Rum Jungle Mine Site Rehabilitation Project Failure Modes and Effects Analysis (FMEA) for the Rum Jungle Stage 2 Design Phase

18 September 2015

Northern Territory Government

O'Kane Consultants




Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

Rum Jungle Mine Site Rehabilitation Project Failure Modes and Effects Analysis (FMEA) for the Rum Jungle Stage 2 Design Phase

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18 September 2015

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1 INTRODUCTION

The Department of Mines and Energy, Northern Territory (DME) retained O'Kane Consultants Pty Ltd (OKC) to facilitate a failure modes effects analysis (FMEA) for the former Rum Jungle Mine site. The initial FMEA-focussed workshop was held on 9-12 February 2015 and FMEA documentation was subsequently prepared by OKC. A second detailed design focussed workshop was held on 13-16 July to present additional work and refine the overall rehabilitation approach in the context of risks that were previously identified. This document provides an update to the previously issued FMEA documentation. The update is provided to document details of the July workshop and modifications to the overall rehabilitation approach.

Both workshops were well-attended, comprising DME representatives, stakeholders and various technical professionals.

1.1 Report Organisation

This summary report provides background information on the FMEA process, documents the key workshop discussion topics and summarises the key recommendations. This report has been set out as follows:

- Section 1 – Introduction.
- Section 2 – FMEA, background information relating to an FMEA.
- Section 3 – Provides a record of the formal FMEA conducted in February 2015 and preliminary approach.
- Section 4 – Provides a record of the July 2015 workshop and modifications to the approach.

2 FAILURE MODES EFFECTS ANALYSIS

2.1 FMEA Process

An FMEA is a top down systematic approach to risk appraisal, and identification of controls. The aim is to foresee the potential risks associated with a system and therefore build redundancy or mitigation measures as required. The analysis can be used as a tool to support/communicate adopted strategies and/or to determine where further understanding may be required. Its value and effectiveness depends on having experts with the appropriate knowledge and experience participate in the evaluation process, during which failure modes are identified, assessed, and controls are developed to reduce the likelihood of a particular failure or consequence occurring.

The process is threefold:

1) Identify the function of the likelihood of a particular failure mechanism;
2) Identify the impact, or severity, of this failure should it occur; and
3) Identify the level of confidence in having the ability to control the mitigation measures.

The process is commonly used to identify critical closure planning tasks and support studies for the development of waste material disposal strategies. A matrix approach is used to determine the severity of a consequence upon a design.

2.2 Risk Definitions

The term 'risk' encompasses the concepts of both the likelihood of failure, and the 'expected' frequency of failures, and the severity of the expected consequences if such events occur. The criteria set for the likelihood of a risk occurring is outlined in Table 2.1, while Table 2.2 identifies the criteria pertaining to assessment of severity of consequences specific to Rum Jungle.

Table 2.1: Likelihood of Risk Used in the FMEA

Likelihood Class	Likelihood of Occurrence
Not Likely (NL)	< 0.1% chance of occurrence
Low (L)	0.1 – 1% chance of occurrence
Moderate (M)	1 – 10% chance of occurrence
High (H)	10 – 50% chance of occurrence
Expected (E)	> 50% chance of occurrence

Table 2.2: FMEA – Severity of Effects as Agreed at the Onset of the FMEA

Consequence Categories	Low	Minor	Moderate	Major	Critical
Environmental Impact	No observable effect	Minor localized or short-term effects.	Deleterious effect on valued ecosystem component.	Extensive deleterious effect on valued ecosystem component with medium-term impairment of ecosystem function.	Serious long-term impairment of ecosystem function.
Consequence Costs	< $100,000	$100,000 - $500,000	$500-000 – $2 million	$2 million - $10 million	> $10 million
Human Health and Safety	Low-level short-term subjective symptoms. No measurable physical effect. No medical treatment.	Objective but reversible disability/impairment and/or medical treatment. Injuries requiring hospitalisation.	Moderate irreversible disability or impairment to one or more people.	Single fatality and/or severe irreversible disability or impairment to one or more people.	Multiple fatalities.

3 FEBRUARY 2015 FMEA WORKSHOP

3.1 Purpose

FMEA was used to appraise proposed rehabilitation strategies for aspects of the Rum Jungle rehabilitation project. Rehabilitation strategies were largely developed prior to the workshop as part of closure planning and are documented in the DME's current Conceptual Rehabilitation Plan (CRP), May 2013. The FMEA appraises the various rehabilitation strategies from a risk of failure context based on experts' knowledge and stakeholder participation, and thereby is able to provide reasoning-for and confidence-in selected closure strategies. The objectives of the Rum Jungle FMEA workshop were to:

- Present findings of detailed investigations undertaken during the 2014 dry season.
- Further refine the preferred rehabilitation strategy to enable DME to progress the staged rehabilitation approach outlined in the CRP.
- Minimise the likelihood of failure by utilising technical experts and stakeholders to systematically identify failure modes. This provides confidence in the adopted strategies prior to detailed design and construction.
- Provide an evaluation of the consequences of rehabilitation 'failure' and the impacts of such on the environment, stakeholders and the public.
- Reduce operational/rehabilitation costs related to failure and follow-on effects following construction.
- Provide a record of the workshop and discussions relating to rehabilitation strategies and aspects of the rehabilitation design.

3.2 Workshop Agenda

The general agenda for the FMEA workshop is provided below in Table 3.1.

Table 3.1: Workshop Agenda

Date / Time	Activity	Facilitator(s)	Attendees
Monday 9 Feb			
0830 - 1000	Intro & revisit summary from May Planning Workshop	DME & O'Kane	All
1015 - 1300	Summary of works: - Geotechnical pitting and footprint design - Groundwater - WRD test pitting	RGC	All
1330 - 1430	Hydrobiology	LDWQC	All
1430 - 1500	Flood assessment	Water Tech	All
1515 - 1700	OKC Summary: - Borrow material investigation - Conceptual design of new WSF	O'Kane	All

Date / Time	Activity	Facilitator(s)	Attendees
Tuesday 10 Feb			
0830 - 1700	Failure Mode Effects Analysis	DME & O'Kane	All
Wednesday 11 Feb			
0830 - 1700	Design refinement, identification of data gaps and task allocation	DME & O'Kane	All
Thursday 12 Feb			
0830 - 1700	FMEA (finalise)	DME & O'Kane	All

3.3 Attendees

A complete list of workshop attendees is provided below in Table 3.2.

Table 3.2: List of Workshop Attendees

Attendee	Representing
Tania Laurencont,	Department of Mines and Energy
Mitchell Rider,	Department of Mines and Energy
Cass Stokes,	Department of Mines and Energy
Mark Greally,	Department of Mines and Energy
Mike Fawcett,	Department of Mines and Energy
Peter Waggitt.	Department of Mines and Energy
Virginia Leitch,	Department of Industry
Joshua Reakes	Department of Industry
Rhonda Sarmardin	Northern Land Council
Greg McDonald	Northern Land Council
Mike O'Kane	O'Kane Consultants
Andre Kemp	O'Kane Consultants
Shonny Lehane	O'Kane Consultants
Christoph Wels	Robertson Geoconsultants
Paul Ferguson	Robertson Geoconsultants
Richard Walton	Water Technology
Ross Smith	Hydrobiology
Andy Markham	Hydrobiology
Corinne Unger	Environmental Consultant
Darron Cook	Jacobs / Sinclair Knight Merz
Michael McLeary	Jacobs / Sinclair Knight Merz
Ross Edwards	Jacobs/ Sinclair Knight Merz
Grant Sarra	Grant Sarra Consultancy Services
Richard McAllister	Department of Environment
David Jones	DR Jones Environmental Excellence
Ken Evans	CDU

3.4 FMEA Domains & Closure Strategy

The FMEA workshop was conducted in sessions that focused on the key aspects of the proposed rehabilitation strategy for Rum Jungle. Specific FMEA worksheets were developed for the:

- Proposed new purpose built Waste Storage Facility (WSF);
- Dewatering of Main Pit;
- Backfilling of Main pit;
- Clean up of the copper extraction area; and
- Cumulative and interactive elements.

