a major hydraulic connection between the underground mine and McArthur River will likely have a major impact on the dewatering requirement and pit lake inflows and outflows. The groundwater flow and solute transport model should be modified to reflect the presence of a major hydraulic link between the McArthur River and underground mine, and sensitivity runs completed to assess the likely range of results
The extent and aquifer properties of the palaeo-channel appear to be poorly understood, e.g., widths of up to 1 km have been suggested and pit inflow rates from this aquifer estimated at 1 to 4 ML/day, despite low yields from test bores of less than 2 L/s	The modelled high inflow rates to the mine from this aquifer suggest it is a major component of the dewatering effort. Further field investigations are required to define the palaeochannel and estimate the aquifer properties
The water and solute inputs to the groundwater flow and solute transport model from the NOEF are based on outputs from other models and do not appear to allow for worst case performance of the cover or partial cover failure. The NOEF is considered a major risk to the groundwater environment, especially after closure when other controls are removed/rehabilitated	Sensitivity runs should be completed using the groundwater flow and solute transport model to estimate the possible range in results should the final NOEF cover perform below expectations or partially fail
The groundwater flow and contaminant transport model includes attenuation values based on laboratory testing. These have a major impact on the predicted transport of Contaminants of Concern (CoCs), with modelling results indicating limited migration of metals 1,000 years after closure. The effectiveness of metals attenuation is highly dependent on the groundwater flow mechanism, in this case flow through a porous medium. Attenuation will be less under fracture flow conditions, which are thought to occur in discrete areas including zones around the TSF and NOEF	Further sensitivity runs should be completed using the groundwater flow and solute transport model to estimate the possible range in CoC transport assuming limited attenuation. In addition, monitoring data should be assessed to identify actual break through times for CoCs and other metals in both monitoring bores and surface water monitoring stations. This data can then be used to calibrate the model with respect to retardation

Table 4.4 – Summary of Groundwater Model Uncertainties (cont'd)

Uncertainty	Comments and Recommendations
<p>A number of parameters adopted in the calibrated model are considered to lie outside the expected range for the material type:</p> <ul style="list-style-type: none"> ♦ Palaeochannel Kh = 10 m/d, seems high given the low aquifer yield (<2 L/s) ♦ Reward Dolomite Kh = 0.3-1.5 m/d, seems high for a bulk value, without extensive karst development ♦ Cooley Dolomite North Kh = 5 m/d, seems high for a bulk value, without extensive karst development ♦ Fine- and coarse-grained overburden and palaeochannel Sy = 0.02, seems low for a granular medium ♦ Reward, Cooley & Western Dolomite; and fractured bedrock Sy = 0.1, seems high for rocks with secondary permeability 	<p>Modelling results will be influenced by variation in aquifer properties, especially K. Further model validation and sensitivity runs are required to confirm these property values</p>
<p>Model calibration does not include calibration against base flow data. This would assist in reducing the uncertainties in a number of key model parameters (e.g., recharge, evapotranspiration and groundwater-surface water interaction)</p>	<p>Analysis of the flow data for McArthur River and Barney and Surprise creeks should be carried out to estimate the groundwater contribution to these watercourses along reaches within the groundwater flow and contaminant transport model. The results should be used for further model calibration</p>
<p>Presence of groundwater-dependent ecosystems and springs, which could be impacted by pumping drawdowns</p>	<p>Under the terms of reference for the EIS, MRM should confirm whether groundwater dependent ecosystems and springs are present in areas likely to be impacted by groundwater level drawdowns</p>

4.3 References

Barnett B., Townley L.R., Post V., Evans R.E., Hunt R.J., Peeters L., Richardson S., Werner A.D., Knapton A. and Boronkay A. 2012. Australian Groundwater Modelling Guidelines, Waterlines report. June. National Water Commission. Canberra.

EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

5. Surface Water Quality Management

5.1 Is the Information in the EIS Sufficient?

The mine has developed a complex and comprehensive water management system that, as described in the EIS, will be adapted as required to allow Project implementation. Surface water quality monitoring data up to October 2015 indicates that adverse impacts on downstream surface waters due to the mine are currently limited, although some effects are noticeable in watercourses within the mine lease boundaries (and this is not unexpected) and some non-compliance with waste discharge site-specific trigger values SSTVs due to mine activities has occurred (ERIAS Group, 2016). Given MRM's efforts to date, the information contained in the EIS, and the particular difficulties that may be incurred when implementing remediation measures post-closure, this review has focused on the period after mine closure. However, comment on impact predictions for the proposed remaining operational period is also provided where relevant.

5.1.1 Terms of Reference

The EIS Terms of Reference (TOR) prepared by the NTEPA required that MRM address the following key risks related to water:

- ♦ Contamination of groundwater from mining activities potentially causing groundwater quality impacts outside of the mineral lease or expression of contaminated groundwater to surface water.
- ♦ Contamination of on-site surface water from AMD including metalliferous and saline drainage under circum-neutral conditions, potentially causing adverse impacts to downstream environmental values.

The relevant environmental objective specified in the TOR is to 'ensure that ground and surface water resources and quality are protected both now and in the future, such that ecological health and land uses, and the health, welfare and amenity of people are maintained'. Specific information requirements for the EIS are also provided in the TOR. A number of water-related measures listed therein concern matters such as hydrogeology, site water balance, and AMD minimisation and management, and these are addressed elsewhere in this report. However, it should be noted that the TOR also specifies that:

- ♦ Surface water beneficial uses be discussed. The EIS TOR cross-reference table (EIS Appendix B) refers to Sections 8.1.3.3, 9.3, 10.2 and 12.2 as being relevant to this requirement. Although reference is appropriately made in these sections to values such as aquatic and terrestrial ecosystems/cultural and spiritual values for downstream receiving waters, the discussion would benefit from specific reference to the beneficial uses that have been declared for the McArthur River Area, i.e., aquatic ecosystem protection, recreational water quality and aesthetics (as referred to in the waste discharge licence (WDL)), while those for the McArthur River Catchment Area are environment, cultural and riparian (also referred to in the WDL). In particular, the presence of two sites of conservation significance

(SOCS)³ that are located downstream of the mine site (and are referred to in the WDL) should be acknowledged:

- 'Borroloola Area', which includes McArthur River from the mine site almost down to the town of Borroloola (NRETAS, undated_a).
- 'McArthur River coastal floodplain', including open saline flats and extensive mangrove systems, where 'pollution' from industrial developments associated with the McArthur River Mine is specifically listed as a management issue for this area that is rated as being of international significance (NRETAS, undated_b).
- ♦ Pre-mining surface water quality be summarised. The EIS TOR cross-reference table (Appendix B) refers to Sections 8.3.5 and 8.7.1, and Appendix U, as being relevant to this requirement. Appendix U notes that the reliable period of record dates back to 2007, and that the detailed review of natural surface water quality data at McArthur River Mine (which is summarised in that appendix) is based on data from 2007 to 2014⁴ (although the summary as presented in Appendix A of Appendix U actually extends from January 2008 to December 2015). However, underground mining commenced in 1995, hence the TOR requirement as worded is not met (although this may not be the case if only open cut mining is considered, since open cut site works commenced in 2007 after earlier mining from a test pit in 2005 and 2006).

The IM also notes that MRM's focus in relation to metals is on filtered metals rather than total or unfiltered metals. The IM acknowledges that this is consistent with the WDL and the known greater bioavailability of filtered metals compared with that of particulate-associated metals, but contends that a comprehensive discussion of surface water quality should include consideration of the latter.

- ♦ Where required, a conceptual site model (CSM) should be used to illustrate interactions between discharge risks and related sensitive receptors, where this should be consistent with NT EPA guidance (NTEPA, 2013a). Chapter 3 of the EIS contains a narrative-style CSM, which is supported by a number of diagrammatic or pictorial CSMs such as the hydrogeological conceptual models for the various OEFs, and table CSMs that include proposed controls (as well as the text and figures in, e.g., EIS Appendix E). However, the EIS would benefit from an overall diagrammatic or pictorial CSM that addresses the main issue in terms of waste (rock and tailings) management and potential adverse impacts on local and downstream environmental values/beneficial uses, including:
 - The estuarine reaches of the McArthur River and associated depositional or backwater areas (if any), and coastal waters.
 - Potential stressors such as particulate-associated metals, as well as filterable species and erosion-derived sediment.

³ A third SOCS that should also be considered is the Sir Edward Pellew Island group.

⁴ The IM also notes this is not entirely consistent with the statement in Section 8.3.5.4 that a 'comprehensive surface water and groundwater monitoring program...has been underway for over 20 years'.

- Associated processes such as downstream biogeochemical cycling of trace metals and changes in metal speciation and partitioning, and sedimentation/floodplain deposition (including consequent changes in bed sediment metal concentrations).
- Receptors such as local communities via consumption of 'bush tucker', taking into account both operational and post-closure phases.
- Mine-derived versus natural loads of stressors such as metals, sulfate and suspended solids (as opposed to just concentrations).

A further consideration with respect to the TOR is the over-arching requirement for the EIS to 'include an assessment of the Project's risks to the surface and groundwater resources in the vicinity of the site, as well as downstream'. Further discussion concerning the surface water quality aspects of this requirement is presented in the following section. However, it should be noted that the TOR requires these risks to be measured from 'baseline conditions (i.e., pre-mining)' and, as noted above, the EIS does not seem to meet this requirement. Assessment of risk to surface water resources should also take into account the additional aspects listed above in relation to the CSM, which would allow a more comprehensive assessment to be presented in the EIS. The IM also contends that a risk assessment in relation to surface water quality and associated beneficial uses should take into account the No Project scenario, since this will both support regulators in the process of making an informed decision about the Project and more fully inform other stakeholders about the relative merits (or not) of the Project.

5.1.2 Further Comments

5.1.2.1 Selected Stressors and Modelling Approach

As identified in the EIS, the Project's environmental protection philosophy is to 'protect the downstream environment from McArthur River Mine impacts at all times' (EIS Section 8.1.3.2), and this is repeated a number of times throughout the EIS. A series of CSMs has been developed 'to understand the potential risks posed by a source to a receptor'. However, as noted above, the conceptual models as presented in EIS Chapter 3 focus on soluble (dissolved) parameters and, to a lesser extent, suspended sediment. The tables that summarise key source-pathway-receptors for the open cut, NOEF and TSF (EIS Tables 3-10, 3-14, 3-15, 3-16, 3-17, 3-18, 3-19, 3-20 and 3-21) refer variously to 'soluble oxidation products' and, on three occasions in relation to the NOEF and once in relation to the TSF (during the closure phase), 'sediment, turbidity' or just 'sediment', with no reference to particulate-associated metals or other stressors.

The EIS also assumes that complying with the WDL trigger values at SW11 will protect all relevant beneficial uses. This is reflected in the statement that 'The potential impacts on these receptors are conservatively measured at the SW11 monitoring location just beyond the lease boundary and are measured in accordance with the WDL trigger levels' (EIS Section 8.1.3.2) and Figure 8-48 (EIS Section 8.6.1). In relation to metals and metalloids, the WDL trigger levels are for soluble concentrations and do not address particulate metals or possible downstream changes in metal speciation and partitioning between soluble and particulate phases.

The contaminants that were selected for modelling were sulfate, Pb, Zn, Cd and As, with turbidity for surface water modelling only. Although a brief rationale is provided (EIS Section 8.1.3.4),

discussion about other parameters is not presented. Aquatic ecosystem values were considered to be most conservative of the environmental values and were therefore adopted as a management focus (EIS Section 8.1.3.3). However, the EIS should acknowledge that the WDL trigger value for As is 24 µg/L while the drinking water health-based Australian guideline value is 10 µg/L, i.e., ecosystem protection is not the most conservative value for this element. The IM also acknowledges the statement in the EIS that the selected potential contaminants were presented to and discussed with the NTEPA.

The explicit aim of the waterways model was to estimate (EIS Section 8.6.2.2):

- ♦ The long-term background surface water flow volumes, dissolved CoC concentrations and sediment loads generated upstream of McArthur River Mine.
- ♦ The potential surface water quantity and quality impacts from McArthur River Mine along the waterways within the study area during the operational and closure periods.
- ♦ The potential surface water quality impacts of predicted overflows from mine water storages during the mine operational period on CoC concentrations on the receiving waterways.
- ♦ The potential surface water quantity and quality impacts of the mine pit lake connection with McArthur River (including 'isolated', 'backwater' and 'flowthrough' scenarios) on McArthur River 'flow concentrations'⁵ and CoC loads (including suspended sediment) at SW11.
- ♦ The mixing zones incorporated in the waterways model and its influences at SW11.

The IM's view is that specific gaps in the results presented in the EIS (some of which have already been referred to above) include consideration of:

- ♦ Downstream, i.e., beyond SW11, particulate metal and sulfate loads, conductivity, and sedimentation of mine-derived material, both in the main channel and floodplain (depositional) environments, and comparison with background values.
- ♦ Consideration of biogeochemical processes in the downstream environment (and the IM notes that PHREEQC and GWB were used for predicting water quality in the mine pit lake, although assessment of the implications of partitioning between particulate and dissolved metal species in downstream waterways may be all that is required).
- ♦ The expected range in TSS concentrations from sediment basin overflows, particularly in relation to high rainfall/flood events (and Section 7.6.3 of EIS Appendix U notes that the capacity of the 'Type F' sediment ponds, which may be used on site, will be regularly exceeded).

However, the IM also acknowledges the statement in the EIS that the assessment approach presented in the EIS was presented to the NTEPA and DPIR throughout the consultation process. The IM's position is that, while a focus on water quality trigger levels given in the WDL and water quality at SW11 provides an important first tier of assessment, an EIS that is meant to address

⁵ This is quoted directly from the EIS; the meaning of 'flow concentrations' is uncertain.

the broader issue of impacts on the entire McArthur River system over a 1,000-year period should be supplemented by additional levels of assessment as described herein, thereby allowing a more comprehensive assessment of the risk. This should include consideration of total loads of mine-derived metals and suspended solids (and ANZECC/ARMCANZ (2000) recommends that load-based guidelines be developed for suspended particulate matter in the context of sedimentation and smothering of benthic organisms (as well as nutrients and biodegradable organic matter)), and more thorough assessment of likely impacts in the downstream environment beyond SW11.

The IM also recommends that such additional assessment should be commensurate with the level of risk that is posed by the various hazards. For example, assessment of the impacts of suspended solids from the site on downstream beneficial uses due to increased turbidity, TSS levels or sedimentation, or changes in bed sediment quality, may warrant only a screening level assessment rather than a full risk assessment. This may also apply to other stressors such as particulate-associated metals. Nevertheless, the absence of such assessments is a gap in the EIS, if only because it doesn't allow stakeholders to form an overall view of the Project's impacts. In this context, a finding that, for example, particulate-associated metals would have no material impact on the downstream beneficial uses, including those associated with the estuarine reaches or coastal waters into which McArthur River discharges, would be useful information and is worth explicitly stating in the main EIS (and not be buried in various appendices).

