Appendix 19.

SLR Consulting Australia (2020j) *Rum Jungle Rehabilitation – Stage 2A Detailed Engineering Design – Water Treatment Facility Design Report*. Report to the Department of Primary Industry and Resources, Northern Territory.

NORTHERN TERRITORY
GOVERNMENT

Department of **Primary Industry and Resources**

RUM JUNGLE REHABILITATION - STAGE 2A
DETAILED ENGINEERING DESIGN

Water Treatment Facility
Design Report

Prepared for:

NT DPIR - Mines Division
GPO Box 4550
Darwin, NT, 0801

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with NT DPIR - Mines Division (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

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680.10421.90060-R01-v1.0 Issued for Implementation	27 May 2020	Peter Cupitt	Paul Delaney / DPIR	Danielle O'Toole
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EXECUTIVE SUMMARY

The waste rock Acid and Metalliferous Drainage (AMD) processes at the former Rum Jungle Uranium Mine site in Northern Territory are significant contributing sources of contamination impact both onsite and to the East Branch Finniss River (EBFR) via surface and groundwater pathways. The AMD impacted groundwater plumes across the Rum Jungle site are contributing to loads of copper and other metals within the EBFR. A groundwater capture and treatment system is proposed to be constructed to target the pathways within the Main and Intermediate Waste Rock Dump (WRD) zones and to address other historically impacted groundwaters onsite that contribute significant impact to the EBFR.

In addition to groundwater capture and treatment, surface water treatment is required for two abandoned open mining pits, referred to as the Main and Intermediate Pits, during the Main Pit backfilling operation. The pits will be isolated from the main EBFR flow path; however, the local catchment rainfall and groundwater inflows to the pits will require removal in order to maintain safe operating water levels within the pit backfill system.

A Water Treatment Plant (WTP) is required to treat both ground and surface waters of varying degrees of quality and quantity and to respond to the strong seasonality of the site. The WTP is to be temporary in nature to address the impacted groundwaters and operational pit surface waters during the rehabilitation construction works. The water quality output from this WTP is to satisfy the Locally Derived Water Quality Objective (LDWQO) (Hydrobiology, 2016). A reference groundwater extraction and WTP design involving a ‘Geco’ high density sludge AMD treatment process has been prepared. A suitabily qualified Contractor will be required to build and operate the WTP to produce an effluent which satisfies the LDWQO for a period of 11 years.

At the conclusion of Main Pit backfilling and other site earthworks activities, an extended groundwater treatment program is to be maintained, in conjunction with a monitoring regime, to address residual groundwater impacts and consequently reduce impacts to EBFR. The decommissioning of the groundwater abstraction and WTP would occur at a time agreed by the Proponent and appropriate Regulators. This period has been estimated to be 5 to 10 years.

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1 Introduction

To meet key environmental and cultural objectives for the rehabilitation of the former Rum Jungle Mine site a treatment strategy for contaminated site groundwater and surface water sources is required. It is proposed to use a combination of a Water Treatment Plant (WTP) together with in-situ treatment. This report details the decisions made in the water treatment strategy development and provides a reference design for a WTP, in-situ treatment, groundwater interception and integration with other rehabilitation activities.

1.1 Project Background

The Northern Territory Government (NTG), represented by the Department of Primary Industry and Resources (DPIR), proposes the rehabilitation of the former Rum Jungle Mine site (the Project), located 6 km north of Batchelor, Northern Territory (NT). The project location and regional setting are shown on Figure 1.

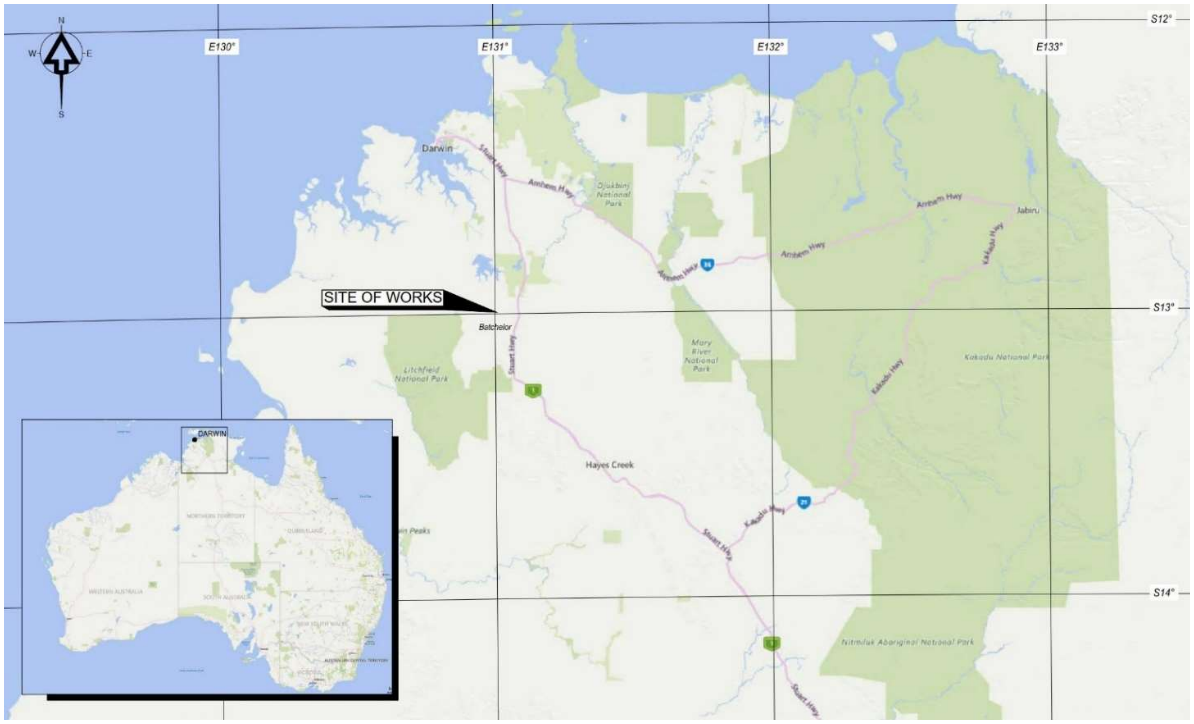


Figure 1 Project Location

The former Rum Jungle mine was rehabiliated in the 1980s, however recent studies indicate that the site needs further rehabilitation. Since 2009, the NTG and the Australian Government have been working under a National Partnership arrangement to complete investigative work to inform a rehabilitation plan, deliver site maintenance and continue environmental monitoring. The results of these programs have been used to develop an improved rehabilitation strategy that is consistent with the views and interests of Traditional Aboriginal Owners and that meets contemporary environmental and mined land rehabilitation standards.

The Project's high-level objectives are two-fold and focus on environmental remediation and restoration of cultural values of the site as described in the Draft Environmental Impact Statement (EIS) (NT-DPIR, December 2019) and below:

- Improve the environmental condition onsite and downstream of site within the EBFR This includes the following key outcomes:
    - Improved surface water quality conditions within EBFR in accordance with locally derived water quality objectives (LDWQOs).
    - Achieve chemically and physically stable landforms.
    - Support self-sustaining vegetation systems within rehabilitated landforms.
    - Develop physical environmental conditions supportive of the proposed Land Use Plan.
- Improve site conditions to restore cultural values. This includes the following key outcomes:
    - Restoration of the flow of the EBFR to original course as far as possible.
    - Remove culturally insensitive landforms from adjacent to sacred sites and relocate ensuring a culturally safe distance from the sacred sites.
    - Return living systems including endemic species to the remaining landforms.
    - Preserve Aboriginal cultural heritage artefacts and places.
    - Isolate sources of pollution including radiological hazards.
    - Maximise opportunities for Traditional Owners (TO) to work onsite to aid reconnection to country.

1.2 Current Site Condition

Historic mining and rehabilitation activities have altered the landscape within the former Rum Jungle Uranium Field, most prominently seen at the Rim Jungle site. Further rehabilitation will see a final landscape that, whilst still altered, has improved functionality and reduced environmental and cultural impact. The Rum Jungle complex is a typical example of an open pit legacy mining site of which there are many examples across Australia’s landscape. Rum Jungle features such as open pits and waste rock dumps (WRDs) are show in Figure 2.

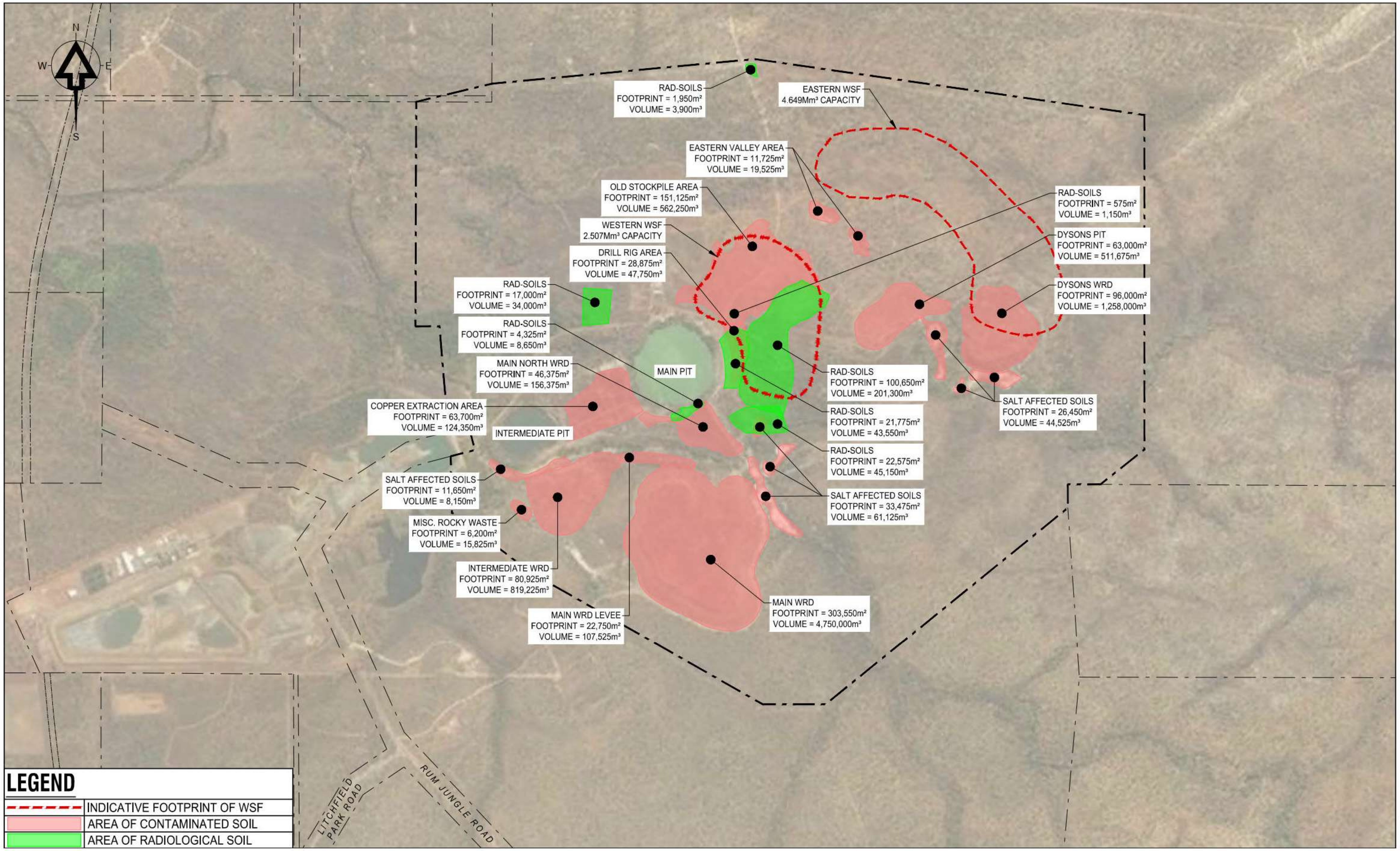


Figure 2 Existing site conditions in proximity to the EBFR

The most significant contamination mechanism at the Rum Jungle site is the impact to ground and surface waters by AMD. The primary AMD sources are the sulphide-bearing waste rock in the historic WRDs, leached low-grade ore and contaminated soils placed in shallow zones of Dyson's Pit during initial rehabilitation in 1984/85. Further groundwater contamination has occurred due to metalliferous liquor lost during an experimental heap leach operation from 1965-1971 in the Copper Extraction Pad area.

The key environmental objective of the Project is to improve water quality within the EBFR and Finniss River proper to LDWQOs (Hydrobiology, 2016). Copper is the primary Contaminant of Concern as described in the EIS (NT-DPIR, December 2019). Impacts to the cultural landscape of historic activities are related to the course of the EBFR and the general environmental health onsite. Land access is also currently impacted by Asbestos Containing Materials and radiological soils present at surface.

For comprehensive detail on the site condition, studies into the contamination processes, details regarding the contamination pathways and receptors the reader is referred to the Draft EIS document (NT-DPIR, December 2019). Significant work has been completed over recent years to characterise site conditions and to establish an agreed future landform and land use with Traditional Owners.