The different domains of the FMEA were based on a modified rehabilitation strategy developed from 'Scenario 4' outlined in the CRP. Broadly, the refined strategy involves:

- Construction of a new purpose built WSF in an area sited above selected flood levels comprised of excess waste material which cannot be accommodated in the Main Pit void. This will include excess materials from Dysons, Main and Main North WRDs, and other site contaminated materials;
- Dewatering Main Pit and if required treating the water to meet applicable discharge requirements;
- Backfilling Main Pit with waste rock considered to have the highest potential to produce Acid and Metalliferous Drainage. The material is to be selectively sourced from Dysons backfilled pit area, Intermediate WRD and Main WRD. Lime will be incorporated into the waste as it is backfilled into the pit;
- Utilise Intermediate Pit as water detention/dilution reservoir. This aspect is a deviation from the previously-preferred Scenario 4, which is outlined in the CRP;
- Construction of a cover system over the Main and Dysons Pit and the new WSF; and
- Construction of other features for water treatment, potentially including wetlands or reactive barriers.

The scope of the FMEA includes all significant landforms including pits (Main, Intermediate and Dysons), all WRDs (Main, Intermediate and Dysons) and the copper extraction pad. The scope excludes 'relevant nearby sites' referred to in the CRP, including Rum Jungle Creek South, Mount Burton and Mount Fitch.

A brief overview and key discussion points for each significant landform are provided in Sections 5.1-5.4 below.

3.4.1 Foundations, Waste Placement and Cover (New WSF)

The proposed new WSF will incorporate industry leading practice design principles. Important aspects of the design include the overall landform geometry, the siting of the landform with respect to floodwater, the integration of the landform into the existing landscape, acceptability to stakeholders and long term geotechnical and geochemical stability.

The WSF will manage all the excess waste material not disposed in the void of the Main Pit. Discussions during the workshop advocated construction of the WSF in a 'layered' fashion to allow for minor adjustments to the footprint of the landform to provide flexibility in actual material volumes encountered.

Revegetation of the WSF is a key closure objective and will stabilise the surface cover materials.

The FMEA worksheets are provided as Appendix A. Key recommendations for the proposed WSF are provided in Section 6.1.

3.4.2 Dewatering Pits

Main Pit will be dewatered (and backfilled). A refinement of the rehabilitation strategy (from that outlined in the CRP) is to retain Intermediate Pit in its current open state, rather than dewater and backfill. This is to provide strategic flexibility (storage/treatment capacity) utilising Intermediate Pit as a surface water storage reservoir and long term surface water buffer. Main Pit will be dewatered prior to backfilling to manage water levels, prevent the uncontrolled release of pit water, for backfill consolidation and to provide better tailings encapsulation. It is envisaged that dewatering will be required over multiple successive wet seasons.

The potential for scheduling delays was discussed. Dewatering time will affect overall project scheduling and should occur prior to any earthworks during the first dry season. Dewatering may be considered during the wet season to provide flexibility in the overall project schedule

Recommended controls are discussed in Section 6.2 and the FMEA worksheets are provided as Appendix A.

3.4.3 Backfilling Main Pit

The strategy for Main Pit includes the backfilling of the void with potential AMD generating material from Intermediate and Main WRDs and Dysons Backfilled Pit to a level approximately 5m below the natural ground level. Backfilling activities are expected to take 1 to 2 consecutive dry seasons. The backfilling strategy includes the addition of lime to the backfilled material to provide neutralising capacity. This may be conducted on a conveyor belt system during material transport, or during material placement.

It is noted that the preferred rehabilitation scenario described in the CRP includes backfilling both Main and Intermediate Pits. During the workshop a modification to the strategy was proposed (and agreed) that Intermediate Pit be retained as a storage and (potential) treatment reservoir i.e. backfilling will be limited to Main Pit.

The upper limit of the material placement is dependent on local groundwater levels. Main Pit will be covered with a final layer of "clean" material to limit interaction with oxygen and potentially AMD generating materials. It is generally considered preferable for the diverted section of Finniss River to be reinstated to its original alignment i.e. through Main and Intermediate Pits. However, this strategy is dependent on further assessments.

A list of the recommended controls are provided in Section 6.3. The FMEA worksheets are provided as Appendix A.

3.4.4 Copper Extraction Area / Groundwater and Soil

The copper extraction area, located between Main Pit and Intermediate Pit, was assessed by FMEA separately from the proposed pits because of its physical and geochemical differences. The copper extraction area contains waste material, contaminated soils and groundwater. The FMEA discussion focussed on 1) the potential for residual contamination in soils and 2) contamination of groundwater.

The potential for remnant/residual contaminated material to remain after the clean-up of the copper extraction area were raised, although it was noted that these would have a low environmental impact. Cumulative impacts were thought to be more significant and push total load thresholds if not treated.

A list of the recommended controls are provided in Section 6.4. The FMEA worksheets are provided as Appendix A.

3.4.5 Cumulative and Interactive Elements

Concerns were raised during each session that site-wide issues, or effects that may have a larger cumulative consequence, may not be identified or may be underestimated. Therefore a separate FMEA was conducted to specifically identify issues with incremental, knock-on, and/or cumulative effects.

Elements such as flooding, revegetation, increased erosion and downstream impacts of loss of fines were identified in each session, generally with low risk rating. However, the cumulative impact of these issues may raise the risk rating. Rehabilitation scheduling and cost impacts were a common concern for this FMEA domain.

3.5 Workshop Findings & Recommendations

Numerous failure modes were identified for the five FMEAs listed in Sections 5.1 - 5.5. An appreciable number of failure modes and effects ranked above a 'moderate' risk score, highlighting the multi-faceted nature of the rehabilitation strategy and the requirement for carefully considered risk controls. The level of confidence in each assessment and risk areas varied, as a result of the wide-ranging participant expertise and level of current site knowledge for many of the failure modes, effects and pathways.

Many controls have been proposed to limit risk, to inform the proposed rehabilitation strategy, for scheduling and to develop detailed engineering designs. A comprehensive list of the failure modes and scoring is provided in the FMEA worksheets provided as Appendix A.

3.5.1 Foundations, Waste Placement and Cover System (New WSF)

The proposed new WSF comprises an obvious design feature of the rehabilitated site, being proud of the surrounding terrain. The performance-related objectives for the WSF, as specified in the CRP are to be safe, stable (physically, chemically and radiologically) and to reduce and limit future AMD contamination. The FMEA identified a multitude of failure modes.

Discussions of the different (potential) failure modes and controls related predominantly to the following topics:

- Volumetric assessment of the dump (under or over estimations) and the overall waste dump geometry;
- Improper materials characterisation and related geotechnical and geochemical behaviour of the WSF;
- Scheduling of waste placement, limiting the exposure of waste and (wet/dry) seasonality;
- Surface water drainage and erosion (surface water and wind), long term surface stability and implications of waste exposure;
- Revegetation, capillary rise, plant uptake of metals, soil biology and weed propagation;
- Flood levels, wetting of the dump and the interaction of water with components (e.g. toe and foundations) of the proposed WSF;
- Cover system design, surface settlement and impacts to the cover system efficiency; and
- Constructability, compaction issues and quality assurance.

A summary of requirements to manage the higher risk failure modes are listed as follows:

1) Conduct ongoing physical and geochemical waste characterisation to provide confidence in the waste schedule and therefore the ability to construct the proposed WSF.

2) Provide integrated engineering designs and specifications for WSF foundations, geometry and drainage (temporary and permanent). Generate waste placement specifications and construction methodology. This will reduce the risk of geotechnical failure (such as embankment collapse and surface slumping) associated with drainage and local flooding.

3) Conduct landform evolution modelling for engineering designs to confirm that erosion rates support CRP objectives for stability.