5.1.2.2 EIS Findings

Main Comment

As noted above, MRM's surface water quality monitoring data shows that current mine-related adverse impacts on downstream surface waters are limited, and the results presented in the EIS suggest that this will continue to be the case. However, this depends on the efficacy of the proposed management and mitigation measures, and a number of challenges are associated with these measures as described elsewhere in this report (although these are not necessarily acknowledged in the EIS). In particular, predicting changes in water quality after closure is more difficult due to the increasing change in conditions as time passes; it is also worth noting that remedial measures, if required, are also generally easier to implement during operations when personnel and equipment are on site than after closure when demobilisation has largely occurred. Looking therefore at surface water quality after closure, EIS Section 3.3.4.1 describes ten closure objectives for the Project, with the following being of particular relevance from a surface water perspective:

- ♦ Erosional stability; maintainable for these aspects:
 - Sediment release from erosion does not adversely impact on water quality.
 - Resulting suspended solids can be mitigated.
- ♦ Geochemical stability will be defined, managed and monitored:
 - Seepage water quality at toe/base of landforms.
 - Water quality within the mine pit lake.

- ♦ Manage surface water and groundwater such that environmental values and ecosystems are maintained downstream of the lease boundary in the short term (0 to 100 years), and within the McArthur River in the long term (100 to 1,000 years).

The closure objectives include no mention of Barney Creek, Little Barney Creek, Emu Creek or Surprise Creek. In the absence of such references, it appears that protection of the environmental values associated with these streams is not a long-term objective (unless reference to the McArthur River is meant to include these tributaries). This perception is consistent with the statement (EIS Section 8.1.3.2) that 'the receptors for the purposes of the EIS water resources impact assessment are those that exist downstream of the mineral leases' (and this statement is not entirely consistent with the closure objective of maintaining environmental values within McArthur River in the long term). While the appropriateness of this requires consideration by a range of stakeholders and may be considered questionable, the status of these streams after closure with regard to the relevant environmental values should be explicitly stated in the EIS, expanding on the information presented in EIS Section 9.4.2. This is particularly relevant given that the modelling indicates elevated sulfate concentrations in Barney Creek and Surprise Creek post-closure (i.e., annual average concentrations ranging from 1,030 mg/L for the period 2060 to 2070 up to 2,041 mg/L for the period 2200 to 2500 (and reducing to 1,949 mg/L for the following 500 years) at BCS2 at the lower end of the Barney Creek diversion) (Table 9.16 of Appendix U) compared with the WDL SSTV of 341 mg/L, the statement that 'Macroinvertebrate communities within Barney Creek and Surprise Creek are likely to be affected by elevated sulphates and metals ' (EIS page 9-43), and Figure 9.30 of EIS Appendix U which shows these creeks as being impacted by mine seepage during both the operational period and post closure. As also noted in Section 9.8.4 of EIS Appendix U, elevated sulfate (and Zn) concentrations are particularly evident in the dry season.

A related matter concerns Table 9.18 of EIS Appendix U, which shows elevated concentrations of sulfate and Zn compared with the WDL trigger values at the pit lake downstream levee opening outflow for the period 2060 to 2070. Elevated levels relative to the WDL trigger values are also predicted at the same site for sulfate and Zn for the following 40 years. Although this table also shows that WDL values will be met at SW11 during these periods (where the river will be connected to the pit lake for an average of 47 and 41 days per year for the respective periods), and the IM acknowledges the validity of the use of mixing zones in water management, the EIS would benefit from a discussion concerning the impacts that are expected to occur within the mixing zone and the wider implications for the McArthur River system, if any. Although this is discussed to some extent in Section 9.8.6 of Appendix U, the initial sulfate concentration used for the detailed assessment seems to be somewhat lower than the value of 1,087 mg/L shown in Table 9.18. Such a discussion would expand on the discussion presented in Section 9.9 that addresses elevated concentrations of sulfate and Zn (and sometimes other metals) in Surprise Creek, Barney Creek, Little Barney Creek and Emu Creek during operations and post-closure, and should also explicitly address the requirements of the NT EPA's guidelines for mixing zones (NTEPA, 2013b), e.g., the need to ensure that unacceptable impacts on flora and fauna do not occur, as determined by a risk assessment, and that fish migration is not adversely affected. As currently presented, the implications of poorer water quality upstream of SW11 over a period of possibly decades (or centuries) are not adequately addressed in the EIS.

As stated in EIS Section 8.6.2.2, the modelling shows that predicted CoC concentrations at SW11 will generally remain below the WDL trigger levels during operations and the closure assessment period (where the latter reflects a mine pit lake flow-through configuration and ongoing use of Barney Creek collection sumps, and extends from 2047 to 3018 (EIS Section 8.6.4.3)). However, Table 9.17 of EIS Appendix U shows maximum sulfate values for February and December in the period 2100 to 2200 that exceed the WDL trigger level of 341 mg/L. The implications of such exceedances should be discussed.

The EIS also refers extensively to an 'adaptive management' approach which, within the context of surface water quality impacts, is meant to address the uncertainties associated with model outcomes (EIS Section 8.6.1). However, the EIS would benefit from additional information to address specific 'what if' scenarios, analogous to the approach taken for the climate change assessment (EIS Section 8.6.4). Examples of scenarios to consider include what happens if the PAF encapsulation and NOEF cover are not as effective as envisaged in the modelling and adaptive management is also not effective – is 'collect and treat' for the entire 1,000 year post-closure period feasible⁶? What happens if the pit lake stratifies and then 'turns over', with poor quality water from the hypolimnion being discharged to the McArthur River (and a similar scenario is raised as a key potential risk when evaluating project alternatives (EIS page 5-24))? Section 7.1.3 of EIS Appendix U states the following:

It has been assumed that, shortly after placement of the final cover system material, runoff water quality from the final cover will meet the current MRM WDL174-08 SSTV's for SW11. If this is not the case, additional management measures, storage and/or treatment may be required until the runoff water quality is suitable.

This same section also notes that:

The success of the proposed post-closure water management measures at MRM will depend on the water quality of the mine pit lake in the first 20 years when it is initially filled and connected to the McArthur River via openings in the mine levee wall. If the mine pit lake water quality is unacceptable, the lake may need to be isolated from the McArthur River until it is acceptable.

Similarly, EIS Section 3.4.4.3.5.5.7 states that:

Should monitoring of NOEF seepage indicate unacceptable risks to the receiving environment, these contingency measures will be reviewed, further developed and implemented as required.

However, there is limited information as to what these (and other) additional management measures, storage or treatment options might be, their feasibility, or how they will be funded or actually implemented. As noted above, the question remains as to whether MRM is acknowledging that, should a worst-case scenario eventuate, ongoing (up until 3018 and possibly beyond) collection and treatment remains an option. The IM's view is that, given these uncertainties and the discussion presented elsewhere in this report concerning matters such as the long-term effectiveness of the NOEF cover, such an option should be discussed and the associated downstream impacts, if it were to be implemented, assessed. This would also address

⁶ The IM notes the comment in EIS Section 4.10.2.3 that 'Seepage management systems, in place to collect and treat water affected by leaching of oxidation products from the base of the NOEF, will remain throughout the closure period until such a time that monitoring confirms it is no longer required. These systems will remain in place at least throughout the adaptive monitoring phase following cessation of operations'.

the comment in Section 9.2.6.4 of EIS Appendix T (Groundwater) that, in relation to the TSF and NOEF, 'it is expected that metal plumes will develop over very long periods of time (thousands of years and greater) and may require long-term management'. The IM also notes that Table 2 of EIS Appendix Z (Economic Impact Assessment) allows for 3 + 1 employees from the Borroloola-Gulf Area/Other Northern Territory for the period 2073 to 3017, which is indicative of a long-term presence by MRM in the project area.

In addition to selected metals, the CoCs (as described in the EIS) include turbidity in relation to surface water (and this is a surrogate for total suspended solids). As noted in ERIAS Group (2016), MRM's view is that mine-derived TSS impacts on McArthur River downstream are lower risk and are generally not included in water quality assessments due to the elevated TSS concentrations that occur in McArthur River, particularly during flood events. However, mineralised suspended material reporting to McArthur River during flood events remains a possible pathway for downstream impacts to occur (as would be noted in a comprehensive CSM, and as is reflected in EIS Appendix W (Aquatic Ecology) where this is identified as a potential impact in relation to open cut operations and NOEF surface water runoff), and downstream impacts might therefore be attributable to the suspended solids themselves or their mineralised nature (or both). The EIS notes that (Section 9.4.1.6):

Models of surface water quality throughout the duration of the Project reveal that, with various mitigations measures in place, no increase in the amount of total suspended solids is expected to occur within the McArthur River. On the contrary, a slight decrease in the amount of sediment within the McArthur River downstream of the Project is expected after 2060, when the mine pit lake is connected to the McArthur River and acts as a sediment sink.

However, further comment is required in the main EIS concerning the potential impacts associated with site-derived suspended solids, including consideration of particulate-associated metals, particularly after closure. Even if these are not considered by MRM to be major risks, the main EIS report would benefit from a discussion that places these impacts in the appropriate context. This would also specifically address the risks mentioned in the TOR of altered project inputs of pollutants affecting offsite water quality and aquatic, riparian and wetland habitats, as well as increased sedimentation impacting downstream biodiversity.

Additional Comment

In addition to the general comments provided above, comments that relate to more detailed aspects of the EIS/supporting appendices include:

Appendix U (Surface Water Impact Assessment)

- ♦ Figure 2.2 doesn't show the re-aligned Little Barney Creek around the TSF as being an existing diversion.
- ♦ Tables 3.10, 3.11 and 3.12 summarise surface water quality in McArthur River, Barney Creek and Surprise Creek, and also include WDL trigger values. It would be useful for the tables and accompanying text to clearly and explicitly describe the results as being for total or dissolved (and the IM acknowledges that the text sometimes makes this clear); TSS should also be included.

- ♦ The units for hardness in Tables 3.10, 3.11 and 3.12 (and other tables) should be mg CaCO₃/L rather than simply mg/L.
- ♦ In addition to referring to pre-mining water quality data (see discussion above), the summarised data should explicitly reflect the various stages of project development that have occurred to date, e.g., pre-mining, U/G, open pit.
- ♦ The text in relation to item 1 in Table 7.14 notes that 'and/or additional storage volume would be required to fully contain the contaminated water on site' if surface runoff collected in sediment management structures in the NOEF domain is not within the WDL limits. This begs the question as to how the water quality in these structures would be monitored and how the need for additional storage volume would actually be managed in real time. A similar comment applies to item 5 in the same table and the potential time delay between identifying the need for dilution ratios in McArthur River that are greater than the assumed value of 10, and obtaining increased on-site storage capacity.
- ♦ Section 8.12.1 refers to the stored mass of dissolved CoCs during the operational period up to 2047, as well as contaminant loads from the NOEF dams in high rainfall events. However, total loads of CoCs (dissolved and total) that will be discharged during the operational period and post closure are not presented, nor are corresponding background loads in McArthur River to provide the required context. This is despite the fact that the model was used to simulate daily movement of water volume, CoC loads and TSS loads along the waterways through the McArthur River Mine site (Section 9.1.2).
- ♦ Section 9.2.6 would benefit from clarification as to whether water will need to be pumped from the Barney Creek collection sumps up until 3018 (and possibly beyond).
- ♦ Section 9.6.2 notes that the model generally predicts CoC concentrations 'reasonably well'. However, examination of Figure 9.10 shows that recorded peak sulfate concentrations at a number of sites appear to substantially exceed the modelled values. The implications of this for the downstream impact predictions should be discussed. The application of the model results to the other water quality variables listed in the WDL should also be summarised.
- ♦ Section 9.7.5 discusses water quality in the mixing zone during a significant overflow event. The text refers to 'a day with one of the largest predicted overflow volumes from the NOEF dams was selected', but additional context in terms of hydrological return intervals or similar would be useful.
- ♦ Total metal concentrations are not presented in the main EIS or Appendix U, although they are summarised for some sites in Appendix A (Historical Water Quality Data) of Appendix U, which also includes reference to laboratory determination of 'filtered and total concentrations where applicable' (Section A1.3, Appendix A of Appendix U).
- ♦ Various typographical errors occur, e.g., Figure 3.2 – 'cummulative' in the legend is misspelt; Section 3.3.2, para 2, words missing at the end of the second sentence; repeated text at the start of page 60; Table 4.1 includes 'Mg' as the abbreviation for manganese rather than 'Mn'.

Other

- ♦ in relation to the pit lake, Appendix VI of Appendix T (Groundwater) states that stratification and dilution, as indicated by modelling, will reduce contaminant loads in lake discharges. While the IM does not disagree with this conclusion as a generality, consideration of the likelihood and implications of the pit lake overturning and potentially releasing a 'slug' of poor quality water downstream should be presented.
- ♦ Section 4.2 of EIS Appendix W (Aquatic Ecology) notes that the residual risk rankings presented in the ecological risk assessment in that report 'relied heavily on model predictions being accurate'. Consideration of 'what if' scenarios, particularly those that reflect inaccurate model predictions, does not appear to have been undertaken.

5.2 What Must be Addressed in the EIS Supplement?

Review of the EIS and related appendices relating to surface water quality has identified the following areas that need to be addressed in the EIS supplement:

- ♦ Provide a comprehensive diagrammatic or pictorial conceptual site model(s) that summarises all relevant pathways and stressors, and will facilitate understanding of surface water quality issues, including consideration of beneficial uses, by stakeholders. The accompanying text should also refer to the relevant declared beneficial uses, as summarised in the WDL.
- ♦ Include consideration of stressors and related processes that are not currently adequately considered in the EIS, e.g., particulate-associated metals, downstream sedimentation, downstream biogeochemical cycling, metal (dissolved and particulate) and sulfate loads, and pit lake stratification and subsequent turn over. In relation to loads, the EIS supplement should include a simple schematic representation of the loads from the TSF, NOEF and open cut mine in relation to background loads in Surprise Creek, Barney Creek and McArthur River, expanding on the information contained in EIS Appendix T (Groundwater).
- ♦ Ensure that the level of effort expended in these additional considerations (as referred to immediately above) is consistent with the level of risk; for example, relatively simple screening risk assessments may be suitable for a number of stressors or issues. However, the discussion should provide details about proposed management measures if these are integral to the assessment and residual risk ranking (and not simply state that 'active management measures would be required' or similar), including the feasibility of implementing these measures.
- ♦ Provide further discussion about predicted changes in downstream water quality in terms of the water quality parameters listed in the WDL that were not modelled, and include consideration of changes in bed sediment quality.
- ♦ Provide further detail about measures that could be implemented should monitoring show that the required beneficial values are at increased risk, with a focus on the post-closure period, i.e., provide further detail about what 'adaptive management' might actually mean, notwithstanding the information in EIS Chapter 5 (Project Alternatives) or Appendix Q (NOEF seepage mitigation concepts) (and this is further discussed in Chapter 9 of this report).