2 Water Quality Objectives for the Project

Hydrobiology (Hydrobiology, 2016) was engaged by the DPIR to undertake a downstream impact assessment on the aquatic ecosystems within the EBFR. Their conclusions showed a clear indication of increased metal concentrations in the isolated pools in the EBFR immediately downstream of the mine in the dry season. There were consistent patterns of reduced biodiversity and abundance of flora and fauna in this zone. Tissue metal concentrations in aquatic biota showed elevated concentrations of copper and zinc with a reduction in bioaccumulation downstream. A comparison of toxicosis from metals since the mine's closure in 1971 showed an adaption in the fish biota from decades of exposure. In response to these findings, site specific Locally Derived Water Quality Objectives (LDWQO) were formulated in accordance with the methodologies of the ANZECC/ARMCANZ guidelines to establish release limits from the site. Table 1 compares the general ANZECC limits to the Project LDWQO prepared by Hydrobiology.

Table 1 Water Quality Objectives

Analyte	**Project LDWQOs (mg/L)** (Hydrobiology, 2016)	95% ANZECC Limit (mg/L)
Arsenic	0.013	0.013
Aluminium	0.236	0.055
Cadmium	0.0002	0.0002
Cobalt	0.089	ID
Copper	0.060	0.0014
Iron (2+ and 3+)	0.300	ID
Manganese	0.759	1.7
Nickel	0.130	0.011
Magnesium	86.6	15
Lead	0.003	0.0034
Zinc	0.210	0.008

Analyte	Project LDWQOs (mg/L) (Hydrobiology, 2016)	95% ANZECC Limit (mg/L)
EC (µS/cm)	2,985	ND
Sulphates	1,192	2,000
pH	7-8.5	6.5-8.0

ID – Insufficient data, ND – no data

Robertson GeoConsultants (RGC) were engaged by the DPIR to prepare a MODFLOW/MT3D groundwater model to simulate groundwater flow across site and the interactions of ground and surface waters (RGC, November 2019). The model was enhanced through calibration over a period of 9 years. As Copper was considered a key indicator of riparian health and regularly breaches LDWQOs, the project team sought to identify a solution which would reduce copper loads in EBFR downstream of the site to levels below the Project LDWQOs. The solution provided by RGC involved the establishment of a network of groundwater extraction bores in strategic locations that would draw groundwater from a depth of up to 30m at a rate between 1 and 2L/s on a 24hour basis for a period of 10 years minimum. The groundwater would be treated to meet the Project LDWQOs before release or used within the construction project (NT-DPIR, December 2019).

3 Strategy to Meet the Project Water Quality Objectives

3.1 General

The Project water quality objectives are to be met by:

- Relocating waste rock and other contaminated soils to new waste storage facilities (WSFs) to minimise further AMD production and release of solutes from already existing oxidation product;
- Backfilling the highest Potentially Acid Forming (PAF) waste rock into the Main Pit to submerge material in an anoxic environment and reduce further AMD production; and
- Extracting impacted groundwater from beneath the existing WRDs area and treating before release.

Additional groundwater extraction at the old Copper Extraction Pad and former Stockpile area will improve local groundwater conditions however these groundwaters do not substantially report to the EBFR.

In parallel, the cultural objectives are to be met by relocating EBFR back through Main and Intermediate Pits and leaving these as ‘lakes’ along the realignment.

The strategies to meet these water quality objectives are summarised in the following sections.

3.2 Relocation of WRDs to new WSFs

The existing Waste Rock Dumps (WRD) on the banks of the EBFR are to be relocated and redesigned to new Waste Storage Facilities (WSF). Rainfall during the movement of waste rock may mobilise aqueous metals which would be captured in sediment and erosion control ponds. This impacted water would be transferred to Main Pit for treatment.

3.3 Pit Water Extraction and Treatment

Backfilling of the Main Pit with PAF will displace contaminated water which will require treatment before discharge. As a priority, the treated water would be used for WSF construction, dust suppression, irrigation (if required) with excess discharged to the EBFR during the wet season and irrigated during the dry season. An operating freeboard would also be maintained in both pits for the following reasons;

- Guarantee a water table hydraulic grade towards the open pits to prevent the migration of solutes in the backfill material from entering the groundwater
- Provide storm surge capacity in both pits to prevent overtopping to the EBFR during high rainfall events
- To attenuate the transfer rate to the WTP when higher than average backfill rates are employed

3.3.1 Backfill of Main Pit

The Main Pit is approximately 110m deep and has been backfilled with 63m of tailings. 47m depth of water now overlays the bed at RL 15.9m AHD. Previous investigations have identified that the Main Pit water is impacted by AMD and has a ‘chemocline’ layer of around 4m thick of solutes directly above the tailings. It is currently unknown if the chemocline is still in place or has been lost to surface waters, access to the Pit has been restricted and profiling will be needed in near future to determine the presence and quality of the chemocline prior to implementation of works described in this report. Above the chemocline, the pit lake water has concentrations of soluble metals which are higher than LDWQOs. The Intermediate Pit is also impacted. The displaced water from the backfilling operation of the Main Pit will need to be managed via a pump and treat system.

3.3.2 Construction operating levels in pits

To prevent overtopping of the pits during a major flood event, the freeboards shown in Table 2 are to be accommodated (NT-DPIR, December 2019).

Table 2 Construction operating levels in the pits

Pit	Outlet Culvert Weir Level (m AHD)	Construction Operating Level Range (m AHD)	Drawdown depth from dry season level (m)
Intermediate	57.82m AHD	49 to 50	7.5 to 8.5
Main	59.95m AHD	58 to 59	0 to 1

The water quality within the Intermediate Pit does not satisfy the project LDWQOs and may also require ‘pump and treat’ to maintain the construction operating level.

3.3.3 Surface water diversion

Surface water flows onsite would be diverted away for the Main and Intermediate Pits as far as possible to reduce the volume of water to be treated in the WTP and to reduce the likelihood of the pit system overtopping to the EBFR during pit backfill operations. The inlet of the Intermediate Pit and the outlet of the Main Pit would remain open to prevent local runoff from flooding the construction zone.

Temporary earth bunds are required to the south-west and north-north-west of the Main Pit to divert surface runoff away from the pit. With the water diversion measures in place, the contributing catchment to the Main Pit would be approximately 17.6Ha and the Intermediate Pit 21.2Ha.

3.3.4 Surface Water Pumping Systems

The water level in the Main Pit is to remain relatively static between RL58m AHD and RL59m AHD during the backfilling operation. This level is 1.5m to 0.5m below the Main Pit outlet concrete culvert which would suit a bank mounted self-priming end suction pump with a floating screened intake. The rising main to the WTP would be approximately 185m in length.

A pumping system to extract water from the Intermediate Pit and transfer to the WTP would require either a floating submersible or end suction pontoon pump. The pump would discharge to a designated rising main to convey water to the WTP approximately 700m away.

3.4 Groundwater Seepage Interception System

RGC has confirmed through numerical groundwater modelling that the water quality objectives in the EBFR are achievable by extracting contaminated groundwater from strategic locations across the site via a groundwater seepage interception system (SIS) over a period of 10 years. The 10-year simulation was performed with an extraction at sites next to the Main WRD, the Copper Heap Leach, the Old Tailings Stockpile, the former ore stockpile area and the northern perimeter of the Intermediate WRD. Extraction depths of between 20 and 30m has been shown to be optimal.

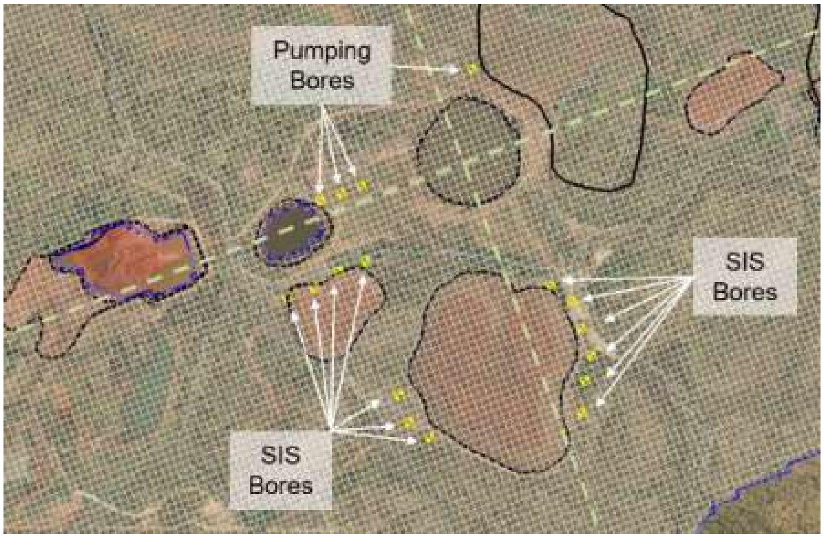


Figure 3 Strategic groundwater extraction locations (ref Figure 10-27 EIS)

The following groundwater extraction regime has been found to be optimal and will be catered for in the remediation treatment of the site:

- 13 x seepage interception system bores and 4 x recovery bores (4 in total) as shown in Figure 3. The maximum extraction rate is limited by the percolation rate of groundwater through the underlying strata
- An extraction rate of 1L/s in the dry season (May to October inclusive); and
- 2L/s in the wet season (November to April inclusive).
- Final hydrogeological test work during bore installation will confirm the location of the SIS bores.

3.4.1 Groundwater Pumping Systems

To transfer groundwater from the five groundwater bore clusters the following design constraints need to be catered for:

1. The five groundwater clusters each contain between 1 and 6 pump units.
2. The flowrate of each pump unit will need to vary between 1 and 2L/s to cater for dry and wet season flowrates.
3. The static lift between the groundwater and natural surface varies between 20 and 30m depending on the location of the borehole.
4. The bore hole locations are between 330 and 1,530m from the proposed WTP site
5. An optional surface water interception system could be incorporated adjacent to the borehole clusters to collect and transfer first flush flows to the WTP.

The ideal pumping arrangement would consist of a multistage borehole pump within each standpipe which extracts groundwater at a controlled rate and discharges to a common water tank local to each cluster. A variable frequency drive added to each borehole pump would enable dry and wet season flows to be managed with the one pump. A high efficiency end suction pump would transfer water directly from the tank to the WTP in a designated rising main.

4 Pre-Construction Drawdown

Prior to backfilling operations, it will be necessary to drawdown the Main and Intermediate Pits to provide adequate surge capacity for large stormwater events, and to create a hydraulic grade for contaminated groundwater towards the Intermediate Pit instead of the EBFR (RGC, November 2019). This pre-construction drawdown will be pumped untreated directly to the EBFR in the event that EBFR surface water flows are sufficient enough to dilute this pumped water to below LDWQOs. These drawdown levels, which are outlined in Section 3.3.2, must be maintained throughout construction.

As detailed in the Draft EIS (NT-DPIR, December 2019), while the current water quality in the Main and Intermediate Pits do not meet the Project LDWQOs, it is important to note the distinction that:

- The output from the WTP will match the LDWQO; and
- The LDWQOs within the Pits applies post-construction.

The water in the Main and Intermediate Pits currently flow to the EBFR therefore there will be no real change from current conditions when pumped out to achieve the required operating levels.

5 WTP Inflow Regime

5.1 Inflow Sequence

The WTP will need to process the following influent from a range of sources over the course of remediation. The following sequence is expected:

1. Activation of the Intermediate Pit WRD groundwater pumping network with a combined flow rate of 4L/s (dry season) to 8L/s (wet season).
2. Maintenance of the operating level in the Main Pit between RL58m AHD and RL59m AHD to account for the displacement caused by the backfilling of waste rock.
3. Activation of the complete groundwater pumping network with a combined flow rate of 17L/s (dry season) to 34L/s (wet season).
4. Activation of a surface seepage system integrated with the groundwater system (to be on standby with activation determined by the water quality results at the gauging station). The combined flowrate from both systems would not increase from a combined flow rate of 17L/s (dry season) to 34L/s (wet season).
5. Management of rainfall ingress into the Main Pit generating an average daily rate of 1L/s (dry season) to 13L/s (wet season).
6. Management of rainfall inflow into the Intermediate Pit generating an average daily rate of 1L/s (dry season) to 8L/s (wet season).
7. Management of groundwater recharge into the Intermediate Pit between 18L/s (dry season) to 31L/s (wet season) (Robertson GeoConsultants Inc, 2019).
8. Treatment of the Main Pit water to satisfy the LDWQO prior to placement of the final clean material cap (over the placed waste rock).
9. Operation of the groundwater and seepage interception system until such time as the proponent agrees with the Regulator to cease abstraction and treatment. 17L/s (dry season) to 34L/s (wet season) (Robertson GeoConsultants Inc, 2019).
10. Decommissioning of the groundwater pumping system and WTP, removal of equipment and remediation of the occupied site.

5.2 WTP Inflow & Outflow Rates

A comprehensive WTP will be required to treat the range of AMD affected surface water and groundwater for a period of 10 years. As the backfilling operation will take less than one third of a possible ten years treatment duration, it is proposed to selectively manage the inflow sources on site so as not to over design the WTP. The groundwater sources from the Intermediate Pit WRD will be the only inflow from the groundwater network to be treated during the backfilling operation. The remaining groundwater sources will be activated at the conclusion of backfilling.

5.2.1 WTP inflow sources

Table 3 and Table 4 summarise the approximate inflow rates to the WTP from the groundwater bores, seepage interception systems, groundwater recharge and surface water sources. The flow rates have been levelled over 24 hours and for the 5-month wet season and 7-month dry season. This is considered a reasonable estimate considering the large storage volumes involved.

All groundwater pumps are variable speed enabling a variation in extraction within any zone to respond to the sample bore monitoring results. The seepage interception system is designed to capture the first flush surface contaminants and will therefore only operate intermittently. The overall system is flexible but for water balance calculations it will operate within this range.