4) Provide engineering designs and specifications for water treatment with additional allowance for treatment rates above predicted. This will limit risks related to construction QA, erroneous estimations of net percolation and/or reduced hydraulic performance of the cover system.

5) Develop a health and safety plan for all site activities. During intrusive investigations pockets of gas were intersected. Site health and safety plans will include briefing site personnel on the risk, and provide preventative measures to ensure a safe working environment. As materials in transport will not be in a confined space any gas risks should be mitigated by natural dispersion.

6) Develop a revegetation plan to support re-vegetation objectives. Further investigations into potential sources of borrow materials will include an assessment of any limitations of the material, and potential requirements for amelioration of the material, through fertilisers etc.

7) Develop a weed control plan throughout the construction and establishment phases to limit the propagation of invasive/aggressive species, (e.g. gamba grass). This will include vehicular wash-down requirements and supporting controls to limit weed-spread in tender contract documentation. Conduct intensive post-closure monitoring of weeds. These controls must be rigorously adhered to, with significant and high priority maintenance requirements for weed management during the first 5 years of revegetation establishment.

8) Develop a detailed construction schedule to minimise the exposure of reactive waste during the wet season. Also, investigate the feasibility and requirement for a temporary, re-usable HDPE liner for covering AMD-generating waste.

9) Site the WSF above local flood (and groundwater) levels to prevent flooding / inundation of the WSF, including foundations. The site is to be designed for the 1 in 200 year events and assessed against the 1 in 1000 year events. This is to limit the impact of material loss through excess erosion and increased erosion due to miscalculated flood levels.

10) Calculate the cut/fill balance for accurate materials scheduling. This will limit the risk of over/underestimation of waste volumes. Utilise survey and digital terrain models for highest accuracy. Develop waste schedules for construction with tolerances for bulking and compaction and ensure that schedules are sufficiently flexible to accommodate error tolerances.

3.5.2 Dewatering Main Pit

Discharge limits set for potential releases from site with respect to water quality must be met to fulfil the objectives of the CRP. The FMEA identified a list of failure modes relating to dewatering activities.

The FMEA appraised various failure modes including:

- Inability to dewater within the scheduled timeframe;
- Failure to sufficiently dewater and maintain required water levels;
- Unexpected ingress of water;
- Failure to meet discharge license conditions; and

- Poor pit wall stability.

A summary of the requirements to manage the failure modes and associated risks are listed as follows:

1) Prepare a dewatering schedule based on water balance, pumping capacities and discharge allowances. Pumping is expected to be conducted during the dry seasons but may extend to wet season if required.

2) The engineering design must incorporate a levee for temporary and/or final design of pit catchment diversion prior to dewatering. Levee is to be designed to accommodate 1 in 200 year water levels and will remain in place during backfilling of the pit.

3) Engineering designs must include safety-in-design features to provide safety for personnel. This must include due consideration of access around potential geotechnical failure zones.

4) Continue monitoring to confirm existing water quality (metals) of all (including downstream) water sources, to enable a comprehensive assessment of impacts derived from future dewatering activities.

3.5.3 Backfilling Main Pit

The FMEA identified a list of failure modes relating to backfilling activities.

The FMEA appraised various failure modes including the:

- Impact of groundwater inflow;
- Inadequate addition and mixing of lime during backfilling;
- Geotechnical failure of the pit walls and subsidence of the (infill) floor;
- Potential for submerged objects to hinder the construction of working platforms; and
- Scheduling delays

A summary of the recommendations to manage the failure modes and associated risks are listed as follows:

1) Assess (Main Pit) groundwater levels in drought conditions with an appropriate degree of sensitivity analysis. Assess with respect to 1 in 100 year exceedance probability drought conditions. This will limit the risk of error in estimation of available volume for reactive waste placement below (dry period) groundwater levels. Note that this was identified as part of the WSF FMEA but is more appropriate here.

2) Determine the available storage volume of reactive PAF waste.

3) Develop a safe work plan to limit the risks of pit wall and tip head geotechnical failure. Include tip head design in engineering design package to provide safety in design.

4) Site and construct a groundwater monitoring bore to predict groundwater inflows and thereby limit pit flooding risks.

5) Develop the overall project schedule further to quantify the cost of delays.

6) Confirm lime dosing rates and overall volume/cost of lime required.

7) Construct levee as per Section 6.2 to reduce construction schedule risks caused by inability to meet the backfill schedule and/or ingress of water.

3.5.4 Copper Extraction Area – clean-up of groundwater and soils

Residual contamination from the copper extraction area is generally thought to be minor, and that the contribution to total load, and the effect on release thresholds, are the more significant concern in achieving closure objectives. Identifying if the contamination in this area is mobile or not and potential strategies to address any potentially mobile contaminated groundwater is therefore a key part of the rehabilitation strategy.

The FMEA appraised various failure modes, including:

- The hydrological regime differing from the current understanding;
- Insufficient removal of contaminants;
- Residual copper contamination/contamination of the diversion channel;
- Additional volumes of contaminated materials being encountered; and
- Erosion of contamination of any replaced materials and scheduling considerations.

An integrated list of the key recommendations to manage the failure modes and associated risks are listed as follows:

1) Continue to develop an understanding of water levels and hydraulic gradients of key features including pits, groundwater, the depth of contaminated waste and diversion channel levels.

2) Continue to assess the metal concentrations in the mine area to provide an estimate of likely contribution.

3) Assess sensitivity of cover/borrow requirements for contamination extents/depths beyond anticipated.

4) Specify requirements for replaced (cover) material to limit erosion of the cover system.

5) Provide flood channel designs as part of the overall engineering works, design storms will consider 1 in 200 year and 1 in 1000 year events.

6) Produce a sediment control and revegetation plan to limit erosion of replaced material.

3.5.5 Cumulative and Interactive Elements

Based on the preferred rehabilitation strategy for the former Rum Jungle Mine site, the project will be completed in phases over a period of three to four years, with the earthworks completed during dry season periods. A recurring concern during the FMEA workshop was identified as failures leading to scheduling delays and subsequent project impacts. A large project like this will require significant project management, co-ordination of consultants and contractors and should budget time to deal with unexpected issues accordingly.

A summary of cumulative and interactive failure modes that were identified include:

- Failure to estimate clean and dirty water volumes, and compounding effects of those inaccuracies for water treatment, the construction schedule and related costs;
- Failure to develop a proper material balance for waste and borrow materials and impacts to water treatment volumes, scheduling, seasonal preparation and costs;
- Disturbance to previously undisturbed areas including weed spread and the need to rehabilitate borrow areas;
- During the phases of design and construction site wide ecosystems and pathways are disrupted e.g. The potential spread of weeds during construction and rehabilitation establishment;
- Loss of resources (e.g. soil) through failure of erosional controls and subsequent knock-on effects;
- Planning failure and impacts to construction sequencing, seasonal preparations, delays and failure to fully implement the design(s). This includes failure to identify and implement critical path activities;
- Ecological disruption and compounding effects to the overall ecosystem;
- Fire and destruction of vegetation by wildlife, increased erosion and impacts to project planning; and
- Site access and approval and impacts to overall project planning.

The following recommendations were made during the FMEA with respect to cumulative and interactive elements:

1) Develop a site wide water balance to accurately reflect the clean and dirty elements during construction. The water balance must include seepage and models should assess the impact of successive failures over more than one wet season.

2) Develop a site wide materials balance for waste and borrow materials. The site wide requirements for borrow materials, and calculations of waste material volumes will be developed to ensure that filing and receiving approvals for any offsite sources of materials can be completed within a timely manner with regards to the project scheduling requirements.

3) Define rehabilitation footprint. The potential for additional materials for rehabilitation of haul roads, storage areas and ramps, and re-routing of these should be considered when proposing borrow material volumes required. All permits, approvals and licences should be completed in a timely manner, with engagement of authorities as early as possible. Focus on restoration of biodiversity and stability during the first 5 years of vegetation establishment.