- ♦ Provide further discussion about the merits of the Project on surface water quality (including bed sediment quality) and beneficial uses in relation to (i) pre-mining conditions and (ii) the No Project scenario.
- ♦ In relation to the potential need for additional storage volume to fully contain contaminated water on site so as to meet water quality requirements at SW11, provide further information about the relationship between water quality monitoring and how MRM will meet this requirement in real time.
- ♦ Provide further discussion about the post-closure impacts on those reaches of Surprise Creek, Barney Creek, Little Barney Creek, Emu Creek and McArthur River that are upstream of SW11 but may be impacted in the long term. This discussion should encompass both water quality and associated beneficial uses, and address matters raised in guideline documents such as NTEPA (2013b).
- ♦ Provide independent verification of the modelling used to predict downstream impacts, i.e., MRM's waterways model and its interface with the Goldsim model. This should include comment as to the correlation of modelled values with recorded values during model validation, and the implications.

5.3 References

- ANZECC/ARMCANZ. 2000. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand. Canberra.
- ERIAS Group. 2016. Independent Monitor: Environmental Performance Annual Report 2015: McArthur River Mine. Report No. 01164C_1_v2. August. Report prepared by ERIAS Group for the Department of Mines and Energy, Darwin.
- NRETAS. Undated a. Sites of Conservation Significance. Borroloola Area. A WWW publication accessed on 15 April 2017 at <http://www.territorystories.nt.gov.au>. Northern Territory Government. Darwin.
- NRETAS. Undated b. Sites of Conservation Significance. McArthur River coastal floodplain. A WWW publication accessed on 15 April 2017 at <http://www.territorystories.nt.gov.au>. Northern Territory Government. Darwin.
- NTEPA. 2013a. Guidelines on Conceptual Models. Version 2.0. November 2013. Northern Territory Environment Protection Authority. Darwin.
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EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

6. Mine Site Water Balance

6.1 Is the Information in the EIS Sufficient?

6.1.1 Adopted Design Flood Standards

6.1.1.1 The Use of AEP Flood Design Standards Misrepresents Risk

Background Information

The two key ways in which design flood standards are usually expressed in the industry are:

- ♦ Annual Exceedance Probability (AEP). This is the likelihood of occurrence of a flood of a given size or larger in any one year; usually expressed as a percentage.
- ♦ Service Life Exceedance Probability (SLEP). This is the likelihood of exceedance during a project's adopted service life, rather than as an annual likelihood.

For example, the AEP method is used to define the levels of service of roads (Austroads, 1994):

Freeways and arterial roads – should generally be designed to pass the 50 or 100 year ARI flood without interruption to traffic. However for arterial roads in remote areas, a reduced standard is commonly adopted where traffic densities are low.

Also, as an example, the SLEP method is used in the design of bridges (Austroads, 1994):

All bridges are to be designed so that they do not fail catastrophically during a flood that has a 5% chance of being exceeded during the Design Service Life of the structure. Assuming a 100 year Design Service Life, this equates to a flood with an ARI of 2000 years.

The SLEP is given by:

$$P = 1 - e^{-\frac{L}{Y}} \quad (\text{Equation 6.1})$$

Where:

P = probability of one or more exceedances of the design capacity during the design life

L = design life (years)

Y = design AEP (years)

McLuckie et al. (2016) point out that while design standards are commonly expressed as an AEP, it is likely that stakeholders interpret and apply this more as a SLEP or an exceedance frequency over the adopted service life. For example, the McArthur River levee has a design AEP of 0.2% (1-in-500) flood. Conceptually this is usually interpreted (incorrectly) as the levee will only be exceeded once in 500 years. However, if the levee has a design life of (say) 50 years then equation 6.1 shows the levee has a 10% chance of overtopping during the design life. Further, for a design life of 100 years the levee has an 18% chance of overtopping during its life.

Action Required

The EIS should express design flood standards as SLEP rather than AEP.

6.1.1.2 Justification of the Adopted Design Flood Standards

Background Information

There are three general approaches to managing the likelihood or consequences of flood risk used in the industry. These are:

- ♦ Use of design standards that relate to a particular flood event:
 - Design flood standards are typically adopted across an entire floodplain or government service area. For example, the use of a minimum floor level for a building relative to a design flood level.
- ♦ Providing a certain level of service:
 - Level of service standards are generally aimed at maintaining the serviceability during a flood of a particular magnitude. For example, having a road trafficable in a design flood of a certain AEP.
- ♦ Use of risk based management approaches:
 - Risk-based decision making processes are recommended for management of risks for, ‘... non-standard and critical infrastructure where a broad design flood standard may not be appropriate’ (McLuckie et al., 2016). Examples of this type of infrastructure include (from McLuckie et al., 2016):

Dam safety risks and design of spillways and outlets.

Risk management decisions for projects with a relatively short time frame, such as construction projects as well as temporary infrastructure (such as a coffer dam during construction).

Structures that are particularly susceptible to overtopping or inundation. For example, a bridge superstructure that cannot withstand active flow or impacts from debris, or a flood levee that is not designed for overtopping and will likely result in failure.

Standard Practice

There is no ‘industry standard’ for the design of water management structures (e.g., drains, levees) for the closure of McArthur River Mine which takes into account the unique mine features and potential off-site impacts.

Action Required

A risk based management approach should be used to set design flood standards for all elements in the mine site. This includes operational and closure phases.

Adopted Design Flood Standards

Background

The EIS has adopted different flood magnitudes as the design flood standards for the various mine site elements. For example:

- ♦ The main McArthur River levee is designed to have a 0.2 % (1-in-500) annual exceedance probability (AEP) flood immunity.
- ♦ NOEF drains are designed to contain the 1% (1-in-100) AEP discharge.
- ♦ The NOEF PRODs are designed to have 1% (1-in-100) AEP flood immunity.
- ♦ The power station and rehabilitated WOEF will have a levee to protect it from the 0.2% (1-in-500) AEP flood.

There is no discussion or justification in the EIS for the adoption of the design flood standards (AEPs) for the different design elements (e.g., McArthur River Levee, NOEF batter drains). In particular:

- ♦ There is no detailed risk assessment of the adoption of flood magnitudes.
- ♦ There is no justification for the difference in design flood standards for different elements. For example, the design flood standards for the McArthur River Levee and the rehabilitated NOEF batter drains are the 0.2% (1-in-500) and 1% (1-in-100) AEP events, respectively. If it is assumed the levee has a design life of (approximately) 50 years (if the flow through pit is adopted) and the NOEF batter drains have a design life of 1,000 years, then from Equation 6.1 the probability of failure during the design life is 10% and 100%, respectively. Further, if the rehabilitated NOEF drain design life was only 100 years, Equation 6.1 shows there is a 63% probability of failure during the design life. The failure of an NOEF batter drain post closure may be catastrophic to the integrity of the NOEF cover (including the compacted clay liner).

Action Required

A risk-based management approach should be used to set design flood standards for all elements in the mine site.

6.1.1.4 There is no Consideration of the Uncertainty Associated in Magnitude Estimation

Background Information – Flood Frequency Analysis

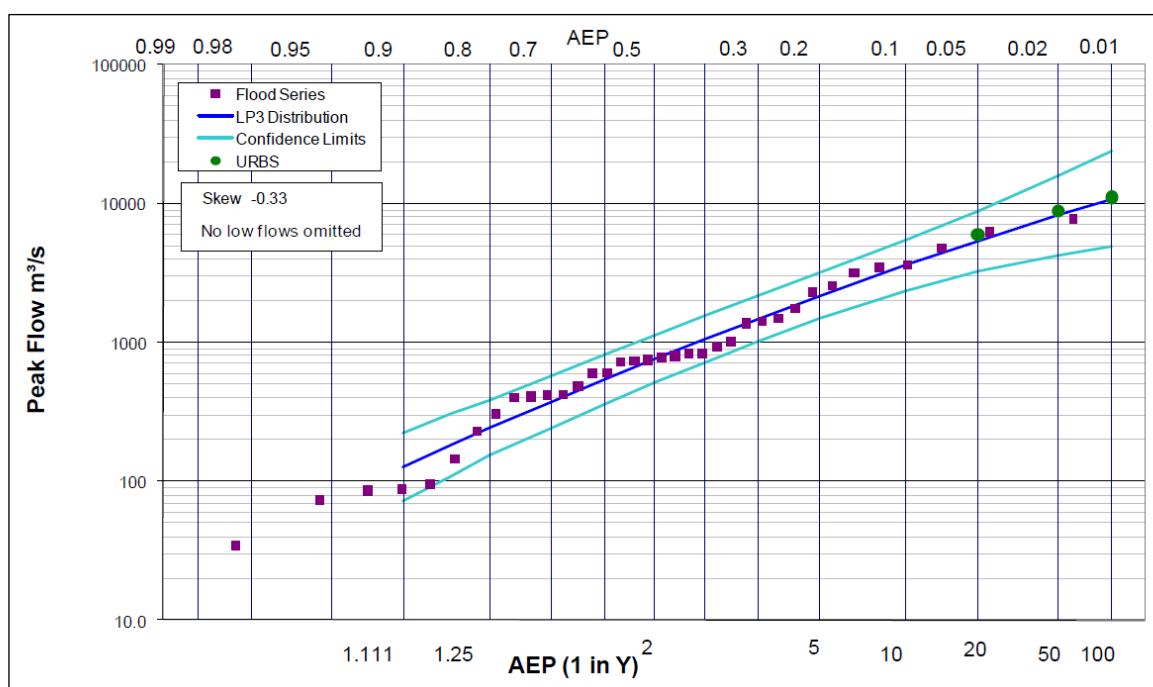
It is widely accepted that there is substantial uncertainty in flood magnitude estimates. For example, consideration and management of this uncertainty is a common theme throughout the revised Australian Rainfall and Runoff (ARR) (Ball et al., 2016a); with an entire chapter devoted to the subject (Ball et al., 2016b). The flood frequency analysis (FFA) adopted for the Phase 3 EIS provides a good example of the uncertainty in flood magnitude estimation. Consider Figure 6.1:

- ♦ The 1% (1-in-100) AEP discharge is approximately 11,000 m³/s with 95% confidence intervals of approximately 5,000 m³/s and 23,000 m³/s.
- ♦ The estimates for the 0.2% (1-in-500) and 0.1% (1-in-1,000) AEP discharges are 16,600 m³/s and 19,100 m³/s (EIS, Appendix U).
- ♦ Therefore, the 0.2% and 0.1% AEP discharges are within the 95% confidence limits of the 1% (1-in-100) AEP discharge. To put this another way, the uncertainty in the 1% (1-in-100)

flood magnitude estimate means that it could easily be as large as the adopted 0.1% (1-in-1,000) AEP flood.

The 95% confidence limits shown in Figure 6.1 are a measure of the line of best fit to the observed data. That is, the fit assumes the observations are correct. It is widely accepted that there are a large number of possible errors/uncertainties in the observed data (e.g., rating curve error/extrapolation, non-stationarity in the catchment characteristics or climate, length of record) (See Kuczera and Franks (2016) for further examples). It follows that the actual uncertainty in FFA estimates are likely to be much larger than those shown in Figure 6.1.

Figure 6.1 – Flood Frequency Analysis Results for McArthur River at MIM Pump Gauging Station



Source: WRM, 2012.

Background Information – The Rational Method

The FFA is (in general) considered the most accurate technique to estimate flood magnitudes (Ball et al., 2016b). The EIS only uses FFA to estimate McArthur River discharges. The Rational method is (in most cases) used to size on-site drains (e.g., batter drains on the rehabilitated NOEF). Of note, the Rational Method is considered so inaccurate that it is no longer supported in ARR (Ball et al., 2016a). It follows that the uncertainty surrounding the drain designs (using The Rational Method) is likely to be substantially larger than that for the McArthur River discharges (using a flood frequency analysis).

Action Required

The uncertainty in flood magnitude estimation needs to be included in the selection of design flood standards in the EIS.

6.1.2 Mitigation Measures Adopted in the Risk Assessment

Many of the mitigation measures defined in the risk assessment do not reduce the risk and/or present an alternative design that introduces other risks which are then not assessed. Table 6.1 lists examples of inadequate mitigation measures (relating to surface water management) in the risk assessment.

Table 6.1 – Examples of Inadequate Mitigation Measures in the Risk Assessment

Risk Number and Impact	Additional (post-EIS) Mitigation Measure	Limitation
BB50: Site-wide flood. Overload of adaptive management controls (long-term)	Site closure strategy. Adoption of adaptive management and reactive management principles	A site-wide flood would occur too fast for any 'adaptive management strategies' to be adopted, and could be catastrophic
BB41: Poor mine pit lake water chemistry, leading to inability to relinquish site	Option to maintain or revert back to open cut closure Alternative 6 (isolated void) - water level management and/or ongoing treatment	There is no assessment of the additional risks associated with alternative 6, an isolated void. For example, the need to maintain the McArthur River levee for 1,000 years
BB49: Site-wide flood as a result of McArthur River overtopping the levee (short-term; 30-100 years), leading to widespread erosion, overwhelming of water treatment facilities, disruption of operations, and lack of access	Social Involvement/Community Engagement Plan - that provides information on the status and avenues of communication to confirm that benefits of and objections to the mine are achieved. Site controls that limit releases of unacceptable levels of contaminant beyond SW11 trigger levels	A site-wide flood would occur very quickly with limited warning time, and could be catastrophic. It is unclear how any of the mitigation measures listed address this risk
BB57: Poor water quality in mine pit lake due to slow filling, leading to a change in water chemistry and inability to meet water quality criteria.	Option to maintain or revert back to open cut closure Alternative 6 (isolated void) - water level management and/or ongoing treatment. Ranked on the basis of ongoing water management being able to restrain the environmental impact - but some media attention with inability to meet commitment	There is no assessment of the additional risks associated with alternative 6, an isolated void. For example, the need to maintain the McArthur River levee for 1,000 years

6.1.3 Inadequate Risk Assessment of the McArthur River Levee

The McArthur River levee was excluded from the EIS. The as-constructed McArthur River levee currently has 0.1% (1-in-1,000) AEP flood immunity (with 0.4 m freeboard). With climate change this immunity will reduce to the 0.2% (1-in-500) AEP flood with 'a reduced freeboard' (the levee's design flood standard is the 0.2%, 1-in-500, AEP flood). Risk ID BB49 identifies that a site-wide flood as a result of the McArthur River overtopping the levee (short-term; 30-100 years) would lead to widespread erosion, overwhelming of water treatment facilities, disruption of operations and lack of access. The limitations of the risk assessment are:

- ♦ It does not identify that failure of the McArthur River levee may also result in the filling (or at least partial filling) of the open cut.