Table 3 WTP inflow from groundwater and SIS sources

Source	Dry season flow rate (L/s)	Wet season flow rate (L/s)
Groundwater and Seepage Interception Sources		
Main WRD (east), 6 groundwater bores	6	12
Main WRD (east), SIS sump pump	1-6 (with an equivalent reduction in groundwater cluster)	1-12 (with an equivalent reduction in groundwater cluster)
Main WRD (west), 3 groundwater bores	3	6
Main WRD (west), SIS sump pump contingency	1-3 (with an equivalent reduction in groundwater cluster)	1-6 (with an equivalent reduction in groundwater cluster)
Intermediate WRD (north), 4 groundwater bores	4	8
Intermediate WRD (north), SIS sump pump contingency	1-4 (with an equivalent reduction in groundwater cluster)	1-8 (with an equivalent reduction in groundwater cluster)
Heap Leach, three groundwater bores	3	6
Old tailings, one groundwater bore	1	2
Subtotal Groundwater & SIS	**Approximately 17L/s**	**Approximately 34L/s**

Runoff to each of the pits has been calculated based on the contributing catchment with diversion bunds in place. The evaporation calculations are based on the average of 7mm/day during the dry season and 6mm/day during the wet season on a lowered Pit water level which has a reduced surface area.

The groundwater recharge rates with a lowered water level were simulated by RGC (RGC, November 2019).

Runoff captured in the WSF sediment basins would be pumped to the WTP in a controlled manner and therefore could be delayed during heavy rain events. These rates have been based on an average during the construction period.

Table 4 Surface water & groundwater recharge rates to the WTP

WTP Input	Dry season flow rate (L/s)	Wet season flow rate (L/s)
Groundwater Ingress and Surface Water Sources		
Rainfall contribution to the Main Pit	1	13
Evaporation from the Main Pit	-7	-6
Rainfall contribution to the Intermediate Pit	1	8
Evaporation from the Intermediate Pit	-2	-2
Groundwater recharge into the Intermediate Pit during construction	18	31

WTP Input	Dry season flow rate (L/s)	Wet season flow rate (L/s)
Groundwater recharge into the Main Pit	0	0
Waste Storage Facility sediment basins	1	15
Subtotal Groundwater & SIS	**Approximately 12L/s**	**Approximately 59L/s**

As the WTP will operate on a 24-hour basis and the backfilling on an 8-hour day shift, the size of the treatment facility can be substantially reduced by the temporary storage of the displaced Main Pit water and treatment after hours. The magnitude of the WTP has been designed to facilitate a backfilling rate of 100L/s during the wet season. Table 5 summarises the available capacity for displaced water treatment during backfilling. A greater backfilling rate is possible during the dry season due to the absence of rain induced sources freeing up the spare capacity for Main Pit displacement.

Table 5 Backfilling rates

WTP Input	Dry season flow rate (L/s)	Wet season flow rate (L/s)
Displaced water during backfilling		
Estimated Main Pit water displacement rate = backfill rate (8-hour average duration)	Approximately 180 L/s	Approximately 100 L/s

5.2.2 WTP output sources

The WTP will require a treatment capacity of 100L/s operating on a 24-hour basis to accommodate the range of sources and achieve a day shift backfilling rate of 100L/s during the wet season. Table 6 summarises the output rates from the WTP.

Table 6 WTP output

WTP Output	Maximum dry season flow rate (L/s)	Maximum wet season flow rate (L/s)
WTP treatment rate		
High pH treatment stream	60L/s	60L/s
Neutral pH treatment stream	100L/s	100L/s

Treated water will be required for dust suppression and WSF construction during days where the prevailing weather will generate airborne droplets. Untreated Main Pit water will be used on the WRF on calm days to reduce the volume of water needed to be treated. Table 7 summarises the expected range of irrigation water demand during a day shift over the wet and dry seasons during the construction period. Surplus treated water would be irrigated to evaporate or discharged to the EBFR.

Table 7 Irrigation water demand

WTP Output	Dry season flow rate (L/s)	Wet season flow rate (L/s)
Displaced water during backfilling		
Minimum construction water for dust suppression	30	25
Maximum construction water for dust suppression	40	40

5.3 Main Pit Water Quality

The water quality in the Main Pit will vary during the backfilling operations from the disturbance of the chemocline and the placement of waste rock materials. To both reduce the load on the WTP and to provide an alkaline environment around the waste rock placement, an operational strategy will be implemented to blend finely crushed limestone with the waste rock material during the backfill operation. To further reduce the incidence of AMD release during the placement, a hydrated lime slurry would be on standby to dispense if the local pH falls below neutral.

5.3.1 Current Main Pit water quality

To achieve the starting operating level of RL58m AHD in the Main Pit approximately 188ML will need to be pumped from the Main Pit to the EBFR during the wet season and/or used for dust suppression and compaction of waste rock. Treatment of Main Pit water would commence when the backfilling operation commences.

Pit water quality profile testing results performed in July 2014 show a very homogeneous concentration of metals above the chemocline (40.9m) with a marked increase below (4m). Table 8 summarises the concentration of metals, non-metals and sulphates above and below the chemocline. Profile testing results in 2008 indicated the chemocline to be 8m thick indicating a thinning or settlement has occurred in the subsequent 6 years.

Table 8 Concentration of aqueous metals and soluble sulphates in the Main Pit

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Element	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
Above Chemo	3.7	0.7	13.5	8.6	0.95	0.7	0.076	0.069	0.043	0.032	0.024	<0.001	<0.001	<0.001	0.005
Chemo	177	13.2	953	487	209	1.55	7.48	5.090	3.2	7.93	1.750	0.005	0.008	0.004	1.36

Note: Highlighted cells indicate aqueous metal concentrations exceeding the LDWQO

Table 9 summarises the conductivity, pH, temperature, total dissolved solids, total suspended solids, density, sulphate concentration and turbidity of the water above and below the chemocline.

Table 9 Properties of the water in the Main Pit

Location	Conductivity µS/cm	pH	TDS mg/L	TSS mg/L	Turbidity FNU	Density kg/L	$CaSO_4$, $MgSO_4$, $NaSO_4$ mg/L
Above chemo	191	5.8	125	0	6	1.000	76.5
Chemo	8,400	4.1	5600	0	6 to 2249	1.007	7,930

Note: Highlighted cells indicate noncompliance with the LDWQO.

5.3.2 Main Pit Water Quality During Backfilling

The chemocline is estimated as 4m thick with a surface level at RL 19.92, 40.95m below the water surface and has a concentration of contaminants two to three magnitudes greater than the overlying water and a pH as low as 4.1. It is likely that this layer has thinned further since 2014 however this cannot be confirmed until updated profiling is complete. Disturbance of this layer during the backfilling may contaminate the homogeneous profile above.

Monitoring of water quality at the point of backfill material placement within the Main Pit shall be the responsibility of the Backfill Operations. Monitoring will be via water quality monitoring probes placed off the backfill material delivery system (barge/conveyor or similar) at multiple depths to monitor the changes to the pit lake water quality, proximal to the location of placement, throughout the backfilling operations. Changes to Pit lake water quality proximal to backfill placement will be managed by the Backfill Operations via a Trigger Action Response Plan (TARP) in the event of adverse water pH changes. The data will also be used by the WTP for operational purposes.

5.3.3 Main Pit quality prior to placing the cap

It is difficult to accurately predict the water quality within the Main Pit after placement of 0.06Mm^3 of sand and 1.85Mm^3 of waste rock during backfill. It is likely the water quality will exceed the LDWQOs and as such, will require treatment to ensure that the placement of the clean material cap over the waste rock will not entrain elevated contaminants. This will require the treatment of approximately 180ML of water to satisfy the LDWQO and retention of a sufficient depth of water over the waste rock to operate a barge and place the cap. A range of options to achieve this gaol have been provided in Section 9.

5.3.4 Intermediate Pit water quality to maintain the operating level

The water quality in the Intermediate Pit expresses a chemocline at a depth of 43.9 to 44.2m (RL 13.1m AHD). The most recent testing in 2014 indicates a more defined chemocline has developed over the six years since the testing results of 2008. The concentrations of most metals are up to two magnitudes greater in the chemocline apart from Cu, Al and Zn which actually have a lower concentration in the chemocline than in the water above (highlighted in yellow, Table 10). The Intermediate Pit underwent in-situ treatment with hydrated lime in 1985. This has had a pronounced and permanent effect on the concentration of these three metals which precipitate either completely or partially in the presence with lime at a pH of 6.5.

Table 10 Concentration of aqueous metals in the Intermediate Pit

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
mg/L	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
Above chemo	3.4	0.7	13.4	7.76	0.300	0.168	0.037	0.052	0.088	0.082	0.020	<0.001	0.001	0.001	0.004
Chemo	6.7 to 51.2	2.5 to 4	119 to 666	73 to 325	3.29 to 11.2	4.3 to 15	0.310 to 0.613	0.137 to 0.261	0.023 to 0.053	0.002 to 0.02	0.018 to 0.051	<0.001	<0.001	0.020 to 0.050	0.005 to 0.099

Note: The orange highlight indicates a concentration above the LDWQO, the green highlight indicates those metals with lower concentrations in the chemocline than the overlying water

Table 11 summarises the conductivity, pH, temperature, total dissolved solids, total suspended solids, density, turbidity and sulphate concentration of the water above and below the chemocline.

Table 11 Properties of the water and concentration of soluble salts in the Intermediate Pit

Location	Conductivity µS/cm	pH	TDS mg/L	TSS mg/L	Turbidity FNU	Density kg/L	Ca-, Mg-, Na-, K-SO_4 mg/L
Above chemo	180	6.4	116	0	1.5	1.000	65.6
Chemo	571 to 5299	5.8 to 6.6	372 to 3316	0	0.7 to 6.6	1.002	617 to 3130

Note: Highlighted cells indicate noncompliance with the LDWQO.

The chemocline is 44m below the water surface and is approximately 13.4m thick. It is proposed to lower the operating level by 8m to ensure the hydraulic profile of the surrounding groundwater drains to the pit rather than the EBFR. Extraction at the water surface would not disturb the chemocline.

There is a thermocline in the Intermediate Pit with the chemocline 1.5 degrees warmer than the overlying column of water. It is expected the chemocline acts like a thermal blanket to trap heat in from the summer temperatures. This would normally generate circulation, but the higher density chemocline would counteract the effect. In summary;

- **The concentration of aqueous metals in the Intermediate Pit are near equivalent to those in the Main Pit apart from Copper concentrations which are double**
- **The concentration of Copper and the pH exceed the LDWQOs.**
- **The concentration of Copper and Sulphates are likely to triple from groundwater recharge (Robertson GeoConsultants Inc, 2019)**
- **The Intermediate Pit water would pass through the low pH stream to target sulphates and copper, it could also serve to pH correct the high pH stream.**

5.4 Groundwater

RGC (RGC, November 2019) have identified five strategic locations from which groundwater is to be extracted and treated over the Rum Jungle site. These include:

1. Main WRD (East).
2. Main WRD (West).
3. Intermediate WRD (North).
4. Heap Leaching Area.
5. Old Tailings Stockpile Area.

In addition to the groundwater extraction, three surface sump wells are to be established at the sag point of the toe drain of the Main and Intermediate WRDs. The sumps are to intercept and capture first flush flows and transfer the solution to the treatment plant.

Figure 4 shows the recommended locations to extract groundwater over the Rum Jungle site. Groundwater modelling has confirmed that the extraction regime will need to persist for over 9.5 years before aqueous metal concentrations are considered safe for the downstream biology in the EBFR.

The monitoring of groundwater will continue during the extraction regime to provide guidance in deciding when and where to vary the extraction rates over the five zones to align with the modelled results.