4) Engage a construction scheduling professional in the design process to review the overarching aims of the project, and ensure that scheduling targets are realistic and achievable, the controller must also be able to quantify the cost of delays, for one week or one month for example, to identify limiting factors.

5) Conduct site wide fire control, including controlled burning in accordance with a schedule.

6) Severe weather events, including cyclones, floods and electrical storms will be monitored, particularly during the beginning/end of the dry and wet seasons. Generate a cyclone/severe weather emergency works plan to detail preventative works should a cyclone / flood event be forecast.

7) Communicate/engage with the ecological consultant regularly regarding proposed works to limit ecological impacts.

8) Develop an access protocol for site.

9) Conduct inductions and prepare approval documents for work teams and site access.

4 JULY 2015 WORKSHOP

4.1 Purpose

The July 2015 workshop was conducted to present additional work undertaken since the February workshop, and to refine the overall rehabilitation approach. The workshop provided a forum for strategy development and though the collaborative FMEA process was not repeated, the revised rehabilitation options were appraised in context of the risks identified in the February workshop. The FMEA worksheets were revised following the workshop and are included as Appendix A.

4.2 Agenda

Date / Time	Activity	Facilitator(s)	Attendees
Monday 13 July			
0830 - 1000	Intro & revisit summary from previous Workshop	DME & O'Kane	All
1015 - 1025	Outputs to the Detailed Business Case	DIS	All
1025 - 1300	• RGC presentation: • WRD characterisation & contaminated material assessment • GW remediation options for Cu extraction area • Main Pit backfilling/ dewatering • Flow & contaminant modelling	LDWQC	All
1330 - 1430	Hydrobiology presentation: 2015 Update on Studies Undertaken	Hydrobiology	All
1430 - 1500	Water Tech presentation: • Flow split Main Pit and Diversion • Levee heights • Post rehab flow-path Main pit • Interception sumps • WSF footprint flood model	Water Tech	All
Tuesday 14 July			
0730 - 1700	Indigenous & Safety Induction Site visit	DME & O'Kane	All
Wednesday 15 July			
0830 - 1700	Revisit elements of FMEA Risk assessment	OKC& DME DIS & Jacobs	All
Thursday 16 July			
0830 - 1700	Design refinement, scheduling, work breakdown structure and future task allocation	DME & O'Kane	All

4.3 Attendees

Attendee	Representing
Tania Laurencont	Department of Mines and Energy
Cass Stokes	Department of Mines and Energy
Mark Greally	Department of Mines and Energy
Mike Fawcett	Department of Mines and Energy
Peter Waggitt	Department of Mines and Energy
Virginia Leitch	Department of Industry
Mike O'Kane	O'Kane Consultants
Andre Kemp	O'Kane Consultants
Ian Taylor	O'Kane Consultants
Christoph Wels	Robertson Geoconsultants
Paul Ferguson	Robertson Geoconsultants
Andy Thomas	Robertson Geoconsultants
Richard Walton	Water Technology
Ross Smith	Hydrobiology
Andy Markham	Hydrobiology
Corrine Unger	Environmental Consultant
Darron Cook	Jacobs / Sinclair Knight Merz
Michael McLeary	Jacobs / Sinclair Knight Merz
Ross Edwards	Jacobs/ Sinclair Knight Merz
Richard McAllister	Commonwealth Supervising Scientist
Rick Van Dam	Commonwealth Supervising Scientist
David Jones	DR Jones Environmental Excellence
Danielle O'Toole	SLR

4.4 Refinement of Approach

The rehabilitation approach was further refined during the July 2015 workshop. The main changes to the approach are summarised in Sections 4.4.1 to 4.4.5 below. Refinements to the approach have been reviewed in the context of the risks considered in the February 2015 workshop, to provide revised risk rankings and identify where additional controls may be required. The FMEA worksheets have been updated and included as Appendix A to reflect the changes.

4.4.1 Proposed New WSF Location

Potential locations for the proposed new WSF were discussed in detail at the July Workshop, though have not been finalised at this stage. Various locations for the New WSF were considered, including:

- An undisturbed area to the northeast of the old stockpile area, and south of the northern lease boundary;

- The old stockpile area northeast of Main Pit; and
- In the current location of the existing Intermediate WRD and further east towards the existing Main WRD area.

The northern location has been adopted for the purposes of this document, owing to OKC's current understanding of DME and stakeholder preferred location. The failure modes identified in the February 2015 workshop were not location-specific and have been updated for location-specific risks. The most-affected failure modes are listed below, with further discussion.

- **The base/liner of WSF is more permeable than designed and failure to construct or attain the design intent and specifications, such as permeability.** Geology maps indicate that this area is underlain by dolostone, which may contain cavities. The area may be prone to further development of those cavities from acidic leakage should it occur. The likelihood of failure has been increased and therefore the risk ranking has therefore been increased to Moderate. Additional controls will be required to reduce the risk of foundation failure for the northern location.
- **Failure of lateral drainage, leading to geotechnical failure of the WSF**. Geology maps indicate that this area is underlain by dolostone, which may contain cavities. The area may be prone to further development of those cavities should AMD occur. This increases the risk of slumping/subsidence of the new WSF surface and cover. The potential for failure of lateral drainage (i.e. plateau drainage and drainage sub-surface drainage through permeable cover system layers) is therefore increased. Additional controls will be required during design to reduce the risk of foundation failure.
- **Foundation not performing as designed leading to differential settlement in excess of design parameters**. Geology maps indicate that this area is underlain by dolostone, which may contain cavities. The area may be prone to further development of those cavities should AMD occur. Therefore the likelihood has been increased to 'Moderate' and overall risk ranking has been increased to 'Moderate/High'. Additional controls will be required and have to be incorporated during the detail design phase to mitigate this risk.

4.4.2 Proposed Re-Classification of Waste

All waste is to be re-classified as PAF for planning of rehabilitation works. This is due to uncertainty in the spatial distribution and geochemical composition of disposed waste, and practical challenges in segregating PAF waste during the proposed rehabilitation works. It is thought that by planning for higher volumes of PAF waste that a placement schedule will be developed to accommodate the worst-case in terms of the volume of PAF waste to manage.

The failure modes identified as being impacted by this change affect various domains and are as follows:

- **Failure of characterisation and segregation by geochemical material properties, leading to performance and scheduling issues**. This comprises two failure modes (one failure mode with two impact categories) relating to the new WSF domain. In the February 2015 workshop, these failure modes were categorised as a low and moderate risk and given the more conservative nature of the proposed characterisation, the risk scores have been retained.

- **Failure of characterisation and segregation by geotechnical materials properties, leading to scheduling issues, insufficient volumes of materials for design as planned**. This failure mode also was identified in the new WSF domain. Previously, this was categorised as a 'Moderate' risk (for cost consequence) and no adjustment to the overall risk ranking or mitigation measures are proposed because base case project costs have not been calculated yet.
- **Insufficient volume available beneath dry season water table to place PAF material leading to additional volume required for the above ground landform**. This relates to the new WSF, the classification of all waste as PAF implies that there is additional PAF waste to be stored in the WSF than under the original classification system. The likelihood has been revised to 'expected' and consequently the risk ranking elevated to 'Moderate/High'.