- ♦ The 0.2% (1-in-500) AEP design flood standard was not selected using a risk based management approach (See Section 6.1.1).
- ♦ It is unclear whether the risk assessment considered the levee during operational and post-closure phases. These phases have different risks and different design lives. In particular, if the isolated pit option is selected for closure, the levee will need to have a service life of at least 1,000 years. EIS, Section 3.3.5 states:

‘...the environmental impact assessment period has been significantly extended (from the Phase 3 EIS approach) to 1,000 years, and this has been reflected in the various technical modelling results reported throughout this EIS.’

This indicates that a risk assessment of the levee has not been undertaken for a 1,000-year service life.

- ♦ There is no risk-based assessment of the adopted freeboard. For example, there is no evidence that a 0.4 m (or a ‘reduced’) freeboard allow for:
 - Variation in crest level due to construction tolerances.
 - Variation in crest level over time due to general deterioration from mine operations (use as a road) and/or weathering.
 - Localised erosion of the levee crest during a large flood due direct rainfall impact and runoff from direct rainfall. This would lower a section of the levee, which may lead to over-topping and further failure by erosion by floodwater.
 - Errors in the flood level estimation.

6.1.4 Assessment of Climate Change Impacts upon Design Flood Standards

It is unclear how the EIS has incorporated the effects of climate change into the adopted flood design standards for the site. In particular those site elements that will still be present from about 2090 onwards.

The assessment of climate change impact upon design rainfall depth undertaken in the EIS showed that the probability of occurrence approximately doubled for all rainfall depths assessed. For example, the current 1% (1-in-100) rainfall depth will become the 2% (1-in-50) AEP rainfall depth under the climate adopted change scenario (see Table 6.2).

Table 6.2 – Rainfall AEPs for Current and Climate Change Conditions

Current AEP	Current Climate Rainfall Depth Adjusted for Long-Term Climate Change Conditions
5% (1-in-20)	9.1% (1-in-11)
2% (1-in-50)	3.8% (1-in-26)
1% (1-in-100)	2.1% (1-in-48)
0.2% (1-in-500)	0.45% (1-in-220)
0.1% (1-in-1,000)	0.24% (1-in-420)

Source: Table 11.8, App U, EIS.

For simplicity, the EIS assumed that climate change impacts would be similar for rainfall depth and flood magnitude AEPs. For example, a feature currently with a flood design standard of (say) the 1% (1-in-100) AEP flood level may only meet a 2% (1-in-50) AEP flood design standard under climate change impacts. The EIS assessment only applies to the 'long-term' (+ 2090) mine site; any change in flood design standards due to climate change only affects structures that will be present post 2090. These include (but are not limited to):

- ♦ The McArthur River levee. The importance of the levee will be dependent upon the final open cut configuration (flow through or isolated). Of note, the levee has a design flood standard of 0.2% (1-in-500) AEP flood but currently has 0.1% (1-in-1,000) AEP flood immunity.
- ♦ The WOEF (i.e., levee, erosion protection, flood protection of encapsulated material).
- ♦ The NOEF (i.e., erosion protection, flood protection of encapsulated material).

6.1.5 Margin of Safety in the On-site Water Storage Capacity to Allow for Model Uncertainties

6.1.5.1 Background

There are numerous assumptions and uncertainties in the site water balance assessment, many of which are identified and acknowledged in the EIS. Even if the water balance modelling is correct, it demonstrates that, under some scenarios, many water storages are at or above the maximum operating level for substantial periods of time; sometimes years. If the water balance modelling is incorrect, there is little available storage to accommodate extra water. For example, for the 31 years between 2016 and 2047, for any years equal to or wetter than the 10th percentile 31-year period:

- ♦ The TSF process water dam (PWD) (EIS Appendix U, Section 8.11.3):
 - Is, '... kept close to its maximum operating level (MOL) for substantial periods of time'.
 - Stores Class 5/6 water for '...significant periods of time (more than 20 years in some cases)'.
- ♦ The NOEF PROD storage behaviour is as follows (EIS Appendix U, Section 8.11.7):
 - ‘– NOEF SPROD: There is a period in the middle stage where, during the wetter sequences, the full supply volume of NOEF SPROD is briefly reached.
 - NOEF SEPROD: There are a number of periods in the early stages where, during the wetter sequences, the full supply volume of NOEF SEPROD is reached.
 - NOEF WPROD: There are a number of periods in the later stages where, during the wetter sequences, the full supply volume of NOEF WPROD is reached.
 - NOEF EPROD: There are a number of periods in both early and later stages where, during the wetter sequences, the full supply volume of NOEF EPROD is almost approached, but not reached.

- For the wetter sequences, the dams are not always able to recover all of their available capacity prior to the onset of the next wet season.

In summary, the model results show that during the wetter sequences, there can be extended periods of time when the NOEF PRODs are near or at their MOL and full supply volumes.'

6.1.5.1 Issue

The adopted risk management approach to the site water balance is as follows:

- ♦ Continual refinement and expansion of the monitoring program.
- ♦ Continual review and refinement of the water balance model.
- ♦ Construction of new storages, augmentation of the existing storages, enlargement of the water treatment plant and/or temporary storage in the open cut.

The limitation in the adopted approach is the assumption that additional water on site (beyond that estimated by the water balance modelling) will be able to be stored on-site. That is, it is assumed there will be adequate lead time to build new storage capacity and/or water can be stored temporarily in the underground void/open cut (UG&OC). The modelling together with historical mine water balance data demonstrate that the volume of water stored on-site exceeds the on-site storage capacity (including the underground storage but excluding the open cut storage) during the wet season when it is not possible to build additional storage capacity.

The key assumptions, uncertainties and limitations in the modelling are:

- ♦ The assumption that past climate is representative of future climate.
- ♦ Limitation in sub-sampling a 126-year rainfall sequence.
- ♦ Uncertainty in water quantity and quality estimates.
- ♦ Uncertainty in model parameterisation.
- ♦ The assumption of 100% pump and pipe serviceability.
- ♦ The use of the UG&OC for storage.

6.1.6 Water Balance Model

6.1.6.1 Assumption that Past Climate is Representative of Future Climate

The climate change assessment undertaken in the EIS shows that the adopted climate change reference period (1986 to 2005) was wetter than the 126-year period adopted for the water balance modelling (1889 to 2015). This illustrates the problem that past climate is not necessarily representative of future climate. In particular, if the climate change reference period (1986 to 2005) is a better indicator of the immediate future climate (e.g., the next 10 to 20 years), there will be substantial additional water to manage on-site. While some sensitivity analyses have been undertaken, they have only addressed 'long-term' impacts from 2090 onwards. Key aspects of

climate change that support the possibility that the past 126 years is not necessarily a good indicator of the next 10 to 20 years are:

- ♦ Impacts will not occur instantaneously in 2090.
- ♦ There is considerable uncertainty in climate change impact predictions.
- ♦ There is already evidence of possible climate change impacts in Australia (e.g., extreme weather). However, it is not possible to confirm the change until sufficient years have passed to provide a statistically significant trend.

6.1.6.2 Limitation in Sub-sampling a 126-year Rainfall Sequence

Background

The water balance model uses SILO Datadrill rainfall and evaporation for the 126 years between 1889 and 2015. The model was run for the 31-year period from 2016 to 2047. The rainfall and evaporation data was 'wrapped around' to produce 126 model 'sequences'. It is assumed this means that sub-sets of the rainfall and evaporation data were selected starting on different years (e.g., sequence 1, start with 1889 rainfall/evaporation; sequence 2, start with 1890 rainfall and evaporation). For latter start years (e.g., 2000), the data is 'wrapped' so that 1889 data comes after 2015 data, to provide a 31-year sequence.

The EIS states that these 126 rainfall/evaporation sequences represent a '...1,000 year assessment period' (EIS, Section 8.2). This is incorrect. The adopted approach uses a 126-year dataset, no additional information is provided by 'wrapping' the data and using different start dates. The only way to produce a 1,000-year data set is to generate a synthetic rainfall and evaporation record with the same statistics as the 126-year record (and even then this would assume the past climate is representative of future climate).

Issue

The limitation in using the adopted approach of wrapping 126 years of rainfall/evaporation data is that all the modelling is based upon past climate and past sequences. These sequences are just a sub-set of probable sequences. For example, for illustration purposes, consider that a period where the on-site storages are all very full was the result of two consecutive above average rainfall years followed by a below average rainfall year. It may be just as likely that the two above average rainfall years were followed by an average or slightly above average rainfall year (given a longer rainfall sequence). This wetter third year may result in some storages reaching their full supply volume thereby putting considerable pressure on the entire water management system.

The key issue is that the limited data set adopted for the assessment shows that there is insufficient margin of safety in the water balance system to allow for slightly different rainfall/evaporation sequences that may be equally as probable as that in the historical record.

6.1.6.3 Uncertainty in Water Quantity and Quality Estimates

Examples of model assumptions/uncertainties that could lead to greater water storage requirements than that estimated are:

- ♦ Intercepted groundwater is Class 4 and UG&OC water is Class 5 (poorer quality). Groundwater interception rates may be lower than estimated, resulting in more inflow to the UG& OC. This would increase the volume of Class 5 water that has to be managed on site.
- ♦ Water quality from any source (e.g., NOEF runoff, UG&OC) is worse than estimated.

6.1.6.4 Uncertainty in Model Parameterisation

Modelling relies on simultaneous calibration of a number of parameters. This results in considerable parameter uncertainty as the same model output can be obtained with different parameter sets (e.g., if evaporation is over estimated seepage may be underestimated to compensate). It is difficult, if not impossible, to identify this parameter interaction using simultaneous calibration. The result is that while the model may be able to replicate the historical water balance (through calibration with actual data) it may be a poor predictor of the future water balance with different conditions (e.g., water quality, rainfall).

6.1.6.5 Assumption of 100% Pump and Pipe Serviceability

The water balance modelling assumes elements of the water balance system (e.g., pumps, pipes and storages) are operational 100% of the time. The modelling does not assess the risk of pump or pipe failure. This is an unrealistic assumption. If a pump or pipe failed during a 'wet' period of the wet season it could be difficult to repair the failure in a timely manner (e.g., due to reduced site access during wet weather or absence of spare parts). A failure of this nature could be catastrophic as excess water may not be able to be transferred to the UG&OC system and uncontrolled releases may occur.

6.1.6.6 Use of the UG&OC for Storage

The EIS Appendix U, Section 8.11.4, shows the risk that water will need to be stored in the open cut. The modelling shows (assuming all model assumptions are correct):

- ♦ Between 2016 and 2019 there is a 45% chance that water will be stored in the open cut for longer than six months. Further, this water may need to be stored for a 'significant period of time (up to two years).
- ♦ Between 2020 and 2036 there is between a 1% and 5% chance of water being stored in the open cut for more than six months.

It is unclear whether mining operations will allow the storage of excess water in the open cut above the floor level for extended periods of time. It is acknowledged that the open cut has been used to store excess water in the past (e.g., 2017; EIS Section 8.6.2). . The impact upon mine operations may either make mining operations uneconomic (jeopardising the closure planning) or pressure the operator to release additional water off-site (putting pressure on the regulator to licence these discharges).

6.1.7 Details of How/Where Additional Storage will be Created

There are no details of how/where additional storage will be created by either augmenting existing storages or constructing new storages. It is unknown whether there is land available for new storages and/or existing storages can be augmented. MRM have previously indicated that the

required lead time to construct a new storage would be a minimum of three years. It is unknown what assumptions are inherent in that time frame.

6.1.8 EIS Surface Water Commitments

The surface water commitments to maintaining and augmenting the existing surface water monitoring and management systems are too vague. The site water management strategy (i.e., adaptive management) is fully reliant upon the monitoring and data management network. The Independent Monitor has previously identified improvements that are yet to be implemented and it is anticipated that additional improvements will be identified in the future. The monitoring and data management network is too vital to the successful management of mine site water to not be committed to in detail. Items that need to be committed to are:

- ♦ Monitoring of inflow, outflow and water level of existing storages (that are not already fully monitored).
- ♦ Undertaking specific studies to quantify processes (e.g., pond evaporation, fan/sprinkler efficiency).
- ♦ Ongoing review and development of the site water balance model.
- ♦ Ongoing maintenance and development of the site water management database.

6.2 What Must be Addressed in the EIS Supplement?

- ♦ The design flood standards should to be determined using a risk based management approach. For example, the downside risk and cost of remediation of an NOEF drain overtopping may be large (e.g., scouring of the cover and exposure of/damage to the CCL). However, the additional cost of designing the drain for (say) a 0.5 (1-in-200) or 0.2 (1-in-500) AEP may be small. The determination of design flood standards is to include:
 - Justification of the adopted design flood standards.
 - Adoption of service life exceedance probability (SLEP), rather than annual exceedance probability (AEP), where appropriate.
 - Assessment of the uncertainty associated with flood magnitude estimation.
- ♦ The McArthur River Levee should to be included in the EIS. As a minimum, the following should be included in the assessment:
 - The impact of levee failure upon the filling (partial or full) of the open cut.
 - The impact of levee failure on receiving water quality. This is the case where water in the open cut is discharged directly to the McArthur River. The assessment is to consider whether the open cut was empty, partially full or full of water prior to levee failure.
 - Levee failure mechanisms (e.g., overtopping, piping, slumping).
 - The different levee service lives (operation and closure) and the different open cut closure scenarios (i.e., flow through, open downstream or isolated).

- The selection of the design flood standard using a risk management approach.
- The selection of the adopted freeboard.
- Variation in crest level due to; construction tolerances, general deterioration over time from mine operations (use as a road) and/or weathering; and localised erosion of the levee crest during a large flood due direct rainfall impact and runoff from direct rainfall.
- Errors in flood level estimation.
- ♦ Additional on-site storage capacity is required to allow for the assumptions/uncertainties in the water balance modelling. It needs to be demonstrated how additional storages will be constructed and/or existing storages will be augmented, if required, to manage additional water on site. Documentation is to include, as a minimum:
 - The storage location/locations.
 - Design drawings with enough detail to provide confidence that the storage can be constructed and/or augmented in the allotted area.
 - An estimate of construction time frames from the decision that additional storage is required to operation. The estimate is to include all assumptions.
- ♦ The water balance modelling is to include the impact of pump/pipe failure (during critical periods of high rainfall) on water management.
- ♦ It needs to be demonstrated how the effects of climate change have been incorporated into the adopted flood design standards for the mine site. In particular, for those structures that will still be present from about 2090 onwards.
- ♦ Where the phrase ‘adaptive management’ is used to address a risk, possible options need to be identified. These options in-turn need to be subject to a risk assessment.
- ♦ The water resources commitments need to include the following:
 - Monitoring of inflow, outflow and water level of existing storages (that are not already fully monitored) (as required).
 - Undertaking specific studies to quantify processes (e.g., pond evaporation, fan/sprinkler efficiency) (as required).
 - Ongoing review and development of the site water balance model.
 - Ongoing maintenance and development of the site water management database.