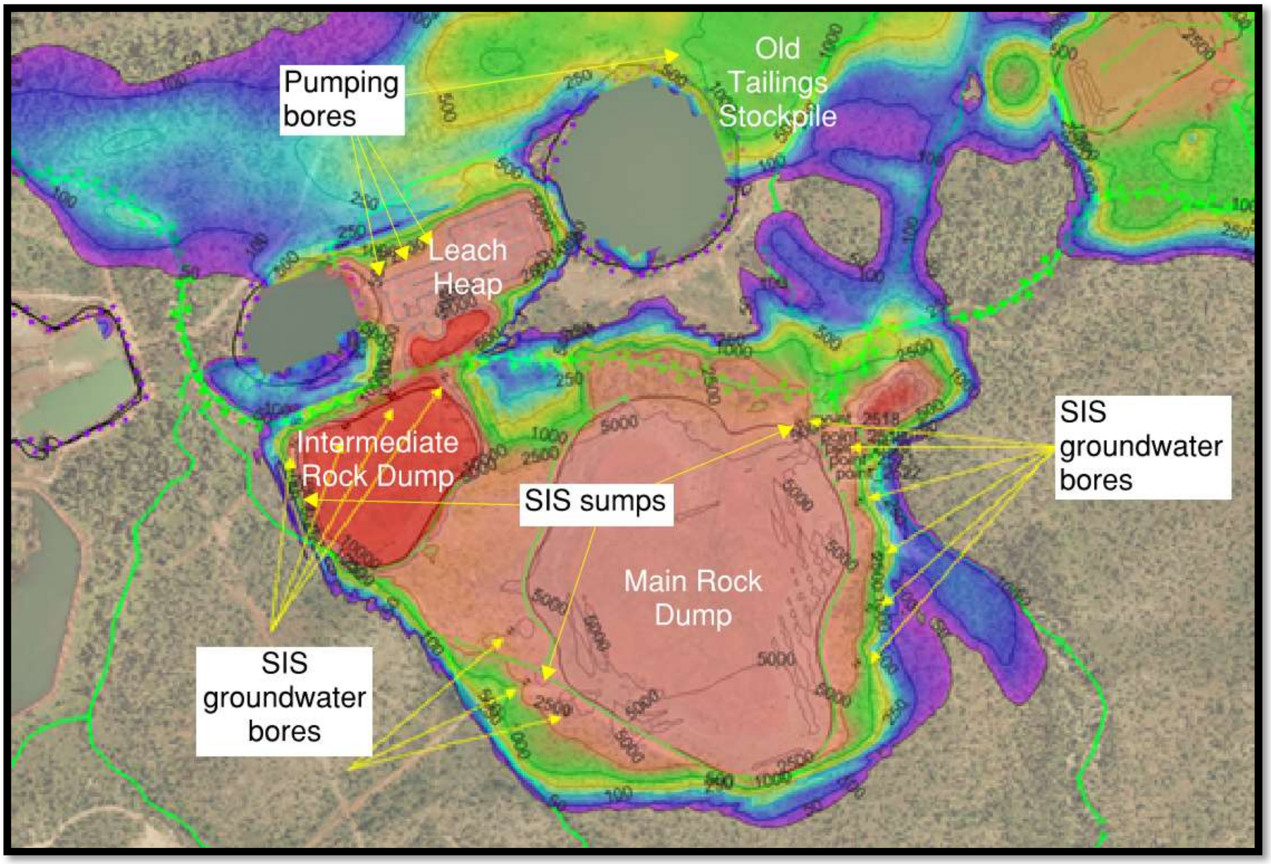


Figure 4 Location of groundwater and surface water extraction

5.4.1 Main WRD (West)

Table 12 summarises the closest monitoring bores to the extraction sites west of the Main WRD. The monitoring bores have been used as a proxy to the water quality expected from the groundwater from the three bores. In the absence of published data, a naming convention for the groundwater extraction bores has been established with the waste rock initials followed by a consecutive number.

Table 12 Closest borehole pump to the monitoring bores for the purpose of pump & treatment design

Extraction Borehole Pump[1]	Closest Monitoring Bore for Water Quality Estimation
Main WRD 1	RN025165, RN022084, RN029993
Main WRD 2	RN030001, RN030002
Main WRD 3	RN023061

[1] Refer to drawing 680.10421.PIP.D01 for bore reference

Table 13 summarises the mean concentrations of metals likely to be extracted from the Main WRD (West) bores.

Table 13 Concentration of aqueous metals in the groundwater from the Main WRD West, mean values

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Location	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
Main WRD (west)	49	8	3060	393	30.2	26.2	1.5	1.0	0.8	1.0	n.d	0.006	n.d	n.d	n.d

Note: The orange highlight indicates a concentration above the LDWQO. 'n.d.' indicates no data.

Table 14 summarises the conductivity, pH and sulphate concentration of the groundwater near Main WRD East.

Table 14 Properties of the groundwater from the Main WRD West (mean values)

Location	Conductivity µS/cm	pH	Ca-, Mg-, Na-, K-SO_4 mg/L
Main WRD (west)	14150	5.7	12773

Note: The orange highlighted cells indicate non-compliance with the LDWQO

5.4.2 Main WRD (East)

RGC (RGC, November 2019) have recommended six groundwater bores screened to a maximum depth of 30 m in the locations identified in Figure 5.

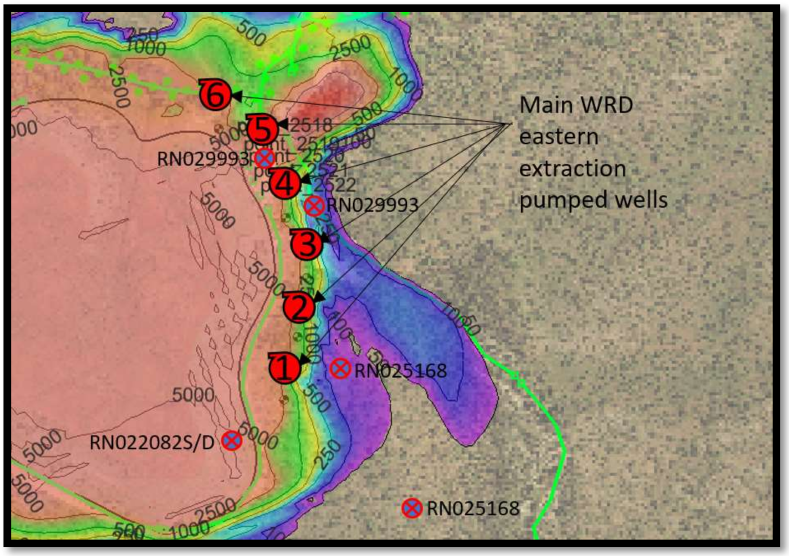


Figure 5 Main WRD (East) Monitoring Bore Locations

Table 15 summarises the closest monitoring bores to the extraction sites. The monitoring bores have been used as a proxy to the water quality expected from the six bores for design of the pumps and treatment plant. It is recommended the groundwater monitoring continue for the course of the remediation to verify if the desired improvements in water quality are being met.

Table 15 Closest borehole pump to the Monitoring Bores for the purpose of pump & treatment design

Extraction Borehole Pump[1]	Closest Monitoring Bore for Water Quality Estimation
Main WRD 4	RN02282S/D
Main WRD 5	RN02282S/D
Main WRD 6	RN022411
Main WRD 7	RN022411
Main WRD 8	RN029993
Main WRD 9	RN029993

[1] Refer to drawing 680.10421.PIP.D01 for bore reference

Table 16 summarises the mean concentrations of metals extracted from the Main WRD (East) bores.

Table 16 Concentration of aqueous metals in the groundwater from the Main WRD East, mean values

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Location	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
MRD (east)	n.d.	n.d.	442	72	8.19	3.2	2.81	2.46	2.25	11.49	3.12	4.00	5.00	n.d.	0.57

Note: The orange highlight indicates a concentration above the LDWQO. 'n.d.' indicates no data.

Table 17summarises the conductivity, pH and sulphate concentration of the groundwater.

Table 17 Properties of the groundwater from the Main WRD East (mean values)

Location	Conductivity µS/cm	pH	Ca-, Mg-, Na-, K-SO_4 mg/L
Main WRD (east)	3360	4.2	2060

Note: The orange highlighted cells indicate non-compliance with the LDWQO

5.4.3 Intermediate WRD

Table 18 summarises the closest monitoring bores to the extraction sites near the Intermediate WRD. The monitoring bores have been used as a proxy to the water quality expected from the groundwater from the four bores.

Table 18 Closest borehole pump to the monitoring bores for the purpose of pump & treatment design

Extraction Bore Hole Pump[1]	Closest Monitoring Bore for Water Quality Estimation
Intermediate WRD 1	RN023060
IWRD 2	MB10-06
IWRD 3	MB12-30S/D
IWRD 4	MB12-295D

[1] Refer to drawing 680.10421.PIP.D01 for bore reference

Table 19 summarises the mean concentrations of metals likely to be extracted from the Intermediate WRD bores.

Table 19 Concentration of aqueous metals in the groundwater from the Intermediate WRD, mean values

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Location	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
IWRD	n.d	n.d	2740	464	2.2	7.8	0.8	0.7	0.06	0.08	n.d	0.004	n.d	n.d	n.d

Note: The orange highlight indicates a concentration above the LDWQO. 'n.d.' indicates no data.

Table 20 summarises the conductivity, pH and sulphate concentration of the groundwater.

Table 20 Properties of the groundwater from the Intermediate WRD (mean values)

Location	Conductivity µS/cm	pH	Ca-, Mg-, Na-, K-SO_4 mg/L
IWRD	13664	4 - 6	11450

Note: The orange highlighted cells indicate non-compliance with the LDWQO

5.4.4 Heap Leach

Three locations have been identified to install a groundwater borehole pumps in the Heap Leach zone. These pumps would discharge to a common rising main and discharge groundwater from a depth of 30m to the balance tank within the WTP. Table 21 summarises the closest monitoring bores to the extraction sites in the Heap Leach area. The monitoring bores have been used as a proxy to the water quality expected from the groundwater from the three bores.

Table 21 Closest borehole pump to the monitoring bores for the purpose of pump & treatment design

Extraction Bore Hole Pump[1]	Closest Monitoring Bore for Water Quality Estimation
HL 1	MB10-11
HL 2	MB10-23
HL 3	MB10-24

[1] Refer to drawing 680.10421.PIP.D01 for bore reference

Table 13 summarises the mean concentrations of metals likely to be extracted from the Heap Leach bores.

Table 22 Concentration of aqueous metals in the groundwater from the Heap Leach, mean values

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Location	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
Heap Leach	n.d	n.d	n.d	n.d	379	127	116	93	442	5.3	195	n.d	0.04	n.d.	n.d

Note: The orange highlight indicates a concentration above the LDWQO. 'n.d.' indicates no data.

Table 23 summarises the conductivity, pH and sulphate concentration of the groundwater.

Table 23 Properties of the groundwater from the Heap Leach (mean values)

Location	Conductivity µS/cm	pH	Ca-, Mg-, Na-, K-SO_4 mg/L
Heap Leach	10390	4.6	9120

Note: The orange highlighted cells indicate non-compliance with the LDWQO

5.4.5 Old Tailings Area

One location has been identified to install a groundwater borehole pump on the western side of the Old Tailings Area. This pump would discharge directly groundwater from a depth of 30m to the groundwater balance tank within the water treatment pump. Table 24 summarises the closest monitoring bores to the extraction sites in the Old Tailing Area. The monitoring bores have been used as a proxy to the water quality expected from the groundwater from the bore.

Table 24 Closest borehole pump to the monitoring bores for the purpose of pump & treatment design

Extraction Bore Hole Pump[1]	Closest Monitoring Bore for Water Quality Estimation
OTD	RN022644, MB14-17S/D, MB-20S/D

[1] Refer to drawing 680.10421.PIP.D01 for bore reference

Table 25 summarises the mean concentrations of metals likely to be extracted from the Old Tailings bore.

Table 25 Concentration of aqueous metals in the groundwater from the Old Tailings Dam, mean values

Family	Alkali metals (mg/L)		Alkaline earth metals (mg/L)		Transition metals (mg/L)					Poor metals (mg/L)				Nonmetal (mg/L)	Actinoid (mg/L)
Location	Na	K	Mg	Ca	Mn	Fe	Co	Ni	Cu	Al	Zn	Cd	Pb	As	U
OTD	18	1	172	141	8.2	0.06	18.4	11.7	52.7	1.7	n.d.	0.02	n.d.	n.d.	

Note: The orange highlight indicates a concentration above the LDWQO. ‘n.d.’ indicates no data.

Table 26 summarises the conductivity, pH and sulphate concentration of the groundwater.

Table 26 Properties of the groundwater from the Old Tailings Dam (mean values)

Location	Conductivity µS/cm	pH	Ca-, Mg-, Na-, K-SO_4 mg/L
OTD	2178	4.8	1300

Note: The orange highlighted cells indicate non-compliance with the LDWQO

6 Basis of Treatment Design

6.1 Physical Process Requirements

The treatment technology has been developed in response to the following site conditions and constraints:

1. Has the capability to process a variable but low flowrate of highly concentrated aqueous metals with a pH down to 4.2 from groundwater sources blended with displaced pit water with an expected pH as low as 5;
2. Has the capability to process a variable, highly contaminated groundwater flow which varies from approximately 34L/s in the wet season to 17L/s in the dry season. This supply is to be processed for a period of 10 years;
3. Is constructed of materials which can withstand a pH of 4. These conditions would rapidly corrode mild steel and low-grade stainless steel;
4. Be modular and temporary in construction with components which are readily available ‘off the shelf’;
5. Requires chemicals which are readily available, cost effective and can be managed with minimal OHS requirements;

6. Produces a water quality which satisfies the LDWQOs; and
7. Is proven technology.

6.2 Chemical Process Requirements

The concentration of metals in the groundwater exceed those in the surface water by one to two magnitudes. The concentration of metals within the waste rock will be buffered by the addition of crushed limestone and precipitated by the addition of hydrated lime in the Main Pit during the backfilling operation. The volumes extracted from the pits are two to three times those from the groundwater bores. The following conditions need to be catered for to remove the aqueous metals.

6.2.1 Chemical Processes

Aqueous heavy metals precipitate in the presence of hydroxide ions. The formation of metal hydroxides is most efficient at a range of pH's for different metals and different concentrations. Some metals are amphoteric and re-solubilise if the pH increases or decreases from the optimum precipitation valve such as Zn, Cr, Cu, Ni, Cd and Pb. The following graphs are key to identifying the optimal pH to precipitate hydroxide metals found at Rum Jungle.