4.4.3 Main Pit Dewatering & Backfilling Investigation

The proposed backfilling methodology is currently under development to consider a range of logistical considerations such as infrastructure required, overall cost and safe access. Preliminary geotechnical investigations have been carried out and pit wall stability, access and safety were identified as risks. The key failure modes affected by the preliminary geotechnical investigation, include:

- **Geotechnical failure of the pit wall during backfilling leading to interruption of construction**. Project Geotechnical consultants advised the pit wall is likely to be unstable following dewatering. Pit wall instability would affect access (due to safety) should load and haul methods of backfilling Main Pit be used. The risk likelihood has been increased to 'Expected' and therefore the highest risk ranking increased to 'Moderate/High'. Controls are to be identified, during refinement of the backfilling approach to mitigate this risk.
- **Instability and/or bearing capacity failure of backfilled floor during backfilling leading to inability to place waste and inability to access pit floor**. Saturated tailings in Main Pit are considered a potential hazard to access safe trafficability to Main Pit floor. Access is required for waste disposal in the load/haul backfilling alternative. The risk likelihood has been increased to 'high' in the absence of additional controls. Consequently, the previously 'Low' risk rankings are re-calculated as 'Moderate'.
- **Failure to properly predict pit wall instability due to rapid dewatering leading to 1) unanticipated pit wall failure, slump, collapse; and 2) leading to turbulence mobilisation of highly contaminated sediments, further treatment requirements**. This failure mode and dualistic effects were identified in the dewatering domain of the FMEA in the February workshop. Project Geotechnical consultants advised the pit wall is likely to be unstable following dewatering. Therefore the risk likelihood has been increased to 'Expected' and consequently the previously 'Moderate' and 'Low' respective risk rankings are re-calculated as

'High' and 'Moderate/High'. Additional controls will be required to address the safety and cost risks.

4.4.4 Proposed East Branch Re-Alignment

The Finniss River East Branch re-alignment was discussed in detail at the July Workshop. Modifications were proposed to its alignment so that the diversion would be less prone to failure due to subsidence. The proposed re-alignment ties-in with the pre-mine inlet and follows the northern perimeter of Main Pit. Investigation into connectivity with the intermediate pit and the utility of the current diversion drain is ongoing. The failure modes identified as being potentially impacted by this change are as follows:

- **Incision of water eroding replacement material into contaminated residual material leading to 1) contaminated water entering the intermediate pit and 2) back scouring, gullying into the covered main pit**. The failure mode and effects were identified as part of the copper extraction area and contaminated soils domain. The alignment of the East Branch around Main Pit and between Main Pit and Intermediate Pit is potentially encompassed by this failure mode.

  The alignment proposed in the July workshop is more circuitous through the Main Pit than the alignment developed in the February workshop. However, the alignment of the East Branch between the Main Pit and Intermediate Pit is not significantly changed. Longitudinal gradients in the revised approach are shallower through the Main Pit and relatively unchanged elsewhere. Velocities can therefore be expected to be less for the currently-proposed East Branch alignment than for the direct alignment through the Main Pit, proposed in the February 2015 workshop. This generally reduces potential for hydraulic erosion. Conversely the meandering alignment increases the exposed area of the northern bank. The likelihood of erosion has therefore been retained as 'Low' and the derived risk ranking remains 'Low' also.

4.4.5 Proposed New Construction Schedule

During the July workshop the proposed construction schedule was extended from four years to eight years. The failure modes identified as being impacted by this change are as follows:

- **Inability to complete the Main Pit backfill in one dry season leading to extension of construction schedule.** The revised construction schedule, developed in the July 2015 workshop indicates a three year schedule for backfilling. The Main Pit backfill progresses over three consecutive dry seasons. Although the overall schedule is longer than originally anticipated, the risk ranking was not revised due to the fact that base-case costs have not been calculated at this stage and therefore is not considered an over-run at this stage. This does not constitute an increased budget risk.

Appendix A

FMEA Worksheets

FMEA Worksheet - Rum Jungle Feb 2015 Workshop; Foundations, Waste Placement and Cover of WSF

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
1a	Base/Liner of WRF more permeable than designed	Failure to construct (technique, equipment etc.) as per detailed design, not attain design specifications (density, permeability etc.)	M	Mi	Mo	L	L	L	L	L	L	H	Mo	Larger group ranked likelihood as low. If not constructed properly at collection low point some participants thought likelihood Moderate; Could be mitigated. Materials will be placed above and below the liner. Construction and ranking does not include any budget constraints on the specification for the liner.
1b		Failure to construct as per detailed design, **materials** can't meet design specifications	M	Mi	Mo	L	L	L	L	L	L	H	Mo	Materials different or changes over time potentially forming secondary minerals - could get blocked and doesn't drain. Could lead to failure of lateral drainage system.
2	Failure of Lateral Drainage	Leading to geotechnical failure	M	Mo	Mo-H	Mo	Mo-H	Mi	Mo	L	L	M	Mo-H	Increased porewater pressure could cause failure.
3	Flooding to foundations due to in excess of design during WSF construction (groundwater rise as well as flooding from catchment)	Sediment loss to surface water resources	H	Mi	Mo	L	Mo	L	Mo	L	Mo	H	Mo	Rise in groundwater level could lead to increased runoff that may increase erosion of the WSF toe. Can be mitigated with engineering design.
4	Flooding to foundations due to rainfall event in excess of design during WSF construction due to direct rainfall	Sediment loss to surface water resources	H	Mi	Mo	L	Mo	L	Mo	L	Mo	H	Mo	Impact mainly the cost of lost material key, some participants had lack in confidence that mitigation/protection measures would be sufficient.
5	Loss of resource due to flooding and rainfall	Loss of volume of material	H	Mi	Mo	Mi	Mo	L	Mo	L	Mo	M	Mo	Rise in groundwater level could lead to increased runoff that may increase erosion of the WSF toe. Can be mitigated with engineering design.
6	Flooding to foundations due to rainfall event in excess of design for final landform	Contamination to surface and groundwater resources	L	Mi	L	L	L	L	L	L	L	H	L	Critical design element based on flood status. There will be a high level of dilution during high rainfall events. Will only be a short timeframe. Engineering design will be based on appropriate design life plus safety (freeboard).
7	Foundation not performing as designed	Differential settlement in excess of design parameters	M	Mo	Mo-H	Mo	Mo-H	L	L	L	L	M	Mo-H	Differential settlement could happen after construction. Site selection, detailed engineering design of foundation and foundation preparation and QA/QC of utmost importance.
8	Failure to cover exposed waste in existing WRD prior to wet season	Wetting up of PAF waste material and release of contaminants to groundwater and surface environs.	L	Ma	Mo-H	Mo	Mo	L	L	L	L	L	Mo-H	Construction schedule important. Minimise exposed waste material at any given time. Exposed waste could be covered temporarily with large HDPE liner (reusable). The cost of a temporary liner would be a small percentage of overall cost.

FMEA Worksheet - Rum Jungle Feb 2015 Workshop; Foundations, Waste Placement and Cover of WSF

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
9	Failure to cover exposed newly placed PAF waste prior to wet season	Wetting up of PAF waste material and release of contaminants to groundwater and surface environs.	M	Mo	Mo-H	Mo	Mo-H	L	L	L	L	H	Mo-H	Construction schedule important. Minimise exposed waste material at any given time. Exposed waste could be covered temporarily with large HDPE liner (reusable). The cost of a temporary liner would be a small percentage of overall cost.
10	Underestimation of WR materials	Less volumes of material for designed placement	M	Mi	Mo	Mo	Mo-H	L	L	L	L	M	Mo-H	Flexibility of design has to allow for over or under estimation of materials
11	Overestimation of WR materials	Excess volumes of material for designed placement	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Design and construction flexibility is critical. Continuous updating and confirmation of final geometrical design.
12a	Failure of characterisation and segregation of geochemical properties of materials	Leading to performance issues	L	L	L	L	L	L	L	L	L	H	L	Detailed placement and integrated waste rock facility design to account for potential changes.
12b	Failure of characterisation and segregation of geochemical properties of materials	Leading to scheduling issues	M	L	L	Mi	Mo	L	L	L	L	H	Mo	Season 1 is the focus for this scheduling. Is segregation worth all the risks to scheduling?
13	Failure of characterisation and segregation of geotechnical properties of materials	Leading to scheduling issues, insufficient volumes of materials for design as planned.	L	L	L	Mo	Mo	L	L	L	L	M	Mo	Propensity for consolidation as well
14	Failure to identify gas pockets in WRD	Leading to health and safety issues	L	L	L	L	L	L	L	C	Mo-H	H	Mo-H	Construction health and safety plan to address potential for encountering gas pockets
15	Development of gas pockets in material during transport and storage	Leading to health and safety issues	NL	L	L	L	L	L	L	Ma	Mo	H	Mo	Highly unlikely. Material not in confined space; gas should disperse when tipped. In pit disposal to be assessed.
16	Leach down of stored oxidation products takes longer than predicted	Leading to longer water treatment requirements	H	L	Mo	Mo	Mo-H	L	Mo	L	Mo	H	Mo-H	
17	Incorrect waste placement construction method leading to elevated contaminant release	Failure to incorporate lime and waste rock to prevent contamination via metal release, or inadequate volume of lime added	L	L	L	Mo	Mo	L	L	L	L	H	Mo	Differential settlement could happen after construction. Site selection, detailed engineering design of foundation and foundation preparation and QA/QC of utmost importance.