6.3 References

AUSTROADS. 1994. Waterway Design: A Guide to the Hydraulic Design of Bridges, Culverts and Floodways. Ed: D. Flavell. AUSTROADS, Sydney.

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EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

7. Terrestrial Ecology

7.1 Is the Information in the EIS Sufficient?

7.1.1 Terms of Reference

The relevant aspects of the EIS terms of reference (TOR) prepared by NTEPA which relate to terrestrial ecology are outlined in the 'Risk Assessment', 'Water', 'Biodiversity' and 'Rehabilitation and Mine Closure' sections of the TOR. While MRM has covered the majority of required items, there are deficiencies relating to:

- ♦ Sufficient measures to ensure that a stable and functioning final landform is achieved and is compatible with surrounding natural landforms.
- ♦ Details on the availability, sources and volumes of suitable materials required for rehabilitation, revegetation and mine closure.
- ♦ The assessment of risks associated with the impacts on species, particularly the purple-crowned fairy-wren.
- ♦ The assessment of risk of groundwater drawdown and its impact on existing springs and groundwater dependent ecosystems (GDEs).
- ♦ The mitigation of the impact of acid mine drainage on riparian vegetation.

7.1.2 Additional Comments

The Project has the potential to impact terrestrial flora and fauna through vegetation clearing, inadequate rehabilitation and displacement of fauna. With thorough risk assessment and monitoring, these risks can be sufficiently controlled. Several aspects were identified (in particular, insufficient monitoring as part of mitigation measures) that were not adequately addressed in the EIS and will require addressing in the supplementary EIS. These include:

- ♦ Large areas of the mine lease will require rehabilitation once decommissioned. The EIS lacks information concerning revegetation resources, specifically seed and tubestock requirements, where these will be sourced from and if the on-site MRM nursery has the capacity to meet stocking needs.
- ♦ Rehabilitation works for the Project will be extensive and failure to rehabilitate sufficiently can result in loss of habitat and an increased risk of erosion, dust production and sedimentation. Little information is provided as to how rehabilitation success will be monitored and the criteria against which success will be judged.
- ♦ Approximately 20% of the purple-crowned fairy-wrens residing within the MRM lease will be relocated from within the mine levee wall to an area inside a planned expansion of the cattle exclusion fence. There has been no risk assessment conducted detailing the risk associated with attempting this relocation. No details are given as to how the birds will be relocated and how the success of the relocation will be monitored.

- ♦ Groundwater drawdown has the potential to impact springs and groundwater dependent ecosystems (GDEs) (including decreasing the size of Djirrinmini Waterhole) and affect the persistence of waterholes along the McArthur River bed in the dry season, thereby causing vegetation stress, a reduction in habitat for riparian birds and reduced drinking water sources for native fauna. The presence of springs and GDEs has not been determined and the risks to these systems have not been adequately addressed.
- ♦ If acid and metalliferous drainage and uncontrolled discharge of contaminated water occurs, increased sulfate concentrations could decrease the health of riparian vegetation along McArthur River, Barney Creek and Surprise Creek. The EIS identifies this as a risk but does not describe how vegetation will be deemed to have lost condition.

7.1.2.1 Revegetation

A substantial area will require rehabilitation works as part of closure procedures, including the open pit, OEFs, TSF, borrow pits, infrastructure areas, exploration areas, water dams and roads. While the EIS outlines sources and quantities of surface materials (e.g., clay, alluvial, topsoil) required (Appendix S, Section 7.2.5), there is no information on the estimated amount of seed stock and tubestock needed for rehabilitation works and where they will be sourced. Currently, MRM grows the majority of the tubestock required for each year's planting at the on-site MRM nursery. It is unclear from the EIS if the nursery will be able to meet demand for closure.

Additionally, no information concerning target flora species for rehabilitation is provided. Suitable species for each area will differ according to the surrounding land units, site conditions (such as the shallow substrate on the NOEF) and available stock. Previously conducted revegetation works along the river diversions (and other sites) and land unit data provides sufficient information to determine target species for each area, and assess the required densities of seed and tubestock to ensure that closure targets are met. Revegetation procedures can be updated if trials are conducted in future.

7.1.2.2 Rehabilitation Monitoring

The TOR states that sufficient measures should be described that ensure a stable and functioning final landform is achieved and is comparable to surrounding natural landforms. Failure to rehabilitate disturbed areas results in a loss of habitat and a persistence of discontinuous vegetation reducing the ability of the habitat to function. Little information is provided on the methods that will be used to monitor non-riparian rehabilitated areas and the criteria that will be used to determine if rehabilitation is successful. Reference has been made to the rechannel vegetation monitoring plan, but little information from this report has been supplied with the main EIS chapters or appendices.

7.1.2.3 Purple-crowned Fairy-wren Relocation

To facilitate the expansion of the open cut, 10.6 ha of riparian habitat along the old McArthur River channel within the mine levee wall will be cleared (EIS Section 9.4.2.7.6). This area supports twenty purple-crowned fairy-wrens (PCFW), representing approximately 20% of the MRM lease population. The remaining uncleared habitat (5.5 ha) will not be viable due to its small size and isolation. Prior to clearing, MRM plans to relocate the PCFWs into an area inside the planned expanded cattle exclusion fence. Translocations are difficult and often fail (Fischer and

Lindenmeyer, 2000); they require careful planning and allowance of time to assess the success of the relocation prior to the removal of the original habitat.

The EIS currently does not outline a translocation plan that details the risks associated with attempting a relocation, planned relocation methods, a monitoring program, timeline or criteria by which the relocation can be deemed a success or trigger additional mitigation measures. Current criteria are unsuitable in this case. The environmental management plan states that (EIS Chapter 15, Table 15-3):

Riparian birds of conservation significance (Purple-crowned Fairy-wren and Buff-sided Robin) are not to decline by 15% or more within the MRM leases over any one five-year period (Chapter 15, Table 15-3).

Using the current criterion, an unsuccessful translocation could result in a loss of 20% of the population but would not trigger an investigation until after five years. This is inadequate for ensuring that the PCFWs persist within the MRM lease, hence translocation-specific criteria should be determined.

The relocation of PCFWs should be staggered over several events, thereby allowing the effectiveness of each relocation round to be assessed before another round is completed. A review should be conducted after each round detailing the result of the previous relocation and, if required, the improvements that are needed. It is important to ensure that pairs and family units are relocated together in the same round.

McArthur River Mining states that the PCFWs will be relocated into 22 ha of habitat that is currently located outside the cattle exclusion fence and is therefore degraded. This area currently supports only two pairs of PCFW due to the lack of habitat (EIS Chapter 9, Table 9-10). McArthur River Mining plans to expand the cattle exclusion area to include this habitat, therefore allowing vegetation to regenerate. It is important for the survival of translocated birds that the habitat is of sufficient quality and that, if needed, supplementary planting is conducted. The EIS fails to outline how the habitat inside the expanded cattle exclusion fence will be deemed to be of sufficient quality for supporting the twenty additional PCFWs (if not more by the time relocation occurs).

7.1.2.4 Groundwater Drawdown

The TOR requires that the impact of groundwater drawdown on existing springs and GDEs be determined but no information on the presence of springs or GDEs was included in the EIS. Groundwater dependent ecosystems are ecosystems that depend partially or wholly on groundwater for survival, particularly during low rainfall periods. Groundwater extraction has the potential to affect ecosystems below and above ground and dependents include terrestrial flora and fauna, wetlands, river baseflow systems, aquifer and cave systems, and estuarine and nearshore marine systems (Williams, 2009). As part of the EIS supplement, MRM should conduct a desktop study to assess the presence of springs and GDEs and determine the risk of impacting these potentially sensitive systems.

The EIS states that as a result of groundwater extraction, Djirrinmini Waterhole will drop by a maximum of 0.7 m (EIS Section 9.4.1.5). Extraction could also affect the persistence of pools along McArthur River, reducing important water sources for terrestrial fauna and impacting vegetation health. Chapter 8 of this report outlines the impact that this drawdown may have on

aquatic life and, specifically, the freshwater sawfish. Recommendations discussed for inclusion in the EIS supplement in Chapter 8 are also supported here to assess the impact to terrestrial fauna and flora.

7.1.2.5 Impact of AMD on the Health of Riparian Vegetation

There is a risk of decreased health of riparian vegetation as a result of acid and metalliferous drainage from the NOEF, TSF and pit lake and uncontrolled discharge of contaminated surface water into McArthur River, and Surprise and Barney creeks (EIS Chapter 9, Table 9-10).

In relation to the PCFW, the EIS states (EIS Chapter 9, Table 9-10):

High concentrations of sulphates may affect the growth of riverside vegetation important to the Purple-crowned Fairy-wren.

This is also the case for the buff-sided robin (BSR) (EIS Chapter 9, Table 9-11). Despite the risk to vegetation condition identified in the EIS, the mitigation measures outlined do not include the monitoring of vegetation communities along McArthur River, Surprise Creek or Barney Creek to determine if plant health has declined. Vegetation monitoring would complement the water monitoring that MRM has proposed and provide clear evidence of impacts, if any, to riparian vegetation.

7.2 What Must be Addressed in the EIS Supplement?

McArthur River Mining should provide the following in the EIS supplement:

- ♦ A revegetation plan that outlines:
 - Inventory of target species for each rehabilitation area.
 - Calculation of the estimated amount of seed and tubestock required for rehabilitation works and determination of whether tubestock will be cultivated on-site or sourced from elsewhere.
 - A monitoring plan describing how rehabilitation will be monitored and how this will fit into existing rehabilitation monitoring practices.
 - Draft completion criteria by which rehabilitation success will be determined, such as those outlined for cattle grazing land use areas in EIS Appendix S.
- ♦ A PCFW translocation plan that outlines:
 - The risks associated with attempting to relocate the PCFWs and how these risks will be mitigated.
 - A timeline that outlines pre- and post-translocation actions.
 - Detailed description of the method that will be used to relocate the PCFWs.
 - How habitat included in the expanded cattle exclusion fence will be deemed suitable for PCFW relocation.

- How the relocated PCFWs will be monitored and criteria that will be used to assess the success of the relocation.
- ♦ A desktop assessment identifying whether springs and GDEs are present and how they may be impacted as a result of groundwater drawdown.
- ♦ Information requested in Chapter 8 of this review relating to the impact of the drawdown of Djirrinmini Waterhole and other water bodies as a result of groundwater extraction.
- ♦ A riparian vegetation monitoring plan to investigate the impact of increased sulfate levels.

7.3 References

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EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

8. Freshwater Aquatic Ecology

8.1 Is the Information in the EIS Sufficient?

8.1.1 Terms of Reference

The relevant aspects of the EIS terms of reference (TOR) prepared by the NTEPA and which relate to freshwater aquatic ecology are outlined in the 'Biodiversity,' 'Rehabilitation and Mine Closure' and 'Risk Assessment' sections of the TOR. While MRM has covered the majority of required items, there are deficiencies relating to:

- ♦ Impacts on threatened species as a result of the Project, specifically the freshwater sawfish, *Pristis pristis*. Of particular interest are potential impacts to critical habitats, reduced area of occupancy, increased habitat fragmentation and reductions in habitat quality.
- ♦ Degradation of aquatic ecological values as a result of the Project.
- ♦ Rehabilitation of a stable, functional and non-polluting landform.
- ♦ Addressing and compensating for uncertainty in all aspects of the risk assessment.

8.1.2 Additional Comments

Contamination of surface waters and fluvial sediments due to operations at McArthur River Mine constitute the greatest threat to freshwater ecosystems of McArthur River. If potential sources of contamination of surface water, groundwater, dust, soil and fluvial sediments are addressed (as outlined in this report and the EIS), then the majority of risks will be greatly reduced. However, a number of residual issues are inadequately covered in the EIS that require further information in the supplemental EIS. Specifically, these are:

- ♦ Should water quality in the pit lake be too poor to allow the mine levee to be opened and flow through from McArthur River to occur, there are no details of environmental management or potential impacts from contaminated pit lake water to the aquatic ecosystems of McArthur River. Contaminated water from the pit lake may enter groundwater and seep into McArthur River and its tributaries.
- ♦ Ongoing contamination of Surprise and Barney creeks until 3018 and beyond. While contaminant loads are discussed in Appendix T, there is no discussion of the long-term ecological impacts of the elevated contaminant loads.
- ♦ Management of protected fauna entering, exiting and residing in the pit lake. The potential issues with protected fauna, including the freshwater sawfish (*Pristis pristis*) and estuarine crocodiles (*Crocodylus porosus*), include injury when entering or exiting the pit lake, the provision of adequate suitable habitat, and the potential contamination of fauna should they become stranded in the pit lake. Further information is needed to fully address these issues.
- ♦ The extent and impacts of drawdown of groundwater as a result of MRM's operations. It is stated that water levels in Djirrinmini Waterhole are expected to drop by 0.7 m. There is

negligible discussion of the ecological impacts of the drawdown and whether flow duration and additional permanent waterholes on McArthur River will be affected.

- ♦ Ensuring natural flow regimes are maintained in McArthur River while the pit lake is filled.
- ♦ The EIS is heavily reliant on modelling results, which are only as good as the data they are based on. To account for potential errors, the monitoring program needs to be regularly compared to the model outputs and, where required, revised or additional modelling undertaken.

8.1.2.1 Managing Contaminated Water in the Pit Lake if it Remains Isolated

The EIS covers in detail the potential environmental impacts if the mine levee is opened and the pit lake becomes a flow through system. However, there is little information regarding the potential impacts and management should the pit lake remain closed due to high levels of contamination in the lake water. Keeping the pit lake isolated is less preferred due to the greater risks from that approach, as the EIS outlines (Section 4.10.1.3):

The alternative option, to isolate the mine pit lake from nearby catchments, was considered... however, water quality within such a mine pit lake is expected to deteriorate over time, posing a risk to downstream communities and ecosystems in the event of a flood, or when ex-lake water enters the McArthur River via palaeochannels. The current option [i.e. pit flow through], where water quality within the mine pit lake is maintained through annual dilution via contact with the McArthur River, reduces the long-term risks to local environmental and social values.

If the less preferred option of keeping the pit lake isolated becomes the only viable option, there may be inflows of contaminated water into McArthur River. If adequate and appropriate controls are not put in place, the contamination may have lethal or sub-lethal effects on aquatic biota, including protected fauna, which could affect the ecology of the river. In addition, contaminants may accumulate in organisms, which could potentially cause human health concerns if contaminated biota (e.g., fish, mussels, prawns) are consumed.