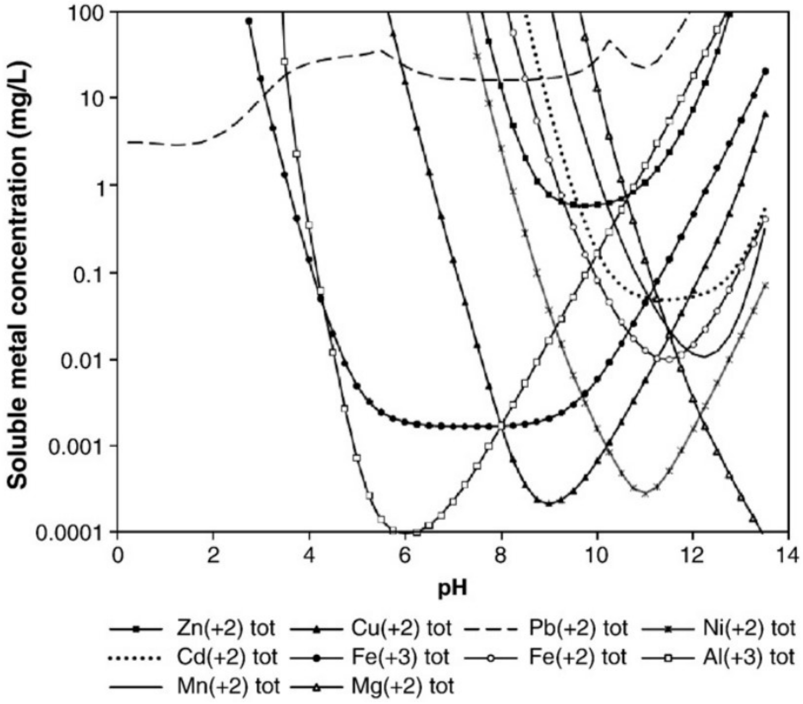


Figure 6 Efficiency of hydroxide precipitation with varying pH (Lewis, 2010)

Figure 6 indicates that the precipitation of Cu hydroxides to satisfy the LDWQO will require a pH of 7.2, whereas precipitation of Mn will require a pH of 10.

The basic treatment method will be to control the pH, oxidise, allow time to react and force settle the metal hydroxides with the aid of polymers on a clarifier. A proportion of the sludge would be recirculated to enhance the sludge settlement process. Waste sludge would either be released with the waste rock to aid settlement of metals, dewatered and buried on site or pumped to Brown's treatment facility for ore processing.

Figure 7, Figure 8 and Figure 9show the aqueous concentration of metals versus pH based on experiments carried out by (Balladares et al., 2018).

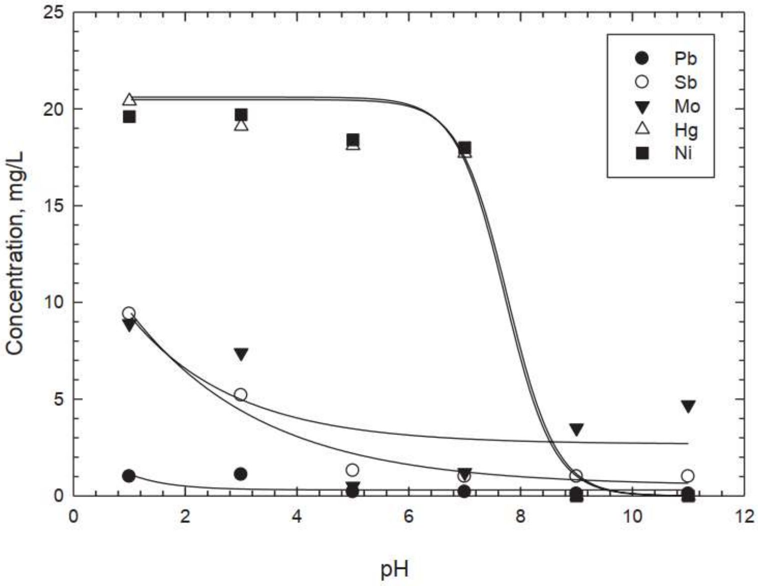


Figure 7 Effect of pH on precipitation of Pb, Mo and Ni (Balladares, 2018)

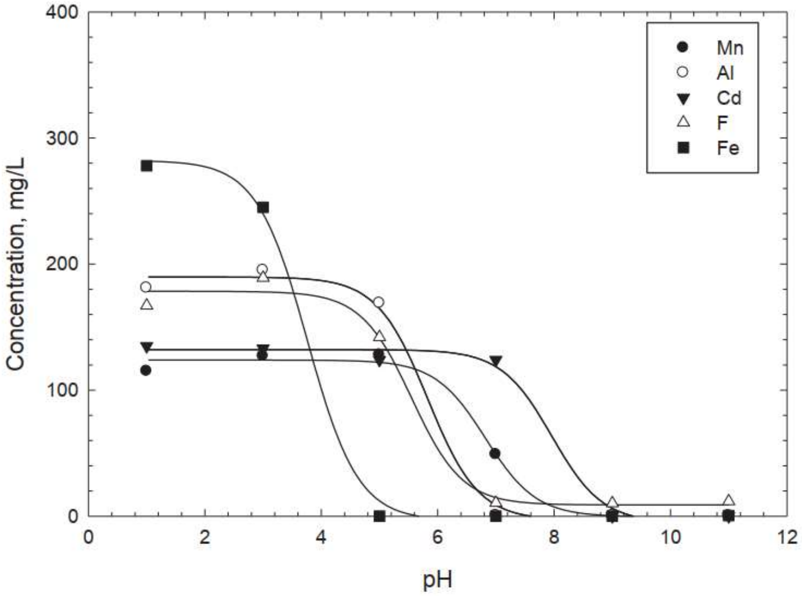


Figure 8 Effect of pH on precipitation of Mn, Al, Cd and Fe (Balladares, 2018)

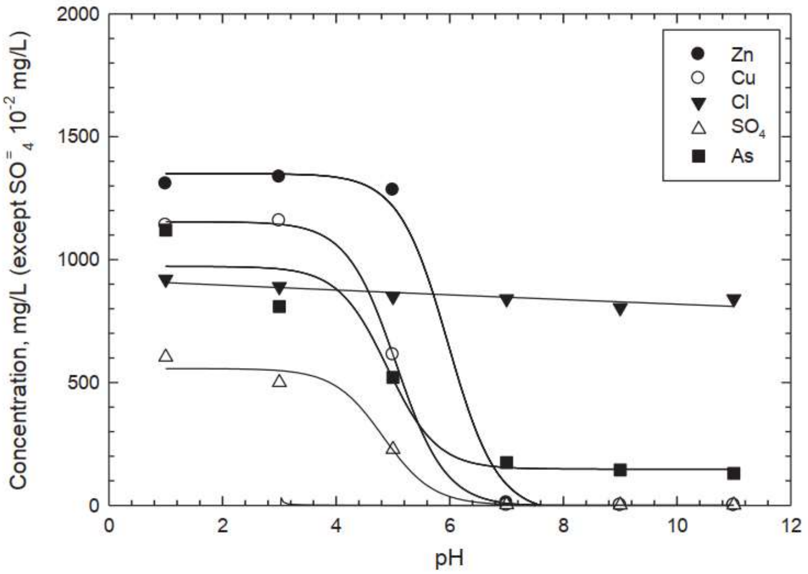


Figure 9 Effect of pH on precipitation of Zn, Cu, As and SO_4 (Balladares, 2018)

Table 27 summarises the ideal pH to precipitate the metals and sulphates encountered at Rum Jungle.

Table 27 Ideal pH to precipitate metals from the range of sources at the Rum Jungle site

Source	SO4	Mn	Fe^{2+}	Co	Ni	Cu	Al	Zn	Cd	Pb	As
Main Pit	>7	>9	>7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Int. Pit	>7	n/a	n/a	n/a	n/a	7.2 - 9	n/a	n/a	n/a	n/a	n/a
Ground	>7	9.2	9	8.1 - 9.6	9.2 - 9.4	7.2 - 9	5.2	8.3 – 8.5	9.7	9 - 10	>7

6.3 Remediation High Level Water Balance

To define the influent quality, quantity and sequence it was necessary to study the water balance holistically taking into consideration the backfill rate, groundwater recharge into the Intermediate Pit, rainfall, evaporation, the waste storage facility sediment basin return, Intermediate Pit WRD groundwater contribution, the contaminants contained within each source over the course of the remediation. The following sections outline the expected remediation and treatment sequence.

6.3.1 Year 1 wet season – Achieving pit operating levels & activating Intermediate Pit WRD groundwater bores

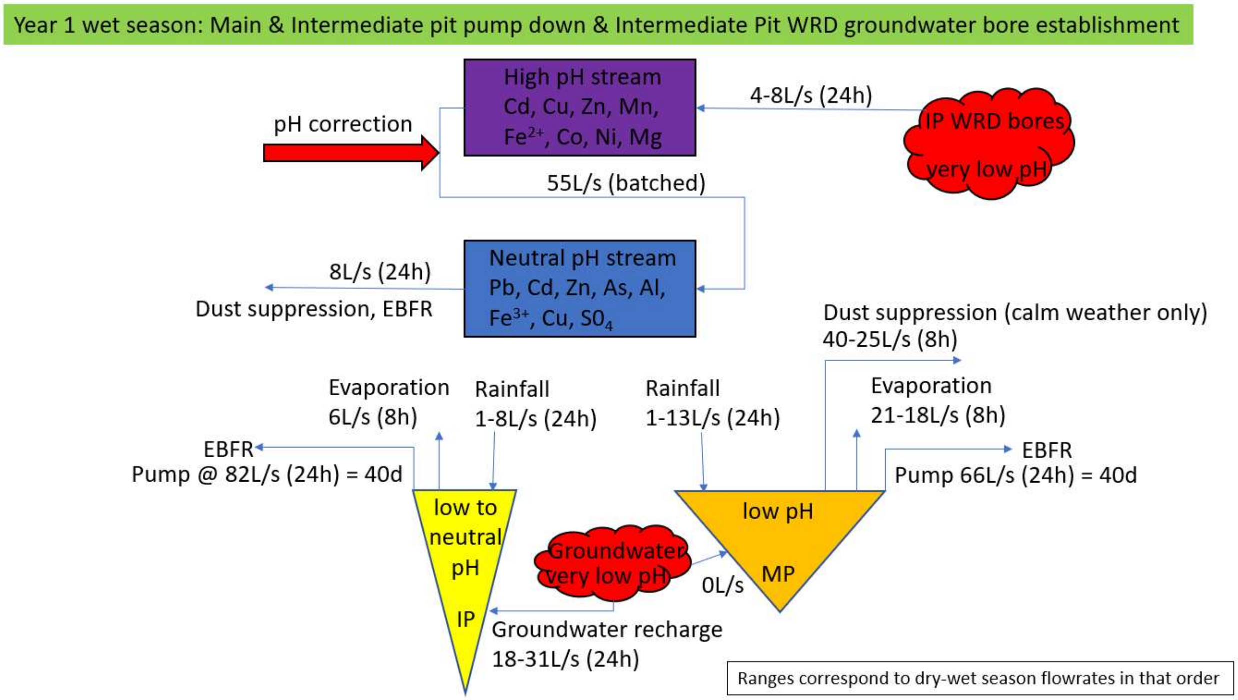


Figure 10 Year 1 WTP arrangement

During pre-construction, a total of approximately 422ML of pit water will need to be removed to achieve the operating freeboard in both pits. Treatment requirements of the pit waters are negated by releasing this water during the wet season as this has been the 'natural' process for nearly 50 years. During this period the Intermediate Pit WRD groundwater bores would be established and the core of the southern groundwater system established encompassing; a groundwater balance tank, a groundwater transfer pump and the rising main to the WTP.

The four Intermediate WRD groundwater bores would each operate at a rate of approximately 2L/s during this period with flows accumulating in the groundwater balance tank located northeast of the Main WRD. When a pre-set level is reached in this balance tank, flows would be transferred at the ultimate groundwater design transfer flow of 26L/s to the high pH stream balance tank for batched treatment.

6.3.2 Years 2 to 4 – Main Pit backfill with Intermediate Pit WRD bores operational

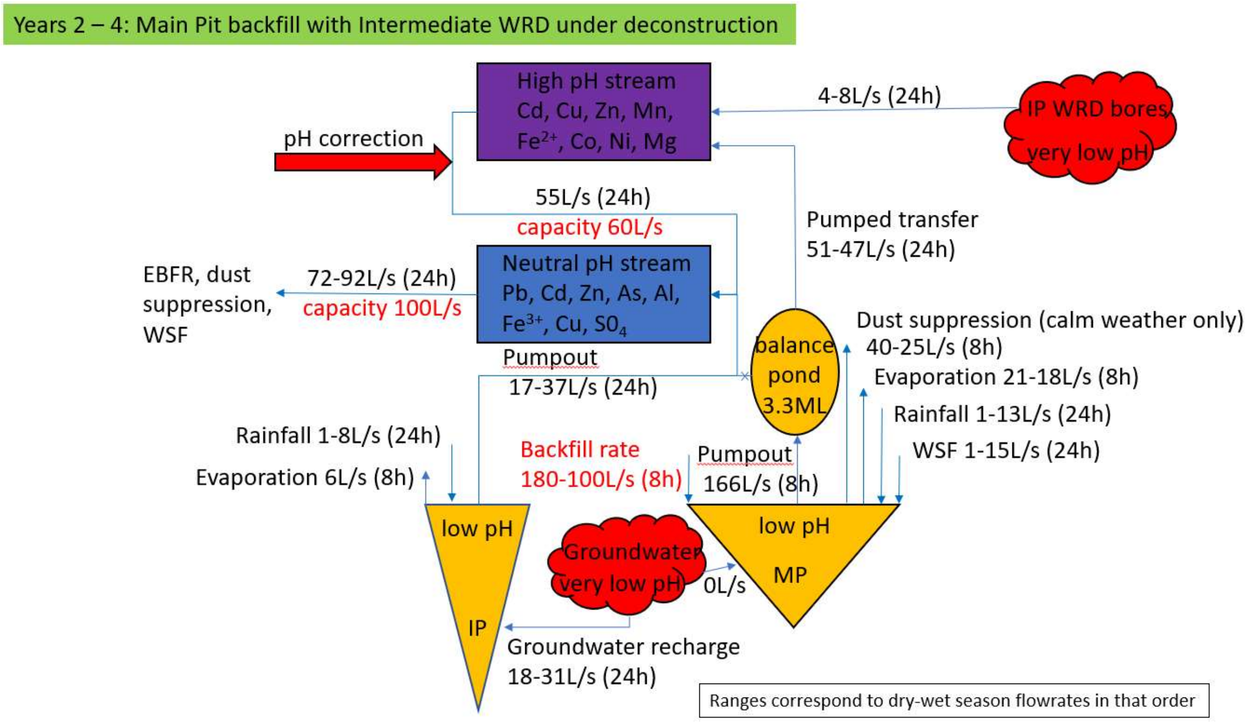


Figure 11 Years 2 to 4 WTP arrangement

The following two to three years will involve backfilling the Main Pit with a waste rock/limestone blend and hydrated lime when required. The backfilling operation will involve waste rock placement over the existing tailings through the water column via a floating barge and conveyor system. The barge will be anchored to the pit crest at several locations. A batch plant and pump will be located and controlled from a nearby laydown area and compound. The purpose of this batch plant is to deliver a sufficient quantity of limestone to the waste rock stream to neutralise existing acidity and provide an alkaline environment when placed. The material supply to the barge will be supported by buoyancy aids (NT-DPIR, December 2019).