FMEA Worksheet - Rum Jungle Feb 2015 Workshop; Foundations, Waste Placement and Cover of WSF

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
18	Incorrect scheduling of waste placement leading to increased seepage	wetting of waste material leading to additional seepage to be collected and treated	L	L	L	L	L	L	L	L	L	H	L	Unlikely to be an issue.
19	Insufficient volume available, beneath dry season water table to put PAF material	leading to additional volume required for the above ground landform	E	L	Mo	Mi	Mo-H	L	Mo	L	Mo	M	Mo-H	Assess the climate record and model groundwater levels in 100 yr drought scenario
20	Hydrogeologic regime not behaving as predicted/modelled	Failure to correctly define groundwater regime (for example greater permeability) leading to release of contaminants to groundwater	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Robust groundwater model with sensitivity analysis updated.
21	Failure of surface water management system due to more intense rainfall events	Higher runoff volumes leading to increased soil erosion and unacceptable sedimentation of local streams	L	Mi	L	L	L	L	L	L	L	H	L	Consider design for surface water management system for 1:200 as compared to 1:100 yr event, small incremental cost compared to large benefit. Assessment period 1000 yr; compare and adjust if deemed required.
22	Formation of erosion gullies on landform embankments due to overtopping of plateau	Unacceptable sedimentation of local streams, exposure of waste rock materials	NL	Mi	L	Mo	L	L	L	L	L	H	L	All surface runoff directed away from crest at gentle slopes; minimal erosion.
23	Formation of erosive gullies on landform embankments due to incident rainfall	Unacceptable sedimentation of local streams, exposure of waste rock materials	L	Mi	L	Mi	L	L	L	L	L	M	L	Design will consider long-term evolution modelling based on site specific materials and climatic conditions.
24a	Formation of holes / macropores in cover profile due to plant roots extending to base of cover profile.	Localised increase in net percolation rates, leading to higher seepage rates than designed	M	Mi	Mo	L	L	L	L	L	L	L	Mo	Include factor of safety in treatment facility seepage quantity design.
24b	Formation of holes / macropores in cover profile due to plant roots extending to base of cover profile.	Higher oxygen ingress rates leads to increased oxidation of sulphides, which ultimately causes detrimental effects on receiving environment.	M	Mi	Mo	L	L	L	L	L	L	L	Mo	Include factor of safety in treatment facility seepage quality design.
25a	Plant uptake of metals and/or salts due to roots extending into waste material.	Excessive bioaccumulation of metals in plant tissue leading to unacceptable health risks to wildlife and humans.	L	Mi	L	L	L	Mi	L	L	L	H	L	The probability of this failure mode is unlikely given the proposed growth medium layer thickness.
25b		Vegetation die-off leading to increased soil erosion and unacceptable sedimentation of local streams.	L	Mi	L	Mo	Mo	L	L	L	L	M	Mo	The probability of this failure mode is unlikely given the proposed growth medium layer thickness. Unknown volume of material that would need to be replaced.

FMEA Worksheet - Rum Jungle Feb 2015 Workshop; Foundations, Waste Placement and Cover of WSF

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
26a	Poor vegetation establishment due to lack of moisture, nutrients, or physical properties of cover material.	Higher runoff volumes leading to increased soil erosion and unacceptable sedimentation of local streams.	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Further characterisation and planning, with limitations on the material source.
26b		Higher net percolation rates ultimately leads to higher basal / toe seepage volumes, which causes detrimental effects on receiving environment.	L	Mi	L	L	L	L	L	L	L	M	L	Design will not only rely on the cover system. Internal dump design will contribute to reduced percolation through waste dump. Integrated design will limit this risk.
27	Failure of vegetation placement and planning	Leading to poor propagation, increased erosion and runoff than predicted	M	Mo	Mo-H	Mi	Mo	L	L	L	L	M	Mo-H	Likelihood is limited to factors outside of our control - climate, etc. See comment on cumulative effects
28	Propagation of invasive/alien species due to poor biosecurity controls	Leading to development of monoculture and impedance to native species propagation	L	Mo	Mo	Mi	L	L	L	L	L	L	Mo	Controls are put into contracts to ensure wash down of vehicles entering and leaving site. Post closure monitoring and eradication.
29a	Changes in cover characteristics due to soil biology	increased oxygen ingress rates and higher net percolation rates	M	Mi	Mo	L	L	L	L	L	L	M	Mo	With all the other systems in place the change in net percolation rates will not be significant
29b		Leading to higher runoff and increased erosion (lower net percolation rates)	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Detailed design and long-term evolution modelling sensitivity analysis to consider this.
30a	Dominance of undesirable species in new landforms, e.g. gamba grass and acacia	Leading to reduced performance of cover system	H	Mi	Mo	Mi	Mo	L	Mo	L	Mo	H	Mo	Gamba clumps together, does not provide good ground cover, following fires leaves bare ground. Data from 2014-15 wet season of acacia dominated ground to be made available. Cumulative effects of this may be classed as moderate for environmental effects
30b		Leading to higher fire intensity and replacement of biodiversity with monoculture	H	Mi	Mo	Mi	Mo	L	Mo	Mi	Mo	H	Mo	Cumulative costs if the entire site needs treatment and re-establishment of native species. Safety ranking assumes mitigation through weed management. Significant and high priority maintenance requirements for weed management, especially during first 5 yrs. Also a perception issue
30c		Leading to reduced accessibility for inspection, monitoring and stability	H	Mi	Mo	Mi	Mo	L	Mo	Mi	Mo	H	Mo	As above, weed controls should be rigorously adhered to for a minimum of the first 5 yrs, to allow for establishment of native flora.
30d		Leading to failure to meet rehabilitation objectives	H	Mi	Mo	Mi	Mo	L	Mo	Mi	Mo	H	Mo	Significant and high priority maintenance required for minimum 5 yrs. Further regular monitoring and maintenance for 15-20yrs (less intensive)

FMEA Worksheet - Rum Jungle Feb 2015 Workshop; Foundations, Waste Placement and Cover of WSF

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
31	Flooding and flow velocities in excess of design	leading to incision of the toe of landform	L	Mi	L	Mi	L	L	L	L	L	H	L	Engineering solutions to be considered and designed, design will consider rock armouring of the toe up to 1:1000 flood level

Rum Jungle FMEA Worksheet - Dewatering pits

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
1	Failure to dewater the main pit during the designed dewatering phase	leading to delay in construction by at least 1 yr	L	L	L	Mo	Mo	L	L	L	L	H	Mo	Assuming all discharge requirements are met. Points towards need to start dewatering in the dry and include water treatment
2	Failure to keep the area dry for the ~ 2 yr period	leading to flooding of main pit and associated construction areas	L	Mi	L	L	L	L	L	L	L	H	L	Levée for temporary and/or final design of diversion prior dewatering during wet season, likelihood assessed on design for 1:200 yr event. Minor enviro impact given we have intermediate pit as a buffer. Mitigate by dewatering in dry season, with first foundation on tailings before wet season starts.
3	Ingress of water at the end of dewatering through the failure of diversion system	leading to mobilisation of tailings and contaminated pore water into pit waters and downstream	L	L	L	Mi	L	L	L	L	L	M	L	Unlikely if dewatering is scheduled correctly.
4	Unable to meet the waste discharge license conditions	leading to delay in schedules	L	L	L	Mi	L	L	L	L	L	M	L	Need more information on downstream concentrations of metals from the pit. Assumes all requirements and testing are met and completed.
5a	Failure to properly predict pit wall instability due to rapid dewatering	leading to unanticipated pit wall failure, slump, collapse	E	L	Mo	Mo	H	L	Mo	Mo	H	M	H	Design criteria to include safety controls to limit work at potential geotechnical failure zones - i.e., a remote operation.
5b		leading to turbulence mobilisation of highly contaminated sediments, further treatment requirements.	E	L	Mo	Mi	Mo-H	L	Mo	L	Mo	M	Mo-H	Additional treatment costs potentially. Dependent on location and time of failure.