To adequately assess the risk to aquatic ecology from isolating the pit lake, MRM should address potential environmental risks associated with the less preferred option in the supplementary EIS. To address potential issues for aquatic ecology, MRM should:

- ♦ Develop models of groundwater and surface water flows and associated contaminant loads from the isolated pit lake into McArthur River.
- ♦ Based on those models, develop strategies to capture seepage and flows into McArthur River to minimise impacts from contaminants in the pit lake.
- ♦ With these controls in place, assess the residual ecological impacts of elevated contaminants in McArthur River and the extent of the impacts.
- ♦ Based on the level of contamination, determine the potential for contaminants to accumulate in aquatic fauna, and for fauna to cause human health concerns if consumed.
- ♦ Determine if the current surface water, groundwater and aquatic biota monitoring program is adequate to assess the level of contamination from the isolated pit lake.

8.1.2.2 Long-term Contamination of Barney and Surprise Creeks

The EIS acknowledges that sulfate concentrations and potentially other contaminants will continue to be elevated for several centuries in Barney and Surprise creeks. Specifically, Section 5.5.2 of Appendix W states that:

It should be recognised that predicted sulphate [*sic*] concentrations (WRM 2016) in Barney Creek, which are affected by the NOEF and TSF, may result in aquatic habitat in the lower part of Barney Creek becoming unfavourable to aquatic fauna at least for some time each year. This is particularly the case during post-wet periods when flow rates subside resulting in lower dilution and mixing rates and evapoconcentration. While modelling predicts concentrations of sulphate will decline after the closure of the TSF and over time, median sulphate concentrations are predicted to remain above 1000 mg/L for several months a year until 2500 (WRM 2016). These are, however, generally low flow months when river connectivity is low.

Appendix U of the EIS indicates that water dewatered from Barney Creek will have sulfate concentrations of 1,949 mg/L until 3018; for comparison, this is more than five times the amount permissible under the current Waste Discharge Licence (WDL). While below the current WDL (62.68 µg/L), concentrations of Zn will also be elevated (30 µg/L) to just below the 80% protection level (i.e., 80% of species will be protected at 31 µg/L (ANZECC, 2000)) for the same time period. There is minimal discussion of the lethal and sub-lethal effects of acute or chronic exposure to these elevated concentrations. Additionally, it is unclear whether long term (>1,000 years) contamination from Barney Creek will eventually raise concentrations of contaminants in McArthur River, affecting the flora and fauna, or whether wet season flows will adequately flush the system annually so that minimal residual contamination remains at the end of each wet season.

In addition, as two water collection sumps are installed on Barney Creek, there is no discussion of how cutting off this tributary for most of the year affects communities in McArthur River. Tributaries can be the principal habitat for some fish species (such as *Mogurnda oligolepis*) or important breeding grounds and nursery habitat for others (e.g., *Neosilurus hyrtl*). In addition, many fish move upstream during high flow events and then downstream as flows recede; by capturing flow in the sumps, fish may be unable to return to the main channel prior to the onset of the dry season. By cutting off this tributary, there may be a measurable effect on fish populations in McArthur River.

In the EIS supplement, MRM should therefore:

- ♦ Perform a desktop study to investigate the long-term effects of elevated sulfates and Zn on aquatic biota and riparian habitats in Barney Creek and McArthur River.
- ♦ Quantify the tributary habitat lost in a local context (i.e., mid McArthur River catchment) and across the entire catchment in general if Barney and Surprise creeks are functionally isolated for 1,000 years.

8.1.2.3 Managing Protected Aquatic Fauna Interactions with the Pit Lake

If MRM proceeds with the flow through option, the pit lake presents several issues with respect to protected aquatic fauna. First, protected fauna may enter the pit lake and, as water levels recede, they may become marooned. Second, protected fauna may be injured traversing barrages as they enter and exit the pit lake. Third, marooned sawfish may be unable to survive due to an

absence of suitable habitat and food sources. Fourth, the contaminated water in the pit lake may adversely affect the health of fauna trapped in the lake, either lethally or sub-lethally.

The principal protected fauna that may be affected by the pit lake is the freshwater sawfish (*Pristis pristis*) and the estuarine crocodile (*Crocodylus porosus*). As the estuarine crocodile can traverse across land to escape poor quality isolated habitat, or to avoid barrages when entering or exiting the pit lake, the freshwater sawfish will be the focus of this section.

Prohibiting Movement of Protected Fauna into the Pit Lake

McArthur River Mining will need to adequately manage the potential for sawfish to enter the pit lake. Before opening the mine levee, MRM will construct an upstream and downstream barrage to control water flowing in and out of the pit lake. McArthur River Mining argues that these barrages, plus engineering solutions such as large rock-filled gabions, will prevent the sawfish and crocodiles from entering the pit lake (EIS Chapter 10 and Appendix W). However, while barrages inhibit movement during periods of low flow, they are not barriers to fish migration during high flows. For example, the 2.6 m high Camballin Barrage on the Fitzroy River, WA, is easily overcome during periods of high flow by sawfish and other fish (Morgan et al., 2005). In addition, it is during periods of increased flow that crocodiles, sawfish and other fish migrate between pools. Therefore, it is while the barrages are inundated and more easily traversed that sawfish will be migrating and potentially entering the mine pit.

Any potential engineering solutions to reduce sawfish movement, such as rock-filled gabions, are of unknown effectiveness in northern Australia. Gabions have been used to exclude invasive fish in southeastern Australia (Knight, 2010). However, these were deployed in on a much smaller scale on far smaller rivers with likely much lower flood peaks (Jackson et al., 2004). If such a construction were to work, it would need to be large enough to cover the width of the floodplain, high enough to prevent movement during large flows, and strong enough to withstand the high flow rates and large debris associated with large wet season floods. Other options, such as vertical batters on the barrages, would need to be spaced close enough to prevent juvenile sawfish from getting through, high enough to prevent fish entering during high flow event and strong enough to withstand the high flows and the entrapment of large debris, such as tree trunks washed downstream. If protected fauna do manage to overcome the barriers, the barriers also need to allow for the fauna to leave the pit lake or else there needs to be a program to capture any protected fauna that enters the pit lake.

As part of the supplementary EIS, MRM should further investigate the efficacy of these exclusion devices and whether they can realistically be effectively deployed. McArthur River Mining should also determine whether other engineering solutions could be utilised, such as electrical barriers at the downstream end that cause discomfort when fish attempt to pass. Other options would likely be required to prevent sawfish crossing the upstream barrage. Investing considerable time and potentially finances into greatly reducing the likelihood that fauna will enter the pit lake would largely minimise other risks and financial costs associated with the other issues outlined in this section.

Barrages Designed to Allow Sawfish to Exit Pit Lake and Prevent Injury When Traversed

Protected fauna may be injured if they traverse the barrages. When the pit lake is initially opened at the downstream end and filled, there will be a considerable drop into the lake (~21 m, from

roughly 35 m AHD to 14 m AHD) and potential for injury annually when the barrages overtop. McArthur River Mining has committed to designing fishway ramps with a slope of 1:30 to reduce the likelihood of injury. However, the feasibility of such a ramp is questionable, as initially it will need to be at least 600 m long to accommodate the initial drop from the barrage to the pit lake. This also begs the question as to whether the fishway has been included in the final design of the barrage and pit lake to cover the initial years of backfilling the lake.

Fishways require extensive planning, and designs need to be tailored to local conditions and fish faunas. Fishways will need to reflect the design outlined in Kirby et al. (2009) or similar that includes a gentle slope and rest areas to allow sawfish and other fish to exit the upstream end of the mine pit lake as water levels recede. If fish exit the downstream end of the pit lake while water is still flowing out of the lake, but floodwaters have receded, the design will need to ensure that sawfish can safely traverse the barrier from the pit lake to McArthur River, but not facilitate sawfish entering the pit lake. Once installed and the lake is flooded, the efficacy of the fishways will need to be monitored and if the design does not allow trapped sawfish to exit the pit lake, the fishways need to be modified to allow the passage of sawfish.

As part of the supplementary EIS, MRM should therefore provide further information regarding the design of the pit lake, with specific details regarding:

- ♦ Measures to prevent protected fauna entering the pit lake.
- ♦ Fishway design that allows protected fauna to exit the lake as floodwaters recede. In addition, MRM should commit to monitoring the fishways to ensure they allow sawfish to leave the pit lake safely, and modifying them if they do not.
- ♦ Structures to prevent injury to protected fish if they traverse the downstream barrage once floodwater recede, but do not increase the likelihood of fauna entering the pit lake.

As the pit is currently very steeply walled, areas need to be provided to allow any crocodiles that become trapped in the pit lake to easily exit the lake by land.

Provision of Suitable Resources for Protected Fauna in the Pit Lake

Should fauna become marooned in the pit lake, adequate resources (i.e., habitat, food) will need to be provided to ensure survival until the pit lake is reconnected to McArthur River.

Freshwater sawfish are generally restricted to waters less than 10 m deep, but tracking data from the Fitzroy River, WA, indicates that 0 to 1 year old sawfish spend their time at an average depth of 0.49 m, and 1 to 2 year olds at a depth of 0.83 m. While they occasionally go into deeper waters, they rarely strayed into water more than 2 m deep. In McArthur River, sawfish have been caught in pools with a maximum depth ranging from 0.6 to 6 m. Sawfish are most commonly encountered over finer bed sediments, from silts to coarse sand, with little algae, macrophyte or detritus present. The topography of the river bottom at sites where freshwater sawfish are caught tends to be quite uniform. Freshwater sawfish predominantly feed on fish and crustaceans, but also consume detrital material (EIS Appendix W, Sections 2.3 and 2.4 and references therein).

Currently, the pit would provide little suitable habitat for sawfish as it is very steeply walled. To cover the resource needs of freshwater sawfish, the pit lake will need to be modified to replicate

shallow sandy habitat and provide suitable habitat for prey species. Specifically, and as noted in Appendix W, Appendix 2, Section 3.2, the modifications would need to reflect the following:

In its simplest form gently sloping bank would need to be provided around the pit edges. Based on river widths in the McArthur River and areas from which *P. pristis* is known it is envisaged that this zone would need to be 30 to 50 meters wide as a minimum. This area should also provide finer substrates ranging from silty mud to coarse sand with a majority of the area being between 0.5 to 2.0 meters deep but up to 10 m on the inner edge. Additional topographic features should be included to create undulation in these edge areas such as sandbars and deep holes (<6 m) with depths gradually decreasing as they approach the shallow runs. The creation of shallow bays in the bank would also provide sinuosity which may provide areas of slower moving waters and within which scouring of fine sediments may be reduced... *P. pristis* utilises a range of depths and foraging strategies and variability in benthic topography would need to be provided akin to a riverine habitat.

In addition, suitable habitat and food for prey species (i.e., large and small woody debris, leaf matter, riparian vegetation, rock piles) would need to be provided. Monitoring would be necessary to ensure that debris and sediments are not washed away during periods of peak flow, and it is likely that engineering solutions, such as rock baffles, would be needed to minimise scour. Riparian rehabilitation would be required to stabilise the sediments and provide habitat and debris. Suitable habitat for freshwater sawfish and their prey would need to cover a range of depths to account for a drop in water level over the dry season.

In addition, a large permanent pool may be very attractive to potential sawfish predators and competitors, including bull sharks and crocodiles, which may further impair the survival of sawfish, so management of the pit lake may also require monitoring and management of these predatory species.

As noted above, the current pit is very steeply walled and it is likely that considerable work will be required to establish a landform suitable for the maintenance of sawfish populations and their prey. As part of the supplementary EIS, MRM should provide a design of the pit lake that specifically addresses the needs of the sawfish as outlined above and ensures that funding is provided for the works.

Contamination of Fauna in the Pit Lake

As water in the pit lake will have elevated levels of contaminants including Zn, As and, to a lesser extent, Pb, there is potential for fauna in the lake to accumulate contaminants and then move offsite and create a potential health hazard for human health. Historically, elevated concentrations of contaminants in water and sediment at SW19, just below the Barney Creek haul road bridge, has led to elevated concentrations of Pb and Zn in fauna at that site. Concentrations of Zn in surface waters flowing out of the pit lake are likely to be elevated until 2100 to concentrations similar to the highest values found in surface waters in Barney Creek in the last five years (EIS Appendix U). It is probable that contaminated water in the pit lake will lead to elevated concentrations of metals in aquatic fauna in the lake. It is unclear what the concentrations of contaminants in the surface waters of the pit lake will be prior to the onset of the wet season, and whether the concentrations of contaminants will have lethal or sub-lethal effects on resident fauna. While there will be limited opportunity for fish to move out of the lake, during periods of high flow the pit lake will be connected to McArthur River and it is during periods of flood that many of the fish of McArthur River migrate, so fish will probably move offsite. While the impacts to

human health are likely to be negligible (Hydrobiology, 2015), monitoring is required to ensure that this is the case.

In the supplementary EIS, MRM should provide details of the potential levels of contamination of biota living in the pit lake, any program to monitor concentrations of metals in fauna inhabiting the pit lake and, if concentrations of metals in fauna are elevated, how the impacts will be managed.

8.1.2.4 Drawdown at Djirrinmini Waterhole

Djirrinmini Waterhole is a culturally sensitive site and is one of two known permanent waterholes upstream of the mine that supports freshwater sawfish, with up to three freshwater sawfish per year caught in this waterhole during annual fish surveys. Dry season water levels in the waterhole are expected to decline by up to 0.7 m as a result of operations at the mine, but will recover within 5 years of mine closure. As most of Djirrinmini Waterhole is less than 2 m deep, a reduction in depth of 0.7 m probably constitutes a considerable loss of dry season habitat. Upstream waterholes provide ideal nursery habitat for freshwater sawfish, as the density of large predators (i.e., estuarine crocodiles and bull sharks) is lower than in the downstream reaches (Morgan et al., 2017), so a considerable loss of habitat at Djirrinmini Waterhole may have important implications for the freshwater sawfish population in McArthur River. In addition, it is unclear how this drawdown will affect other refuge pools in McArthur River diversion channel, which also support sawfish over the dry season, and waterholes further upstream (such as Eight Mile Waterhole) and downstream of the mine. Furthermore, this drawdown may affect how long McArthur River continues to flow during the dry season and, as a result, reduce connectivity. Finally, as the drawdown will reduce the volume and depth of the waterholes in the vicinity of the mine, it is likely that water temperatures in the waterhole will increase, and deep, cooler refuges will decline. Many northern Australian freshwater fish live close to their thermal maxima so even a small increase in water temperatures may prove lethal for sawfish and/or their prey (Pusey et al., 2011).

The Aquatic Ecology Impact Assessment (EIS Appendix W, Section 5.3.2) indicated that:

A physical assessment of available refugia should be undertaken in nearby sections of the McArthur River (including Djirrinmini Waterhole) to assess available habitat (refugia) in the late dry season prior to deepening of the pit to provide a basis for comparison and to identify key refugia.