The maintenance of the operating water level in the Main Pit is considered critical so a large extraction pump with a duty of approximately 166L/s @ 15m head (42kW) is required to transfer the displaced water to a storage pond during day shift. A backfill rate of approximately 100L/s during the wet season and approximately 180L/s during the dry season is therefore made possible by banking water in a 3.3ML balance pond and treating after hours.

In addition to displaced water from the Main Pit, the WTP will need to process groundwater from the Intermediate WRD bores, local runoff to each Pit, pumped discharge from the WSF and groundwater recharge into the Intermediate Pit (as the operating water level is well below the surrounding groundwater level). The Main Pit lake will essentially be used as large raw water pond for holding contaminated effluents from waste rock, site runoff, seepages, and WSF sedimentation ponds.

Pumping the pit lake water to a treatment plant prior to discharge will be the most efficient and economical option at Rum Jungle, particularly because there are other sources that require treatment on the site (Aubé, B., 2009)

To minimise groundwater leaching to the EBFR in the vicinity of the Intermediate Pit the water level is to be artificially lowered to between RL49m and RL50m AHD. Levels lower than RL49m AHD will generate excessive groundwater recharge into the Intermediate Pit. The flow rate of the surface mounted pumping system is to match the groundwater recharge and rainfall and will vary between approximately 17 and 37L/s through the seasons. A radar level sensor mounted on an RHS and cast into the bank and overhanging the water surface at RL 51 will monitor the water level and control the pumping rate to the WTP. To prevent instabilities in the readings the radar should shoot into a UV resistant pipe (ABS, steel, HDPE) which projects into the water to dissipate wave action. Hydrologic modelling has estimated that a 1% AEP flood will raise the Intermediate Pit water level by approximately 0.8m which will take 6 days of pumping at this rate to return to the operating water level range.

The water balance diagram in Figure 11 identifies both Main Pit water and groundwater entering the high pH stream which combines with the Intermediate Pit water in the neutral pH stream. Metals that precipitate at high pH are below the LDWQO in the Intermediate Pit water and do not need to pass through both streams. A cross connection is to be provided to the high pH stream if this situation were to change as a result if the groundwater recharge.

As the flow rates from the Intermediate Pit to the WTP are significantly lower than the pumping rates from the Main Pit, it was considered unnecessary to provide a balance tank for the Intermediate Pit water and operate the pumping station during day shift. Instead a pontoon style pumping station which has the capacity to operate 24/7 remotely using a duty standby pumping arrangement and controlled by the level in the Intermediate Pit is recommended.

6.3.3 Year 5 – Main Pit capped

Prior to the placing of the clean material cap over the waste rock, the water quality in the Main Pit will need to satisfy the LDWQOs. The adopted process would be open to the Contractor’s discretion as long as the discharge constraints at gauging station GS8150200 are met and the water quality in the Main Pit satisfies the LDWQO before the cap is placed.

The quality of water in the remaining 3m may not require a high pH treatment and therefore a connection directly to the neutral pH stream would enable a treatment rate of 100L/s with direct transfer to the Intermediate Pit.

The water balance schematic in Figure 12 is based on ceasing pumping from the Intermediate Pit and allowing it to naturally refill from rainfall and groundwater recharge. It also indicates the treated water from the Main Pit could be used to refill the Intermediate Pit. The remaining 3m in the Main Pt would raise the Intermediate Pit water level by 6.5m. This by no means the required option to implement. Other options have been identified in section 9.2.

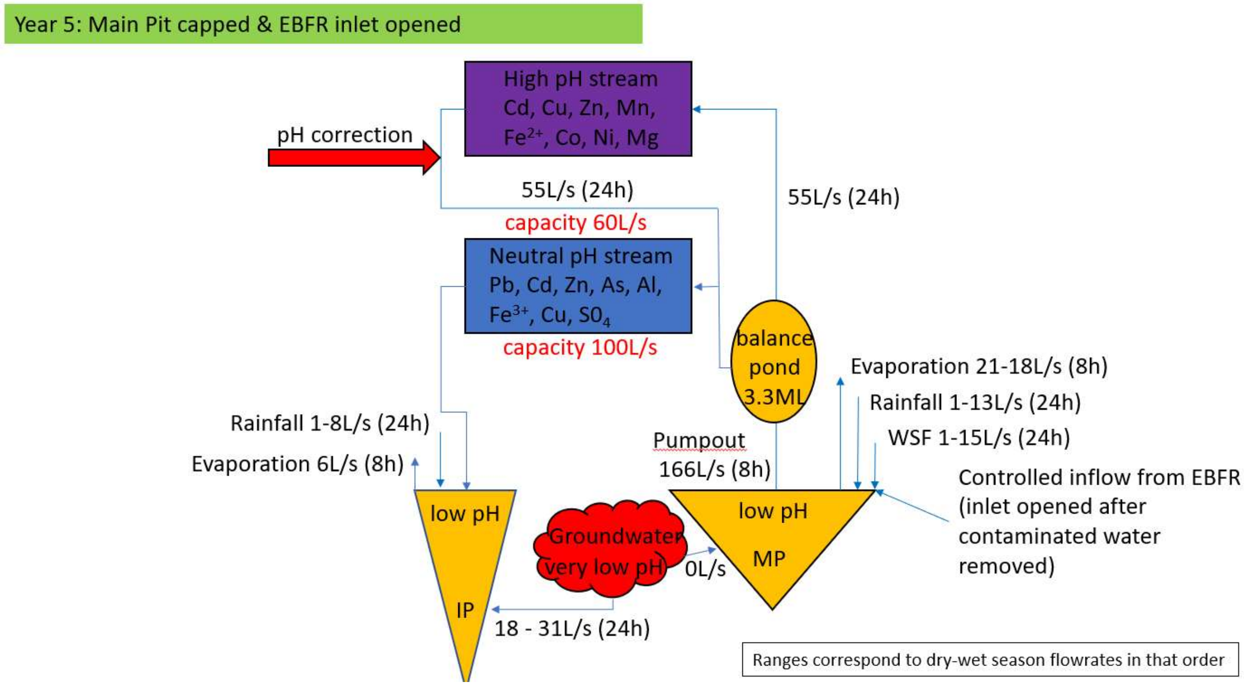


Figure 12 Year 5 WTP arrangement

6.3.4 Years 5 to 10 – Pits open to the EBFR, site wide groundwater network established

Following capping of the waste material in the Main Pit, the final landform to mimic the original flow path of the EBFR would be implemented. The design has focused on minimising erosion to enable vegetation to establish, prevent excessive siltation of the Pits and to provide a passage suitable for native fish to traverse upstream.

The remaining groundwater network would be established during the landform transformation. Groundwater bores from the east and west of the Main Pit, the Heap Leach and Old Tailings zones would be established, and groundwater treated and released to the Intermediate Pit. As the groundwater has a range of metals, a two-stage high density system would be maintained. The WTP would have the capacity to increase the groundwater treatment rate if required or components within the WTP could be decommissioned.

The borewater pumps are VSD enabling select borefield clusters to be increased or decreased if and when required. The groundwater quality would need to be continually monitored to ensure the groundwater improvement is tracking towards the simulated output. The groundwater monitoring will drive the operation of the groundwater pumping network. Figure 13 shows the process stream with the treated water discharged to the Intermediate Pit and overflow to the EBFR.

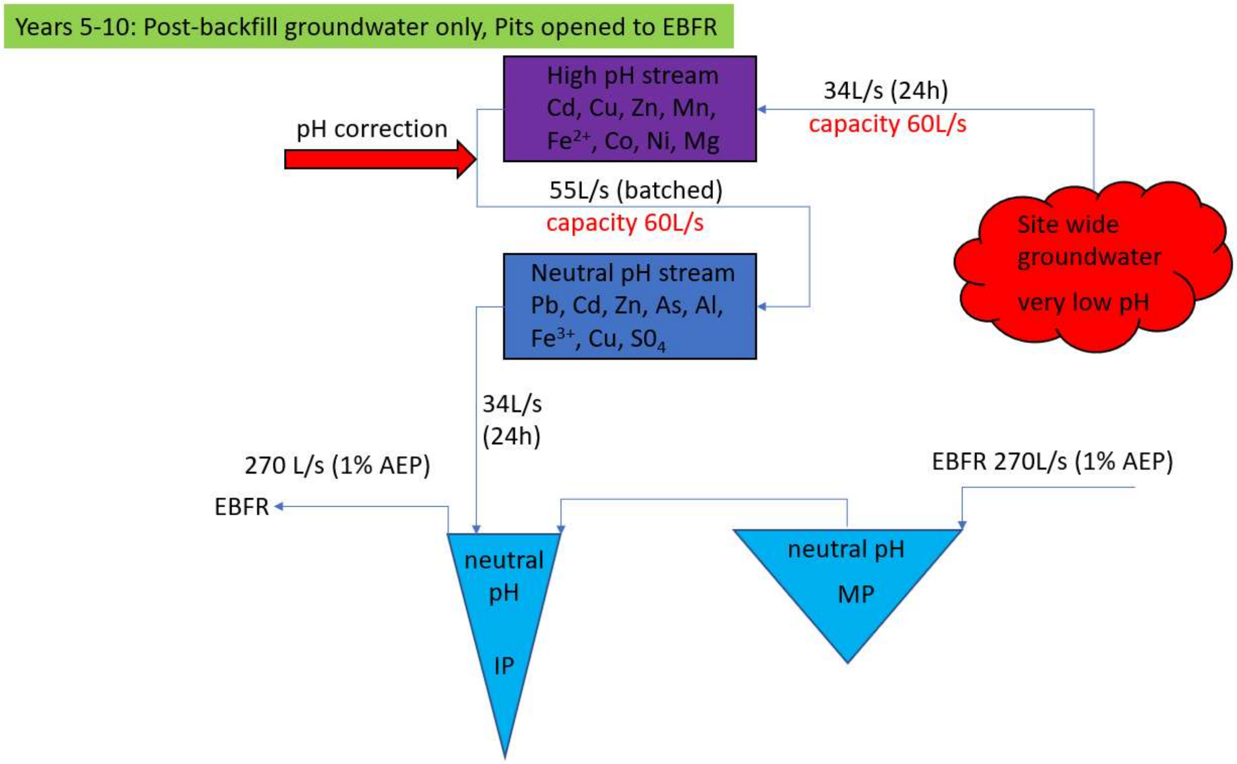


Figure 13 Years 5-10 WTP arrangement

6.3.5 Year 6 and year 10 – Decommissioning

After the backfilling of the Main Pit is complete, the throughput of the WTP may be reduced to treat just the groundwater. Partial decommissioning of the WTP could take place in year 6 in conjunction with the overall project related infrastructure. The decision to reduce the operational capacity of the WTP at this point will depend of the performance of the groundwater extraction system in reducing groundwater contamination. A WTP capacity of 60L/s may be retained in order to ramp up the groundwater treatment regime to achieve the desired goal. The complete infrastructure may therefore be retained. If partial decommissioning of the WTP were to take place, the pond liners and associated pipework of the two storage ponds would be removed and the embankments levelled. The groundwater SIS infrastructure, the core of the WTP infrastructure and an access road for chemical deliveries would remain in place until such time as the proponent agrees with the Regulator to cease abstraction and treatment.

7 The Water Treatment Process

7.1 Water Treatment Objectives

The WTP is required to achieve the LDWQOs (Section 2) for treated water discharged to the EBFR. Any exceedances discharged to the EBFR will be reported upon in accordance with the requirements of the waste discharge licence. Reporting will involve a notification to the NT EPA and all exceedances will be documented in an annual Monitoring Report (NT-DPIR, December 2019).

7.1.1 Water Quality Monitoring

The Operator would be required to:

(1) monitor inflows to the water treatment system during pit backfilling, including flows of displaced pit water and the quality of groundwater pumped from recovery bores.

(2) monitor treated water (flows and daily composite for water quality) where controlled discharge to the EBFR is authorised.