FMEA Worksheet - Main pit Backfill

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
1	Groundwater inflow	leading to flooding of base of pit floor ahead of construction	L	L	L	L	L	L	L	L	L	H	L	Placement of monitoring bore, knowledge of groundwater flows to that point will mitigate this failure. If required, continued water treatment and discharge system will have to be put in place.
2	Liming system along conveyor belt not sufficient	leading to inadequate lime application during material placement	L	L	L	L	L	L	L	L	L	H	L	During the discussion the question of quantifying the cost of delays, for one week or one month for example, were raised. While not possible at this stage, these consequence costs may be revisited, once a scheduling and project plan has been more fully defined.
3	In pit mixing during trucking process is not adequate	leading to inadequate lime application during material placement	H	L	Mo	Mi	Mo	L	Mo	L	Mo	H	Mo	Addition of extra 1% lime (the most expensive product is $150/t, unlikely that this is required, so this would be the upper limit of additional costs).
4	Over addition of lime	leading to cost higher than necessary to achieve the environmental benefit	NL	L	L	L	L	L	L	L	L	H	L	No perceived negative environmental impact; most times to little lime is added.
5	Failure to create a working platform as a result of submerged objects	leading to additional need for conveyance of waste rock, as opposed to using haul trucks	M	L	L	Mi	Mo	L	L	L	L	M	Mo	Will be reviewed as part of scheduling and design. Sufficient thickness of end tipped/conveyed material required and will most likely cover submerged objects.
6	Geotechnical failure of the pit wall during backfilling	leading to interruption of construction	E	L	Mo	Mi	Mo-H	L	Mo	L	Mo	M	Mo-H	Safety plan for work in pit around any areas identified as susceptible to failure.
7	Instability and/or bearing capacity failure of backfilled floor during backfilling	leading to inability to place waste and inability to access pit floor	H	L	Mo	L	Mo	L	Mo	L	Mo	H	Mo	Sufficient thickness of end tipped/conveyed material required and will most likely provide stability.
8	Inability to complete the fill in one dry season	leading to extension of construction schedule	H	L	Mo	Mi	Mo	L	Mo	L	Mo	H	Mo	Increased diversion will be in place. Only incidental rainfall will report to inner pit, with the implication for additional water treatment. Likelihood increased to high following July 2015 workshop, owing to changes to overall construction schedule, does not represent a high risk above baseline as budgeting not conducted at this stage.

Rum Jungle FMEA Worksheet - Copper Extraction Area Clean up

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
1	Hydrogeologic regime not behaving as predicted/modelled during groundwater treatment	leading to migration of copper plume to dolostone to the west northwest	L	Mo	Mo	Mi	L	L	L	L	L	M	Mo	Environmental effect would be a sulfate effect. Potential over time the Cu may develop, low likelihood.
2	Insufficient removal of contaminated materials in waters due to incorrect definition of contaminated aquifer	Continued release of contaminant to intermediate pit and East Finniss River	H	L	Mo	Mi	Mo	L	Mo	L	Mo	H	Mo	Expect the environmental impact to be contained, as currently. Even residual contaminant levels will have low enviro impact. The contribution to cumulative impacts may be more significant, and push thresholds if not treated.
3	Upset of inline treatment system	Leading to contaminated water going into the main pit	L	L	L	L	L	L	L	L	L	H	L	If technological issues occur the system will be shut down and reset.
4	Residual copper contamination after pumping	Leading to contamination of water in the diversion channel	NL	Ma	Mo	Mi	L	L	L	L	L	L	Mo	The temporal release (May - June) is of more concern than the load. Little other dilution of flow, and critical time for local biology. Pulses of high level of contaminant have less influence. Recessional flows and more important than first flush.
5	Residual solid contaminant source that cannot be removed by pumping	Leading to unexpected contamination to diversion channel/East Finniss River	NL	L	L	L	L	L	L	L	L	H	L	Secondary mineralisation unlikely due to pH of waters (3).
6	Residual copper contamination after pumping	Leading to the need to revisit the pumping and treatment of the contaminated water	NL	L	L	L	L	L	L	L	L	H	L	Addressed in previous Failure modes/Pathways
7	Residual secondary minerals not removed by pumping	Leading to continued elevated metal concentrations in groundwater	NL	L	L	L	L	L	L	L	L	H	L	Addressed in previous Failure modes/Pathways
8	Residual copper contamination after pumping	Leading to contamination of water in a diversion channel that is deeper	L	Ma	Mo-H	L	L	L	L	L	L	L	Mo-H	This relates more to elevations. Needs review of detailed water levels in this area. Possibly could be ranked as NL. Low confidence in ranking.

Rum Jungle FMEA Worksheet - Copper Extraction Area Clean up

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences: Environmental Impact		Consequence Costs		Human Health		Safety		Level of Confidence	Highest Risk Rating	Mitigation / Comments
Clean up of soil contamination 0-5 m between main and intermediate pits (Cu Extraction Area)														
1	Errors in classification of material	Leading to remaining contaminated soil in the area	L	Mi	L	Mi	L	L	L	L	L	M	L	Captured in Failure modes and effects 2 and 3, below.
2	Lack of understanding of the chemical cut off contamination levels	Leading to remaining contaminated soil in the area	L	Mi	L	Mi	L	L	L	L	L	M	L	Project that is in progress, results pending. If current work identifies further work to be completed, this will be done. Metals concentration in the mine area should be monitored, to date limited data has been collected, mostly from upstream or downstream of the mine area.
3	Lack of understanding of the depth of contaminated material	Leading to remaining contaminated soil in the area	L	Mi	L	Mi	L	L	L	L	L	M	L	Project work in progress to define this.
4	Additional volume of material required for removal	Leading to more effort to remove material and more borrow material required.	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Cumulative increase in requirement for borrow materials should be considered. Harder digging with increased depth which will require an upscale of equipment and potential increase in costs.
5a	Incision of water eroding replacement material into contaminated residual material	leading to contaminated water entering the intermediate pit	L	Mi	L	L	L	L	L	L	L	H	L	We can control the amount of gullying and scouring by controlling the water level and engineering the surfaces.
5b		leading to back scouring, gullying into the covered main pit	L	Mi	L	Mi	L	L	L	L	L	M	L	Not a single event, a cumulative effect that will have maintenance and monitoring. Assuming that the initial period includes the diversion to allow for establishment of this area. Through the design reduce the flow velocities to minimise potential for scouring
6a	Failure to design the flood channel properly	leading to an overexcavation of the area	NL	Mi	L	Mi	L	L	L	L	L	H	L	Detailed design will be undertaken based on design storm.
6b		leading to an underexcavation of the area	NL	Mi	L	L	L	L	L	L	L	H	L	Widening of the channel, covered in previous effects/pathways due to characterisation
6c		leading to sediment deposition into the intermediate pit and reducing capacity for water treatment	L	L	L	Mi	L	L	L	L	L	M	L	Volume of cu extraction replacement material is not equal to the volume of the pit. Define the proportion of volume required in the pit. Effect/pathway is not necessarily a reflection on failure of design. This assumes that an alternative water treatment would be put in place, in a timely manner.
7	Flow conditions exceeding the designed flow (1:200)	Leading to overwhelming of channel design and sediment erosion and loss of water treatment capacity	NL	Mi	L	Mi	L	L	L	L	L	M	L	Incremental design cost for a 1:1000 design to be assessed, relative to 1:200 design
8	Failure to remove and place the replacement material before the wet season	leading to large scale erosion of unconsolidated materials, filling the pit quickly and altering of channel pathways	NL	Mi	L	Mi	L	L	L	L	L	M	L	Requirement for sediment control and revegetation plan, addressed in initial establishment design with diversion
9	Contaminated groundwater encountered during excavation of materials	leading to water treatment requirements during excavation	L	L	L	L	L	L	L	L	L	H	L	Overall water treatment facility design should be able to cope with potential additional flow.