However, such an assessment was not carried out as part of the EIS and the reason for this is unclear. In addition, the impact assessment states that supplementary flow may be required to maintain permanent refuges during peak drawdown, however, it does not indicate the source of this water.

As part of the supplemental EIS, MRM should:

- ♦ Assess the physical structure of Djirrinmini Waterhole and determine how much permanent habitat will be lost at the waterhole as a result of drawdown.
- ♦ Quantify the depth and extent of the drawdown around the mine in relation to existing waterholes. The loss of habitat at permanent sites that could support sawfish due to drawdown should be assessed, i.e., will there be drawdown at permanent waterholes in the diversion and other natural waterholes and how much habitat will be lost as a result.

- ♦ Quantify the total loss of permanent, useable sawfish habitat in the upper catchment, and compare this to the total available permanent sawfish habitat in the upper catchment.
- ♦ Identify suitable water sources to supplement permanent waterholes, and estimate how much water will be required to maintain enough habitat for the natural sawfish population in the upper McArthur catchment.
- ♦ Determine whether the drawdown will reduce the number of days that McArthur River flows and, if so, the consequent ecological impacts.
- ♦ Assess whether water temperatures at Djirrinmini Waterhole will increase as a result of drawdown, and whether those increases could exceed conditions currently inhabited by sawfish and their prey.

8.1.2.5 Ensure Natural Flow Regimes and Connectivity are Maintained While Filling Pit Lake

The rapid initial filling of the pit void will require 260 GL of water which, based on river flows from 2009 to 2015, is up to 22.2% of river discharge below the mine. As recruitment of many species of fish, including the freshwater sawfish, is positively correlated with the size and extent of wet season, reduction in flows may have impacts on river ecology if the years of scheduled pit filling coincide with naturally poor wet seasons. Reduced recruitment in low flow years is probably due to the reduction in habitat availability, connectivity, flow-related spawning cues and potentially the amount of nutrients and food flushed into the river. Even if less water is extracted during poor wet seasons compared to good wet seasons, the effect will be more pronounced than an average or wet year. In surveys of McArthur River after below average wet seasons, no 0 to 1 year old sawfish are caught, probably due to low connectivity and food availability (Appendix W, Appendix 2, Section 3.1).

As a result, having a flow-based minimum for extraction (i.e., 10 m³/s) may not be adequate to ensure a minimum discharge required for successful sawfish recruitment. The supplementary EIS should outline in more detail the downstream effects during the pit lake filling phase for high rainfall, average and poor wet seasons, and investigate establishing a minimum discharge before water can be extracted from McArthur River and pumped into the pit lake.

8.1.2.6 Validation of Models

Most of the proposals, commitments, and management and mitigation measures outlined in the EIS are based on models that are often reliant on spatially and temporally limited data. For example, the flow gauging stations in Barney and Surprise creeks have only been in place since 2011, and at SW11 on the McArthur River since 2006. As a result, ongoing monitoring needs to be regularly compared to models, and if the models are proved to be inaccurate, they need to be updated and re-run.

In addition, climate change projections and their effects on operations and closure need to be regularly re-visited as there is a high degree of uncertainty in some predictions. While temperature predictions are relatively consistent across climate models, under the higher emission scenario (RCP 8.5) by 2090 the factors that will greatly influence water availability and flow rates vary greatly. Models predict that rainfall could increase by up to 20% or decline by 25%

and evapotranspiration may increase anywhere from 2.5% to 22.5% (CSIRO and Bureau of Meteorology, 2017). A major increase in evapotranspiration with a decline in rainfall could have major impact on flow rates in McArthur River, which would reduce pit lake outflows and natural connectivity for sawfish population, while a major increase in rainfall would increase the likelihood of major floods, which may damage infrastructure and rehabilitation.

In the supplemental EIS, MRM should commit to regularly comparing monitoring data to modelled data. In addition, climate models and their impact on MRM's operations need to be regularly updated as climate modelling improves.

8.2 What Must be Addressed in the EIS Supplement?

To fully address the TOR, MRM should address the following in the EIS supplement:

- ♦ Assess the impacts to aquatic ecology of the less-preferred isolated lake pit scenario. Specifically, MRM should:
 - Develop models of groundwater and surface water flows and associated contaminant loads from the isolated pit lake into McArthur River.
 - Based on those models, develop strategies to capture seepage and flows into McArthur River to minimise impacts from contaminants in the pit lake.
 - With these controls in place, assess the residual ecological impacts of elevated contaminants in McArthur River and the extent of the impacts.
 - Based on the level of contamination, determine the potential for contaminants to accumulate in aquatic fauna, and for fauna to cause human health concerns if consumed.
 - Determine whether the current surface water, groundwater and aquatic biota monitoring program is adequate to assess the level of contamination from the isolated pit lake.
- ♦ Quantify the effects of ongoing elevated contamination in Barney and Surprise creeks until 3018 and beyond, specifically:
 - Perform a desktop study to investigate the long-term effects of elevated sulfates and Zn on aquatic biota and riparian habitats in Barney Creek and McArthur River.
 - Quantify the tributary habitat lost in a local context (i.e., mid McArthur River catchment) and across the entire catchment in general if Barney and Surprise creeks are functionally isolated for 1,000 years.
- ♦ Provide further details of measures to minimise the impacts of the flow through pit lake on the aquatic ecology of McArthur River, in particular the threatened freshwater sawfish. McArthur River Mining should provide further information on:
 - The most effective fish exclusion device(s) to prevent fish entering the pit lake. In order to do this, MRM should investigate the types of fish exclusion devices available and

determine their effectiveness at excluding sawfish from the pit lake, especially during periods of high flow when sawfish are migrating.

- The design of fishways that enable protected fauna to exit the lake as floodwaters recede. In addition, MRM should commit to monitoring the fishways to ensure that they allow sawfish to leave the pit lake safely, and modifying them if they do not.
 - Structures to prevent injury to protected fish if they traverse the downstream barrage once floodwater recede, but do not increase the likelihood of fauna entering the pit lake.
 - The specific design of the pit lake, and how it will meet the habitat and food requirements of any sawfish marooned in the lake.
 - The potential levels of contamination of biota living in the pit lake, any program to monitor concentrations of metals in fauna inhabiting the pit lake and, if concentrations of metals in fauna are elevated, how the impacts will be managed.
- ♦ In response to drawdown at Djirrinmini Waterhole, MRM should:
- Assess the physical structure of Djirrinmini Waterhole and determine how much permanent habitat will be lost at the waterhole as a result of drawdown.
 - Quantify the depth of the drawdown at other waterholes around the mine, including those in the diversion, and how much permanent sawfish habitat will be lost as a result.
 - Quantify the total loss of permanent, useable sawfish habitat in the upper catchment, and compare this to the total available permanent sawfish habitat in the upper catchment.
 - Identify suitable water sources to supplement permanent waterholes if required, and estimate how much water will be required to maintain adequate sawfish habitat.
 - Determine whether the drawdown will reduce the number of days that McArthur River flows and, if so, the consequent ecological impacts.
 - Assess whether water temperatures at Djirrinmini Waterhole will increase as a result of drawdown, and whether those increases could exceed the maximum temperatures that sawfish and their prey are currently exposed to.
- ♦ Outline the downstream ecological effects during the pit lake filling phase for high rainfall, average and poor wet seasons, and investigate establishing a minimum discharge before water can be extracted from McArthur River and pumped into the pit lake.
- ♦ Commit to regularly comparing monitoring data to modelled data. In addition, climate models and their impact on MRM's operations need to be regularly updated as climate modelling improves.

8.3 References

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EIS REVIEW REPORT
MCARTHUR RIVER MINE OVERBURDEN MANAGEMENT PROJECT EIS REVIEW

9. Mine Closure

9.1 Introduction

Planning for the closure of the McArthur River Mine is the key issue of the Overburden Management Project EIS. Previous sections of this report have reviewed particular technical aspects presented in the EIS and these include comment on mine closure in relation to matters such as geochemistry, groundwater and surface water. This section focuses on EIS Chapter 4 – Decommissioning, Rehabilitation and Closure and Appendix S – Conceptual Mine Closure Plan.

9.2 Is the Information in the EIS Sufficient?

9.2.1 Terms of Reference

The EIS Terms of Reference (TOR) prepared by the NTEPA required that MRM address risks associated with rehabilitation, decommissioning and closure. McArthur River Mining identified the EIS TOR requirements for the preparation of a conceptual mine closure plan (MCP) as being those outlined in Table 9.1 below.

Table 9.1 – EIS Terms of Reference Requirements for a Conceptual Mine Closure Plan

EIS TOR Requirement
♦ Mitigation measures to address identified risks
♦ Measures required to prevent contamination of surface and groundwater
♦ Measures to ensure that placement of waste rock will physically isolate it from the environment and that any contaminants arising from the waste rock will not result in any short (whilst operational), medium (post-closure and under institutional control) or long term (post institutional control) detrimental environmental impacts
♦ Measures to ensure the final landform is compatible with natural landforms in the surrounding landscape
♦ Contingencies to make landforms secure and non-polluting in the event of unexpected for temporary closure
♦ Measures to ensure the stabilisation of erosion to a level similar to comparable landforms in surrounding undisturbed areas

Section 4.5 of the EIS TOR (Appendix A) outlines the issues to be addressed by MRM in relation to rehabilitation and mine closure. The items outlined in Table 9.1 above are specific to the mitigation section of the TOR and detail what should be included in a MCP. In addition, the EIS TOR also required that MRM address:

- ♦ Environmental objectives and, specifically, that the EIS should demonstrate that:
 - As far as practicable, rehabilitation achieves a stable and functioning landform which is compatible with the surrounding landscape and other environmental values.
 - The risks associated with closure and rehabilitation of the Project, including the ongoing generation of AMD and contamination of the downstream environment, can be mitigated.

- ♦ Assessment of risks and, specifically, identify risk to the successful closure of the project including:
 - Closure timeframes and objectives, and the Project not realising its projected outcomes (e.g., delays, unexpected or forced closure, etc.).
 - The lack of availability of benign material for construction of infrastructure and AMD management.
 - The effects of quantities and characteristics of problematic waste rock, particularly the pyrogenic characteristics of highly reactive PAF material, on the final pit lake water quality, long-term manageability of the waste material and integrity of management structures.
 - The potential impacts of natural events such as flooding to the integrity and stability of final landforms.
- ♦ Mitigation (as outlined in Table 9.1 above).
- ♦ Monitoring, specifically:
 - Describe the post-mining monitoring and reporting to be used to evaluate and report on the effectiveness and performance of the mitigation measures.
 - Describe the contingency measures to be implemented in the event that monitoring demonstrates that management measures have not been effective.
 - Provide outcome and assessment criteria that will give early warning that management and mitigation measures are not achieving the outcomes and benefits expected and identified by the Proponent.

Review of the EIS has highlighted two areas of the TOR which the IM believes have not been adequately addressed. These are discussed below.

9.2.1.1 Monitoring - Contingency Measures

Appendix B of the EIS provides a table which cross references the EIS to the TOR and directs the reader to Section 8.2 of Appendix S for details on the contingency measures to be implemented in the event that monitoring demonstrates that management measures have not been effective. However, Section 8.2 outlines contingency plans for premature closure and does not detail contingency measures to be implemented in the event that monitoring demonstrates management measures have not been effective.

A contingency that was identified in Chapter 4, Section 4.10.1.3 was that if the pit water quality is not suitable for a flow-through system to be installed then the pit is to be kept as a closed system. This discussion, however, fails to address the impact that keeping the pit as a closed system may have in terms of seepage of contaminated water to groundwater and potentially to McArthur River (see also Section 4.12 and 4.1.3 of this report). This issue is identified in Chapter 5 – Project Alternatives and the flow-through system was favoured due to concern that a closed system would result in a decline in water quality and subsequently a risk to downstream communities and

ecosystems in the event of a flood or when water from the pit lake enters McArthur River via paleochannels. Subsequently, while a contingency has been identified in the event that pit lake water quality is not suitable for a flow-through system to be maintained, the EIS has not addressed the risks identified by MRM associated with implementing this contingency and maintaining the pit as a closed system.

9.2.1.2 Monitoring - Outcome and Assessment Criteria

Section 9.3 of the MCP outlines the proposed monitoring to be undertaken. McArthur River Mining has proposed three phases of monitoring:

- ♦ Adaptive management (0 to 100 years).
- ♦ Proactive monitoring (proactive monitoring in Figure 9-1 of Appendix S appears to be an earlier phase of the reactive monitoring period with both phases to be undertaken over the period 100 to 1,000 years).
- ♦ Reactive monitoring (100 to 1,000 years).

The TOR required that outcome and assessment criteria be developed that will give early warning that management and mitigation measures are not achieving the outcomes expected. Draft completion criteria are outlined in Table 6-1 (EIS Appendix S) but it is not clear how this information will be used as an early warning that management and mitigation measures are not achieving the outcomes expected. The TOR cross-reference table (EIS Appendix B) directs the reader to Section 4.9 and 4.10 of the EIS. However, these sections do not provide any detail regarding assessment criteria that will give early warning that management and mitigation measures are not achieving the proposed outcomes. Section 4.10 provides closure objectives but these are not linked to assessment criteria.

9.2.2 Decommissioning, Rehabilitation and Closure

A MCP has been prepared in accordance with the requirements of the TOR. Comments regarding the MCP are outlined below.

9.2.2.1 Closure Obligations and Commitments

The MCP details in Table 3-1 (EIS Appendix S) the Mine Closure Plan Compliance Register and lists a series of internal Glencore documents, lease conditions and commitments in the 2012 EIS /Supplementary EIS. Previous commitments in the 1992 and 2005 EIS are not outlined. It is not clear if the commitments from the 1992 and 2005 EIS have been superseded or if they remain current. The IM agrees that the MCP should contain a consolidated list of commitments; however, where commitments from previous EISs have been superseded by subsequent EISs this should be clearly documented. It is possible that commitments made previously with regard to the diversion of McArthur River remain current and therefore should be included in the compliance register.

9.2.2.2 Program for Addressing Knowledge Gaps

McArthur River Mining has identified a number of studies that are aimed at addressing current knowledge gaps and detail the target date for completion. What is unclear are the implications of this work in terms of the risk associated with particular mitigation measures. For example, item 34

in Table 4-8 is to confirm rates and magnitude of NOEF settlement through monitoring. While not stated in the MCP, there is a risk that parts of the NOEF will settle at different rates, potentially resulting in a failure of the compacted clay layer. This knowledge gap, however, is not reflected in the risk assessment with failure of the cover due to differential settlement not being considered in the MCP. It is not clear therefore if MRM considers this to be a major risk for the long-term performance of the cover system.