7.2 Reference WTP Process Design

The WTP is an integral part in the overall water management of groundwater, pit water levels, WSF runoff, local catchment runoff, dust suppression and controlled release to the EBFR. As a result, the WTP must be adaptable to service the water management phases of the project listed above. A High-Density Sludge (HDS) two-staged 'Geco' hydroxide precipitation with oxidation, Ion exchange and Greensands/DMI65 catalytic filtration media water treatment process has been proposed to satisfy the LDWQO for the range and blending of influents. The process subjects the influent to a range of pH streams with aeration, flocculation, clarification, pH correction, recirculation of clarified sludge (Aubé, B., & Zinck, J., 2003) and final polishing through ion exchange and catalytic filtration.

The 'Geco' HDS process uses slightly less lime for neutralisation than a standard HDS as it uses residual lime, magnesium hydroxide and particularly calcium carbonate formed in the process to partially neutralise the low pH water in the first reactor (refer Figure 14). Some of the calcium carbonate and magnesium is re-precipitated in the second reactor, but the total remaining alkalinity in the sludge is lower than for a standard HDS process. This means that the 'Geco' HDS process would produce a sludge with a lower alkalinity. A standard HDS produces a more stable sludge but as the raw water contains lower concentrations of Zn, Ni, and Cd than Fe, the sludge stability will not be significantly affected. As the 'Geco' Process does not have a sludge/lime rapid mix tank it is more cost effective. The 'Geco' HDS process has been shown to produce sludges as high as 30% which can be further increased by adding more lime which also improves the stability (Aubé, B., & Zinck, J., 2003). The consistency of the sludge should be investigated before investing in a centrifuge to dewater. A polishing phase before release ensures the LDWQO can be met. Table 28 summarises the expected treatment capacity for each analyte.

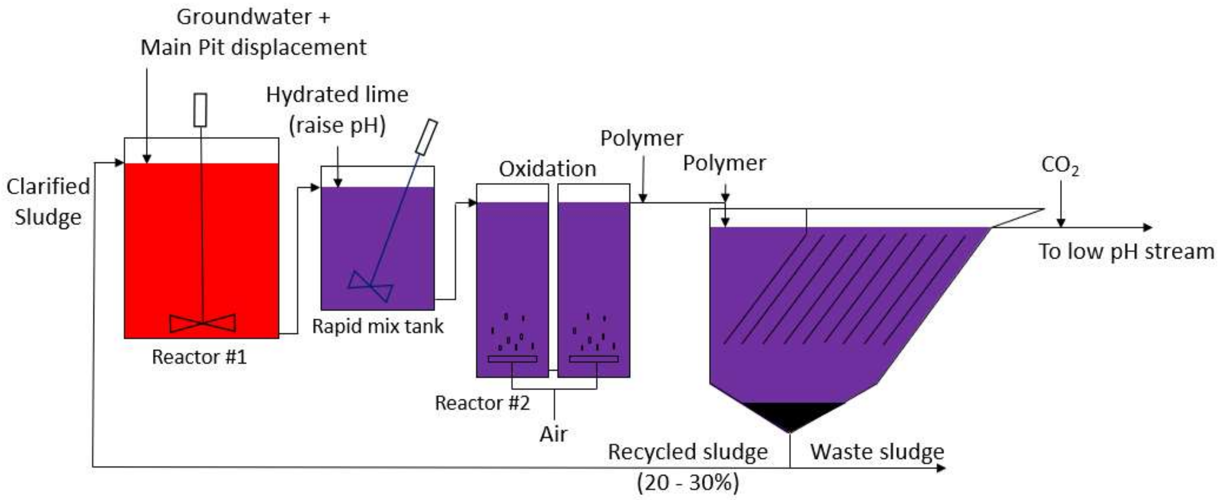
Table 28 Treatment Capability

Analyte	Project LDWQOs (mg/L) (Hydrobiology, 2016)	Geco HDS process removal capability (mg/L)	Ion exchange + Greensands/DMI65
Arsenic	0.013	Co-precipitated with Fe & Al	0.003
Aluminium	0.236	0.0009	Not required
Cadmium	0.0002	0.8	0.0001
Cobalt	0.089	0.0002	Not required
Copper	0.060	0.0004	Not required
Iron (2+ and 3+)	0.300	0.002	Not required

Analyte	Project LDWQOs (mg/L) (Hydrobiology, 2016)	Geco HDS process removal capability (mg/L)	Ion exchange + Greensands/DMI65
Manganese	0.759	7	0.1
Nickel	0.130	0.002	Not required
Magnesium	86.6	12	2
Lead	0.003	10	0.001
Zinc	0.210	8	0.04
EC (µS/cm)	2,985	<3000	<3000
Sulphates	1,192	1000-2000*	1000-2000*
pH	7-8.5	7.6	7.6

*When sulphate concentration exceeds 10,000 mg/L the treated water may have slightly elevated levels. It is recommended the water pass through the Intermediate Pit before discharging to the EBFR

Essentially, individual units would be 'plug and play' and would be rudimentarily connected to one another with either pumps discharging process water pipes over the wall of the downstream tank to eliminate non return valves and provide a starting head or connected via a gravity pipe at the TWL. Pipes should generally be HDPE or ABS. Where pipe integrity is required for in line mixing the pipe should be 316SS. The schematic in Figure 14 details the process streams and the subsequent sections in this report summarise the design and process of the individual units.



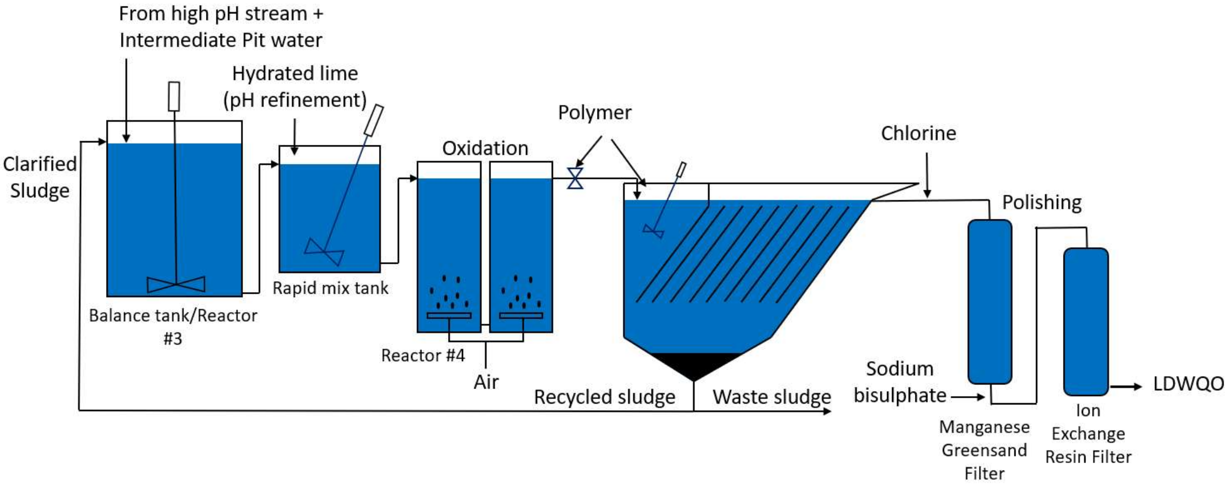


Figure 14 WTP process schematic, high and neutral pH 'Geco' HDS process with polishing

7.3 Balance/ partial dissolution tank

A balance tank on both the low and high pH streams are required to provide a minimum of 30 minutes blending and contact time between the various streams of AMD and recirculated sludge. Approximately 20% of the clarified sludge is to be recycled to this tank (refer Figure 14) where it is contacted directly with groundwater, displaced water from backfilling of the Main Pit, waste storage facility collected runoff, Heap Leach and Intermediate WRD seepage to the Intermediate Pit. The tank may be galvanised steel lined with EPDM rubber or reinforced concrete to withstand pH 3.7 (when groundwater is treated alone).

A tank stirrer is required to prevent the settlement of solids and precipitates in the tank. All pipework and valving are to be 316 SS and/or HDPE. The following tank sizes and slow stirrer mixers sizes are required:

(1) 150kL with a 30kW mixer on the high pH stream

(2) 200kL with an 40kW mixer on the neutral pH stream

The incoming pipework is to pass over the top of the tank to prevent avertedly siphoning the tank if a pipe were severed or disconnected downstream of the supply pump check valves. A DN250 overflow pipe to the Main Pit balance pond should be provided as a safety measure if the level switch fails to cut off the supply pumps. The tank does not require a lid. A DN355 flange at the floor of the tank is to be provided. A resilient seated gate valve with fusion bonded epoxy coating is to be provided at the outlet.

A pH probe in the tank is required to assist Operators in pre-empting the lime pace dosing rate downstream. A low-level switch in the tank inhibits operation of the lime transfer pumps and a high-level switch inhibits the operation of the pond 3 pump.

7.3.1 Pipework between Balance Tank & Rapid Mix Tank (paced pumping)

In order to convert the lime batching process into a continuous flow for the downstream oxidation process, a bank of three Rapid Mix Tanks (RMT) are required. A single DN355 HDPE outlet pipe or larger from the balance tank is to supply a DN355 HDPE suction header pipe perpendicular to the outlet pipe. The suction header branches into three parallel lines each containing an inline or end suction VSD pump in series with a magnetic flow meter. The suction main is to be DN355 HDPE PN10 and the delivery main DN280 HDPE PN10. The pumps duties are approximately 100L/s at 4m head but have a suction head which varies between 0.5m to 3.6m. The pumps are to be paced with the in line magnetic flow meter to deliver a constant 100L/s. The pumps are to be made of materials to withstand a pH of 4. The pumps are to be interlocked to a low-level switch in the tank to inhibit operation if the water level if the tank reaches the bottom water level.

A Fusion Bonded Epoxy (FBE) lined gate, ball or plug valve are to be installed either side of the pumps with an equivalent diameter to the suction and delivery pipes. 200mm of straight pipe is to be provided between the suction side of the pump and the valve. 10 straight diameters are to be provided after the delivery valve and before the magflow meter. 5 straight diameters are to be provided after the magflow meter and before any bend. The pipes are to discharge over the top of the lime RMT's and discharge at least 300mm above the active water level.

All three pumps are to be interlocked to prevent out of sequence operation. The sequence of pumping shall be three minutes pump 1 operation until the high level switch in RMT 1 trips pump 1, followed by two minutes delay until pump 2 is activated and fills RMT 2 until the high level switch in the RMT 2 trips pump 2, followed by two minutes delay until pump 3 activates and fills RMT3 until the high level switch in the RMT 3 trips pump 3, and then the cycle is repeated.

7.4 Lime Slurry Mixing

Hydrated lime is the preferred hydroxide producing chemical due to its relative safe handling and cost effectiveness. Hydrated lime is batched with treated water to form a slake. The treated water is sourced from the treated water sump (S1), refer drawing 680.10421.WTP.D02A.

A package lime slurry mixer is required with a processing capacity of 450kg/h. This estimation is based on the lime consumption when operating with the total groundwater network or during the backfilling operation with the Intermediate Pit WRD groundwater combined. Based on this demand, a 7-day site storage capacity of 75 tonnes is recommended. In addition, roadside space has been provided for a tanker dog to replenish this volume if a delivery to the site is delayed. The bulk storage bin is to include a level indicator based on the weight of product. A low-level alarm will alert the operator to dispense the contents of the truck dog.

An intermittent hopper is required which contains half a day's lime storage or 5 tonnes. The design of the hopper is to minimise arching and hanging up of lime. Compressed air and vibrators are required to prevent the arching. Two of the sides in the hopper should have sides steeper than 70 degrees and the remaining two sides 80 degrees. Volumetric feeders are required under the hoppers with a 20 to 1 adjustment.

A duty standby lime slurry storage tank with a capacity of 3kL and dosing pump which is controlled by the pH in the lime rapid mix tanks. Each tank is to include an agitator with a minimum G value of $500s^{-1}$. Lime slurry should be mixed at approximately 15%wt/v which is to be adjusted on site to suit the influent characteristics. Each lime slurry storage tank is to have an ejector with a capacity of 5kL/h. Two injection lances are to be provided into the top of each RMT.

Lime delivery pipe to the lime bin is to be galvanised steel schedule 80 or schedule 80 uPVC. The velocity is to exceed 3m/s to prevent build-up. Lime slurry pipes are to be clear flexible reinforced PVC so any caking can be dislodged, and the material will withstand HCl.

7.4.1 Lime Rapid Mix Tank (RMT)

Adjusting the pH in the RMT will require a skilled Operator to select the optimal pH to precipitate a range of hydroxide metals present in the blended influent to satisfy the LDWQO. The process has two pH streams to capture those metals which re-solubilise outside the optimal precipitation range. The process will be such that this pH is adjustable via the SCADA.

The desired pH level for each stream will be;

1. High pH stream - adjustable between pH 9 and 10.5
2. Low pH stream - adjustable between pH 6.5 and 8

Hydrated or quicklime is to be mixed in the tanks. The required volume of the tanks and the size of the rapid mixers are to be;

1. High pH stream – 20kL with a minimum 20kW rapid mixer
2. Low pH stream – 30kL with a minimum 30kW rapid mixer

This vessel must be made of 316 SS or epoxy lined concrete or HDPE or fibreglass because of the corrosive nature of the untreated mine water being put into the tank. The mixing blades and shaft should be 3l6SS or rubber covered mild steel.