Rum Jungle FMEA Worksheet - Copper Extraction Area Clean up

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences								Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact		Consequence Costs		Human Health		Safety				
10	Groundwater levels are higher than expected	leading to groundwater expressing itself into the channel, continued discharge of contaminated water into the channel	L	L	L	L	L	L	L	L	L	H	L	Groundwater and pit water elevations should be considered in the design. No shallow groundwater monitoring in this area.
11	Slumping of intermediate pit walls, due to geotechnical failure	leading to loss of volume in intermediate pit for treatment works, and destabilisation of any other works	NL	L	L	L	L	L	L	L	L	M	L	Not considering mass failure, only small scale pit instability, although this does depend on the location of any slumping. Review any geotechnical reports on this issue, initiate studies if information unavailable.

Rum Jungle FMEA Worksheet - Cumulative & Interactive Elements

Failure Mode ID	*Failure Mode Description*	*Effects and Pathways*	*Likelihood*	*Consequences*								*Level of Confidence*	*Highest Risk Rating*	*Mitigation / Comments*
				Environmental Impact		*Consequence Costs*		*Human Health*		*Safety*				
1	failure to develop site wide water balance which accurately reflects the clean and dirty elements during construction	leading to more dirty water than capacity to store and treat and capacity to discharge and manage, offsite discharge of contaminated water	M	Mi	Mo	Mo	Mo-H	L	L	L	L	H	Mo-H	Water balance must include seepage. Ranked as Minor environmental impact, although the failure could occur over more than one wet season and compound/increase the impact.
2	failure to develop site wide water balance which accurately reflects the clean and dirty elements post- construction	leading to more dirty water than capacity to store and treat and capacity to discharge and manage, offsite discharge of contaminated water	L	Mi	L	L	L	L	L	L	L	H	L	Construction stage failure modes identified this item. It is anticipated that during construction stage lessons learnt and mitigation methods will be applicable to the site wide continued works. Good communication with different teams will be required to ensure all lessons/ mitigation methods are discussed with any flow through impacts highlighted.
3	Failure to develop a proper material balance for waste and borrow materials	leading to delays and or failure to construct properly, being unprepared for wet season, and related cost blow outs	M	L	L	Mo	Mo-H	L	L	L	L	H	Mo-H	Identifying off site sources of materials, filing and receiving the relevant approvals and transporting material will increase project costs and potentially lead to delays.
4	Undefined cumulative footprint for rehabilitation	leading to unanticipated need for further rehabilitation onsite	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	The cumulative footprint includes haul roads, material storage areas, ramps. The group identified a moderate likelihood of the re-routing of these, increasing the footprint.
5	Undefined cumulative footprint for rehabilitation	leading to unanticipated need for rehabilitation offsite	M	Mo	Mo-H	Mi	Mo	L	L	L	L	M	Mo-H	Assuming clearing is significant and in areas of little to no previous disturbance. Focus on restoration of biodiversity and stability during the first 5 yrs of vegetation establishment.
6	Failure to design an effective integrated sediment control system during construction	leading to loss of valuable construction resources, damage to infrastructure	L	Mi	L	Mi	L	L	L	L	L	M	L	Infrastructure cost has vulnerability, but should be designed with this in mind. Scheduling and storage/placement of materials is assumed to be managed in an appropriate manner
7	Failure to have integrated planning and system wide integration of sequencing, construction and controls	leading to delays in construction, failure to follow planned designs for construction, cost increases	L	L	L	Mo	Mo	L	L	L	L	H	Mo	A construction scheduling professional should be consulted and involved in the design processes to understand the overarching aims of the project, and ensure that scheduling targets are realistic and achievable.
8	failure to anticipate cumulative effects within the integrated system during construction	leading to exceedance of water quality limits, or design capacity	L	Mi	L	Mi	L	L	L	L	L	L	L	Low rankings are for a one-off event, although these may be reoccurring and require the need to revisit annually.
9	Failure to identify the critical pathways in the schedule for construction and implementation	leading to significant failure in construction schedule, planning for wet/dry season activities	L	L	L	Mo	Mo	L	L	L	L	L	Mo	Construction scheduling has to be engaged. Construction experts/professionals to be consulted and review.

Rum Jungle FMEA Worksheet - Cumulative & Interactive Elements

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences: Environmental Impact		Consequences: Consequence Costs		Consequences: Human Health		Consequences: Safety		Level of Confidence	Highest Risk Rating	Mitigation / Comments
10	Severe fire event across the site	leading to destruction of revegetation, increased erosion, destruction of equipment, delays in construction	L	Mi	L	Mo	Mo	L	L	L	L	M	Mo	Control burning and fire management plan to be put in place.
11	Site wide flood	leading to widespread erosion, overwhelming of water treatment facilities, disruption of construction, lack of site wide access	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Predicting cyclone/severe weather event warning system most probably required. This is particularly important during the early/late season.
12	Spread of unwanted plants during construction and rehab establishment	leading to development of monoculture, destabilisation of landforms, cultural objectives not being met	M	Mo	Mo-H	Mi	Mo	L	L	L	L	M	Mo-H	Weed management plan and wash down areas, access and contractor controls
13	Inadequate control of feral animals	leading to unpredicted impacts on rehabilitated areas during construction and rehab establishment	M	Mi	Mo	Mi	Mo	L	L	L	L	M	Mo	Feral animal management plan to be compiled and implemented at least until ecosystem well established.
14	Unearthing of unidentified radiological source/issue	leading to disruption of schedule, contamination of equipment.	L	L	L	Mi	L	L	L	L	L	H	L	Continuously monitor materials but unlikely.
15	Failure to plan for site wide organism access and habitat opportunities	leading to failure to establish desired ecosystem regime	L	Ma	Mo-H	Mo	Mo	L	L	L	L	H	Mo-H	Ensure ecological input in all phases of design and construction planning and scheduling. Inclusive of terrestrial and aquatic ecosystems. Perception of success and failure has an impact on this failure mode
16	Failure to return all areas of disturbance to sufficient biodiversity	leading to degraded ecosystems, negative perception	L	Ma	Mo-H	Mo	Mo	L	L	L	L	H	Mo-H	captured as above.
17	Inappropriate land use	leading to failure to meet remediation requirements	L	Mi	L	Mo	Mo	L	L	Mo	Mo	H	Mo	Requires appropriate access controls, and the communication of clear expectations of end land use to the community.
18	failure to protect Indigenous cultural heritage places/features	leading to delays in schedule	L	L	L	Mi	L	L	L	L	L	H	L	Compliance with AAPA Authority Certificate will be integrated in every contract for work. Failure to comply will result in fines, removal from site, potential prosecution and construction delays. Reputational impacts, socio-political perceptions. Approval documents, inductions and training will be included for all work teams. Communication through the liaison committee.
19	Failure to gain timely approval from relevant authorities	leading to scheduling delays	L	L	L	Mo	Mo	L	L	L	L	M	Mo	Early engagement. Uncertainty about EIS requirement. This requirement would significantly impact the risk rating.
20	Interactions from neighbouring sites	leading to unanticipated delays in construction and design, changing requirements	NL	L	L	Mo	L	L	L	L	L	H	L	Potentially Browns oxide. There could be water interactions in the intermediate pit / groundwater.

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