9.2.2.3 Draft Indicators and Completion Criteria

The MRM closure framework consists of:

- ♦ **Goals** – these are the closure goals for the site, developed from the ecologically sustainable development (ESD) policy framework, in particular the National Strategy for Ecologically Sustainable Development endorsed by all jurisdictions in 1992 in the Australian Guidelines for Preparing Mine Closure Plans to ensure that development improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends.
- ♦ **Objectives** – a clear set of statements relating to environmental and social aspects of mine closure that describe the intent of the mine closure strategy.
- ♦ **Indicators** – these may be either an agreed value that is measurable and is regarded as the minimum that must be achieved, or a certification that specific closure activities comply with an agreed plan for those activities.
- ♦ **Criteria** – these describe specific elements that can be measured or certified to have occurred and that are considered to be critical to achieving the objectives. Each objective may have more than one criterion, and a criterion may apply to more than one objective.

The IM has reviewed the draft indicators and completion criteria as outlined in Table 6-1 (EIS Appendix S) within the closure framework context developed by MRM. The framework provides a logical progression from high-level goals to specific criteria that are used to demonstrate achievement of the goals. The closure framework, however, does not clearly link each relevant component. For example, the definition of criteria is not linked to indicators but rather to objectives and the definition for indicators does not specifically relate to objectives. The criteria need to specify how the achievement of the indicator will be demonstrated and subsequently how achievement of the indicator demonstrates achievement of the objective.

Examples of where there is no link in the closure framework include:

- 1 The rehabilitation goal of being 'safe to humans and wildlife', which has a draft indicator of exposure to, and availability of, heavy metals and other potentially toxic materials. One of the completion criteria details that cover thickness will be measured to demonstrate that it meets specifications, then outlines that other specific criteria may apply (these are not defined) and evidence of a maintenance program being in place; however, there is no detail regarding how this is actually measured. No criteria have been proposed regarding measurement of exposure or how this indicator would be certified and subsequently this indicator does not appear to meet the framework developed by MRM.

The second completion criterion for this goal is for surface water monitoring results at the compliance point SW11 to meet specified values as outlined in Table 4-2. No mention, however, is made regarding heavy metal contamination of terrestrial fauna or of measuring soils as evidence of meeting this goal. It is noted that metal levels in aquatic fauna are covered under the non-polluting goal.

- 2 The rehabilitation goal of being stable, with the objective of geochemical stability and the indicator being seepage water quality at toe/base of landforms. The completion criterion for the indicator is 'evidence that seepage quality and quantity is static or improving and that downstream compliance limits or specified values (derived from ANZECC 2000 or agreed reference source) are met at SW11 for 10 years'.

As the indicator is seepage water quality at the toe/base of landforms, linking the completion criterion to water quality at SW11 is not an indication of meeting the indicator, as there are other sources (e.g., the open pit) that could impact on achieving this criterion. The IM believes that the indicator is correct but that measurement of seepage water quality should be undertaken at the toe/base of the landforms rather than at a point several kilometres downstream where the impact of other sources of contamination cannot be differentiated. The completion criterion, i.e., seepage water quality, should be based on the cover and groundwater modelling results so that early detection is possible.

There is some inconsistency with the draft completion criteria (see Table 9.2) where the completion criterion is measuring water quality at SW11, with one criterion stating that measurement would be based on compliance limits or specified guideline values (referencing Table 4-2, EIS Appendix S) while the other criterion does not reference Table 4-2 (EIS Appendix S). It is therefore unclear how the second criterion relates to the earlier criterion. It is also noted that while the draft indicator refers to sediment release, the draft completion criterion which refers to Table 4-2 contains no sediment-related trigger values such as TSS or turbidity.

Table 9.2 – Example of Inconsistency in Draft Completion Criteria

Rehabilitation Goal	Rehabilitation Objectives	Draft Indicators	Draft Completion Criteria
Stable	Erosional stability	Sediment release from erosion does not adversely impact on water quality – water quality downstream of the OEFs	Evidence that surface water quality monitoring results downstream of OEFs have met compliance limits or specified guideline values (see Table 4-2) for 10 years
	Geochemical stability	Seepage water quality at toe/base of landforms	Evidence that seepage quality and quantity is static or improving, and that downstream compliance limits or specified guideline values (derived from ANZECC 2000 or agreed reference source) are met at SW11 for 10 years

The nomenclature within the MCP regarding criteria is not clear, e.g., completion criteria (Table 6-1, Appendix S), success criteria (Section 9.3, Appendix S), performance criteria (Section 9.3, Appendix S), monitoring criteria (Section 9.3, Appendix S), closure criteria (Section 9.3.1, Appendix S) and mine closure criteria (Section 9.3.10, Appendix S) are used interchangeably. It is

unclear if these terms are all the same or if they have different meanings. Consistency in terminology is required to ensure that all stakeholders are clear on what is being proposed.

The completion criteria in some instances do not align with the modelling undertaken. For example, Table 9.3 is an excerpt from Table 6-1 (EIS Appendix S) which outlines the draft completion criteria for the proposed cover on the NOEF.

Table 9.3 – Inconsistency Between Modelling and Draft Completion Criteria

Rehabilitation Goal	Rehabilitation Objectives	Draft Indicators	Draft Completion Criteria
Stable	Geochemical stability	Water infiltration rates through the NOEF cover, as determined by large scale lysimeters	5 to 10% of rainfall infiltrates beneath the outer compacted clay layer

Modelling undertaken by O’Kane Consultants (EIS Appendix J, Part 1) showed the following with regard to infiltration rates through the cover:

- ♦ Breccia cover – 4.5% of rainfall.
- ♦ Alluvium cover – 5.9% of rainfall.

The model results were used by Klohn Crippen Berger (EIS Appendix T) as one of the inputs into the groundwater model. Subsequently, the completion criteria are between 69 and 122% greater than the model results, i.e., the proposed measure of success allows greater infiltration through the cover than the model results that have been used as the basis for the impact assessment. The implications are that if the draft completion criteria are accepted and infiltration is at the higher end, i.e., 10%, then the environmental impacts of the greater infiltration of water flow through the cover have not been considered in the modelling. This could result in monitoring indicating that the cover is performing as predicted but that the downstream water quality is different to that modelled. The draft completion criteria need to be linked to the modelling so that changes can be understood in terms of the potential environmental impact.

9.2.2.4 Contingency Plans for Premature Closure

Section 8.2.1 (EIS Appendix S) outlines the strategy for short-term care and maintenance, which MRM has stated could last for one to two years. An action for the OEFs is that temporary wet season covers are completed over any exposed OEF core and PAF(RE) cells. Section 8.3.6 (Appendix S) outlines how MRM has undertaken trials for temporary wet season covers and that performance was observed but the MCP does not detail any of the findings and states that ‘ongoing studies will investigate further refinements to the optimal temporary wet season caps’. This action would appear inadequate as temporary wet season covers have been known to be ineffective in terms of controlling infiltration into the NOEF (ERIAS Group, 2017). Further investigation is required regarding whether the placement of temporary wet season caps is appropriate in the event that the operation is placed in short-term care and maintenance.

The strategy for the TSF is to maintain pond water levels as per the Operating Maintenance and Surveillance (OMS) Manual, with the spigots being used to pump water over the exposed beach for dust control. In the IM’s experience, using the existing spigots to pump water over the exposed

beach for dust control is unlikely to result in water spreading sufficiently to significantly reduce dust emissions as water will behave differently to tailings slurry and is likely to travel from the spigot to the decant pond in a series of channels rather than spread out across the tailings beach.

9.2.2.5 Detailed Closure Costing Calculations

McArthur River Mining has approval for the construction of a 6 ML/day reverse osmosis water treatment plant (Section 3.2.2.9) with waste (reverse osmosis reject brine) to be used as process feed water. In Section 4.10.2.3 it is stated that seepage management systems will remain in place to collect and treat seepage water from the NOEF until monitoring confirms that it is no longer required. Further it is stated that these systems will remain in place throughout the adaptive monitoring phase (100 years). The IM could not find any reference to disposal of brine after the cessation of tailings retreatment. Section 8.6 of Appendix U indicated that the water treatment plant ceased production at the conclusion of tailings retreatment in 2047 which is not consistent with the above statement of water treatment continuing throughout the adaptive monitoring phase (100 years). If the brine is to be discharged into the open pit it is not clear if this input has been included in the pit water quality assessment. Clarification is required regarding whether the water treatment plant will continue to operate after the retreatment of tailings has been completed, the expected treatment rate and where the brine will be discharged.

Three options were identified by MRM for the closure of the TSF:

- ♦ Tailings to remain at the TSF with cover system installed.
- ♦ Re-handling tailings back into final void.
- ♦ Reprocessing of tailings then rehandling back into final void.

The preferred option is to reprocess tailings and placement into the final void. It is not clear if reprocessing of tailings is currently technically and financially viable and subsequently clarification is required regarding whether metallurgical testing has demonstrated the feasibility (technical and financial) of this alternative. If this preferred alternative is not currently technically and financially feasible, is it MRM's intention that the alternative of rehandling tailings back into the final void would be implemented? The IM notes that Table 5-11 indicates that the financial cost to place tailings back into the pit without treatment would have a major impact on company finances. Clarification is required regarding which alternative would be implemented in the event that reprocessing of tailings was not technically and financially viable.

Three phases of post closure monitoring and maintenance (see Section 9.2.1). are described. These phases of post closure monitoring and maintenance are appropriate given the size/scale of the operation and the issues being managed. What is unclear is whether MRM intends to manage the site through these three phases or if at the conclusion of the adaptive management phase it is intended that the site be handed back to the Northern Territory government. In the risk assessment (Table 7-5 Chapter 7), risk ID BB80 states that additional mitigation measures after the EIS include revised mine closure plan including cost estimates and details that this includes adaptive management and reactive management phases. It is further stated that the ranking basis for the residual risk being reduced from high to low is that the following is implemented:

- ♦ Early monitoring and feedback to estimates continually update closure costs and reduce the risk of unforeseen major costs.
- ♦ Funding mechanisms agreed with regulators to provide for adaptive management and reactive management phases.

It is not clear from the risk assessment whether the revised closure cost for the site now includes costs for the long-term adaptive management and reactive management phases of the Project. Furthermore, the level of confidence in the residual risk ranking is considered low with the reason being that it is beyond McArthur River Mining's control. It is unclear from this statement what is beyond McArthur River Mining's control.

It is unclear to the IM whether it is intended that the site be handed back to the Northern Territory Government and the mechanism proposed (e.g., Trust fund) that would fund the ongoing monitoring and maintenance during these later phases.

9.2.3 Adaptive Management

There are numerous references throughout the EIS to adaptive management as being a key strategy to be used by MRM should monitoring results indicate that the proposed mitigation strategy is not successful. As a management concept the IM believes that adaptive management is integral to any monitoring program, which should modify management measures based on monitoring results. Adaptive management is used by both the Queensland Department of Environment and Heritage Protection, and New South Wales Office of Environment and Heritage to monitor the performance of management measures and instigate change where required to incorporate new information and/or technologies as they occur. The IM supports this approach, as there is a need for flexibility and to incorporate continuous improvement into the development of closure strategies.

Section 8.7.3 of the EIS outlines the approach to adaptive management and in particular the timeframes. Reference is made to 'plans being developed to assist with the implementation of 'true adaptive management' rather than simply 'monitoring and reacting'. The reference to 'true adaptive management' is confusing and it is not clear to the IM how this differs from adaptive management. The IM recommends that this term be explained so that stakeholders are appropriately informed as to MRM's intentions.

It is identified in EIS Section 5.1 that alternatives identified as part of the project's consideration of other alternatives may be used should ongoing optimisation and performance monitoring identify a requirement or opportunity to apply adaptive management strategies. What is not clear is the trigger that would indicate that alternative strategies are required. The IM considers this to be particularly important given the concerns about the long-term effectiveness of the NOEF cover system as outlined in Section 2. While MRM has identified a number of alternatives, it is not clear which would remain an option once the preferred option as outlined in the EIS is implemented or is in the process of being implemented, i.e., in undertaking the preferred option does this then exclude other alternatives from being implemented.

Section 5.2.6.2 of the EIS discusses the Project design philosophy being driven by the closure objectives with a focus on managing and mitigating key long-term environmental risks from the outset as part the Project design and operations phases. McArthur River Mining states that 'the

approach includes development of a number of stages within separate short term and long term timeframes, which include adaptive management as a short term management tool'. It is unclear what these number of stages are and how they fit in the short term (<100 years) and long term (100 to 1,000), what is being monitored and how this monitoring is being undertaken, although there is reference to alternatives and contingencies being implemented where monitoring indicates an altered approach to achieving the closure objectives is required.

9.3 What Must be Addressed in the EIS Supplement?

Review of the EIS and related appendices relating to mine closure has identified the following areas that need to be addressed in the EIS supplement:

- ♦ Review the MRM closure framework to ensure that goals, objectives, indicators and criteria are linked.
- ♦ Provide indicators and completion criteria that will give early warning that management and mitigation measures are not achieving the outcomes and benefits expected and identified by MRM.
- ♦ Describe the contingency measures that are technically and financially available to be implemented in the event that monitoring demonstrates that management measures have not been effective and provide a discussion about the likely effectiveness of the NOEF cover system over the full 1,000-year period, including case studies.
- ♦ Update the compliance register to identify all commitments previously made by MRM and flag which of these have been superseded so that a consolidated list can be generated.
- ♦ Clearly articulate the modes of failure of the cover system and undertake a risk assessment and modelling to determine the environmental impact should these failures occur. This should include assessing water quality and the implications with respect to beneficial uses at SW11, in McArthur River and Barney Creek upstream of SW11, and the McArthur River downstream of SW11 for the full 1,000-year period, and not be limited to filterable metals.
- ♦ Investigate if the installation of wet season caps over any exposed OEF core and PAF(RE) cells is appropriate given previous trials which have indicated that these covers do not effectively control infiltration into the OEF.
- ♦ Provide details regarding the funding mechanisms and possible management arrangements agreed with regulators to provide for adaptive management and reactive management phases, i.e., the full 1,000-year period.
- ♦ Clarification and detail is required regarding whether the water treatment plant will continue to operate after 2047, the expected duration and where the brine will be discharged. If brine is to be discharged into the open pit clarification is sought on whether this input has been included in the pit lake water quality model.
- ♦ Provide clarification regarding whether the technical and financial viability of reprocessing of tailings has been demonstrated. If reprocessing of tailings is not technically and financially

viable MRM should provide clarification regarding which of the proposed alternatives would be adopted.

- ♦ Describe the pros/cons from an environmental perspective of the proposed closure strategy relative to the 'No Project' scenario (in greater detail than provided in Section 5.4 of the EIS).
- ♦ Provide further detailed information and clarity regarding how the adaptive management process within the MRM context will be implemented, i.e., triggers for implementation, options available for each rehabilitation goal. The IM suggests that this could be presented by including additional columns in Table 6-1 of the MCP.
- ♦ Outline which alternatives remain viable in terms of implementation after the commencement of the proposed strategies for the TSF, OEFs and open cut final void.

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