The tanks are to be dosed with lime above the TWL. The three tanks are to batch in sequence. Three minutes has been allowed for to fill each tank, two minutes to pH correct and five minutes rapid mix time before discharging to the aeration tank downstream. When decanting the mixing is to continue until the vortex depth is reached. The control is such that when one tank is filling the next is mixing and the third is discharging and so on. All pumps in and out and mixers are to be interlocked to prevent out of sequence operation.

The pH in the lime reactor is monitored and may be used to adjust the set-point of the primary pH control loop based on operating parameters such as feed rate, metals loading, and sludge recycle rate. Based on the available information, the control pH selected for this tank is 9.6 based on the concentration of metals in the raw water and pH 7.6 for the low pH stream.

7.5 Lime RMT to Oxidation Tanks (paced pumping)

In order to convert the lime batching into a continuous flow to supply the oxidation tanks, the three parallel interlocked pumps are to operate in sequence at a rate of 61L/s in the high pH stream and 100L/s in the low pH stream. Both will operate at a head of approximately 6m with the suction head varying as the RMT is lowered. The pumps are to be paced with the in line magnetic flow meter to deliver a constant flow rate. The pumps do not require special coatings or treatments as the limed water prevents corrosion. Standard gate, ball or plug valves are to be installed either side of the pump with an equivalent diameter to the suction and delivery pipes. 200mm of straight pipe is to be provided between the suction side of the pump and the valve. 10 straight diameters are to be provided after the delivery valve and before the magflow meter. 5 straight diameters are to be provided after the magflow meter and before any bend. The pipes are to discharge over the top of the lime RMT and discharge at least 300mm above the active water level.

A low-level switch will trip the aerator delivery pump when the batch tank reaches a level above the NPSH. The aerator tank does not require a high-level switch as it flows to the clarifier under gravity.

All pumps in and out and mixers are to be interlocked to prevent out of sequence operation

7.5.1 Oxidation Tanks - Reactors 2 and 4

A residence time of 40 minutes is required to facilitate the precipitation reactions and oxidise ferrous iron to ferric iron. A minimum storage volume of Reactor #2 in the high pH stream is 145kL and 240kL for Reactor#4 in the low pH stream. The reactor is to consist of an even number of tanks such that the water enters at the TWL of the first tank and travels the longest path to discharge at the TWL of the last tank. This enables the head in the tank to convey the treated water to the clarifier under gravity. Prefabricated rectangular tanks are acceptable which have a serpentine water movement to achieve the required contact time.

The reference design includes:

- Reactor#2 - two 5m high mild steel epoxy coated tanks at 4.3m diameter joined together at the base with a DN355 PN10 HDPE
- Reactor#4 - two 5m high mild steel epoxy coated tanks at 5.5m diameter joined together at the base with a DN560 PN10 HDPE.

The tanks are to be founded on levelled compacted Engineered fill. The minimisation of differential movement and is critical to the even distribution of air from the diffuser which sits on the bottom of the tank.

Each chamber is to provide a removable fine bubble diffused aeration system with the aerations headers in banks. The diffuser membrane is to seal against the supporting member to prevent the ingress of liquid into the air pipework on air supply shut down. The diffusers are to be fixed to distribution headers which sit on the tank floor.

The distribution pipes should be 75mm in diameter or greater to prevent head loss and provide an even distribution of air pressure. The pipework should be 304 SS as a minimum to prevent corrosion from the inside. The tanks are to include pipework supports which allow the distribution pipework to be removed by jib crane if required. Brown's Oxide mine has such a crane.

The reference design has recommended a centralised blower facility with at least 50% standby capacity, but a separate blower may be supplied for each tank. The air blowers are to be either centrifugal blowers or rotary positive displacement (Roots type or equivalent) consisting of lobed rotors rotating within a casing and designed for continuous operation at the required pressures and flows.

Each chamber is to provide a duty/assist Dissolved Oxygen (DO) probe with the air supply paced by the average of the values. The aeration is to provide an adjustment from a normal process oxygen requirement of 100% to a maximum process oxygen requirement of 120%. A feedback loop is to be provided to maintain this level to within ±8% to prevent pace hunting.

7.6 Polymer batching and dosing

The recommended flocculant is Praestol 2540. It is batched with treated water at a concentration of 25g/kL to form a polyelectrolyte. The powder is added to water with vigorous and even stirring. After a dissolving period of approximately one hour the solution is mature and is thus ready for use. Package patching plants with a capacity of 20kg/hour are required. The batch mixing tank shall be completed with inlet, outlet, overflow and drain connections and removable lid. The tank shall have an effective volume of at least 500 litres.

The limed and aerated water gravitates to the clarifier with the flocculant paced dosed to properly agglomerate the precipitates and promote efficient settling in the clarifier. The polyelectrolyte is injected into a dynamic inline mixer located on the gravity line between the final oxidation tank and the clarifier immediately downstream of the oxidation chamber. The mixer is to operate at a rotary speed of between 2000 and 3000 rpm directly in the feed line to achieve a turbulent admixture of the flocculant and limed and oxygenated water.

A dynamic high mixer speed is preferable to a static mixer as it achieves a turbulent and thus ideal admixture of the flocculant. All solid particles have contact with the flocculant and the flocks all have virtually the same size. The formation of very small flocks or big instable agglomerates is minimized with the result of an increased water loss of the flocks in the dewatering machine. Due to the faster loss of water, it is possible to increase the throughput of the dewatering unit or optimize the dewatering degree.

A specific energy input of approximately 20 kWh/tDR is required to create the turbulent conditions. The concentration of the flocculant solution can be increased from typically 0.2% to 0.4% effective substance

Figure 15 Recommended polymer inline mixer

Additional polymer is to be added just before the feed to the clarifier via a diffuser at the inlet pipe to each clarifier. A local control panel is required to control the batching and dosing.

Premixed polymer spilt on the ground is a slip hazard. Any hard ground surfaces around the polymer system is to be lined with either Parbury Nitocote EP410 or an approved chlorinated rubber paint with silicon carbide grit added to produce an anti-slip surface.

7.7 Clarification

The reference design has selected Lamella clarifiers to separate the separate the precipitate. They have been well proven for this purpose (ProChemTech International, 2015). The following benefits make them ideal for the Rum Jungle water treatment site:

- They can be fabricated off site and delivered process ready
- They are extremely efficient and therefore occupy a small footprint approximately 25% less than a standard clarifier
- They do not have any moving parts
- They use very little power apart from sludge management
- They are elevated above the ground so do not require substantial site earthworks
- They can be on sold after the project is complete

As the pH of the wetted areas is neutral or above, they will only need to be constructed of welded carbon steel, sand blasted, primed, and epoxy finished. The support structures only need to be made from welded carbon steel, sand blasted, primed, and coated with industrial enamel.

Clarifier plates are constructed of high density, flat hard polished fiberglass. Clarifier plate spacers are constructed of PVC plastic angle secured with nylon bolts. Inclined plates set at 60-degree angle will eliminate the need to clean the plates. A maximum of 900mm in length has been found to be most efficient (ProChemTech International, 2015). Longer plates have been found to resuspend the settled particles. A very slower squeegee blade is required to force solids into the 45-degree angled hopper.

The reference design has been based on a design loading capacity of 0.61 L/h/m^2 which requires 360m^2 of clarifier surface area for the high pH and 590m^2 for the low pH stream. Each clarifier will need a flow capacity of 25L/s. The high pH stream will therefore require three in parallel and the low pH stream four in parallel. The size of the tanks has been selected to fit ready made on a truck but larger, fewer units would be more economical and could be assembled on site.

7.7.1 Sludge Decant and Recirculation

The sludge lines can be HDPE or steel and will operate at high pressures due to the high density of sludge. PN20 is recommended. A peristaltic pump or metering pump is required to withstand the abrasive nature of the sludge and the high pressures. The reference design requires the recirculation of 20% of the sludge produced by means of a time-proportional control of a pinch valve which splits the flow between the balance tank and waste sludge dewatering system 20:80.

By recirculating the sludge to the balance tank to mix directly with the acid mine drainage, the dry solids content of sludge can reach over 30% solids in the first year of operation (Aubé, B., & Zinck, J., 2003). However, it may take several weeks before the sludge density increases to an equilibrium of around 30%. The density of the waste sludge can be further increased to about 40% by adding more hydrated lime to the sludge directly however this will not be a concern if the sludge is discharged with the waste rock in the Main Pit during backfilling.

In a survey of sludge qualities, the sludge sampled from a plant designed like the reference design was the only one to have a crystalline component (Aubé, B., & Zinck, J., 1999). All other sludge samples, whether high-density or not, were found to be completely amorphous. Geco's sludge also showed the lowest neutralising potential. This is more lime efficient. A high neutralising potential indicates either the presence of unreacted lime or formation of excess calcium carbonate in the system. By contacting the sludge directly to the AMD in the Geco process, unreacted lime is consumed, and carbonates are dissolved. This has the effect of reducing lime scaling in the reactors and clarifier. As the groundwater has high sulphate concentrations and the pH will be high, recycling the sludge will cause precipitation of gypsum to occur on the surface of existing particles instead of the process surfaces.

7.7.2 Waste sludge management

The waste sludge from a Geco process is expected to have a dry solids content of up to 30% (Aubé, B., & Zinck, J., 2003). At this dry solid content, the sludge is like cream. It is understood several weeks of recirculation are required before the process is bedded in and this level of dry solid content is achieved. A dry solids content of 40% can be achieved by the addition of hydrated lime but this process increases the volume of sludge to be managed. At 40% the sludge is like paste and can't be pumped. A dewatering rotary screw press modified for lime sludge can achieve dry densities of 50 to 60% which makes the sludge solid and becomes an excavatable material. This process reduces the volume of sludge substantially and converts it into an excavatable material.

Table 29 summarises the expected volume of sludge generated by WTP running from years 2 to 10.

Table 29 Sludge volumes and management options

Stage	Raw daily sludge volume	Total	Rotary Screw Compacted	Total
Year 2-4	33m^3	36,500m^3	17m^3	15,600m^3
Years 4-10	28m^3	70,300m^3	14m^3	30,100m^3

It is recommended that the clarifier sludge be discharged with the backfill material during the backfill.

Ponds 1 and 3 have a combined storage volume of 7,200m^3 which is insufficient for sludge storage. The ponds could be used as dry beds with the dried material excavated and moved to a WSF. The alternative is to install a rotary screw compactor which will reduce the total volume by 50% and discharge via Archimedes screw into a truck and dog for transport to a holding facility.

7.7.3 Supernatant return

The supernatant from the high pH clarifiers will be pumped to the balance tank of the low pH stream. CO_2 is injected directly into the pipe downstream of the clarifiers to lower the pH. CO_2 will buffer the water to pH 7.0.

Supernatant from the low pH stream will gravitate to the treated water sump for distribution to pond 1 or process water or discharge directly to the EBFR.

7.7.4 pH correction using $C0_2$

Carbon dioxide, CO_2, reduces high pH levels quickly. It is not stored as an acid solution, so it is considered safer than sulfuric acid. It is non-corrosive to pipes and equipment. It requires less equipment and monitoring costs. It requires no handling costs. It can be utilized via a completely automated system. In water solution it forms carbonic acid, HCO_3 which is a weak acid. It shows a self-buffering property as it reaches neutral pH levels. This self-buffering feature allows precise end-point control without the danger of overshooting into undesirable pH levels. The following locations are required for pH correction using CO_2 include;

- Downstream of the high pH stream clarifiers to the sump;
- In the pipeline from the high pH clarifiers before joining the low pH stream.

7.8 Final Polishing

Cadmium, Zinc and Lead Hydroxide precipitation may not achieve the LDWQO when the influent is sourced from only groundwater. AsO may also fall into this category if co-precipitation with Fe^{3+} is poor. To ensure the LDWQO can be met, the hydroxide precipitation may need to be supported with sulphide precipitation. The following graph shows that the LDWQO can be achieved at a neutral pH using sulphide precipitation of these species.

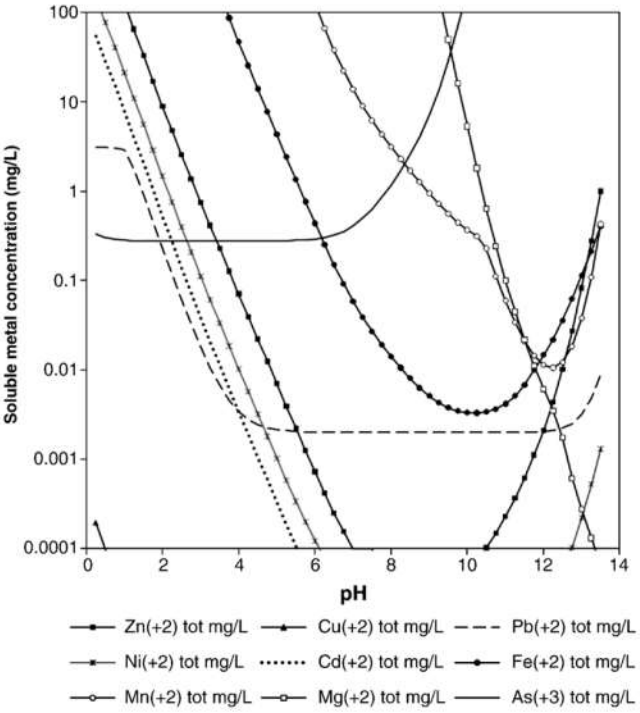


Figure 16 pH dependence of metal sulphide solubilities

The polishing would be achieved using Manganese Greensand Filter in series with a Chelating Ion Exchange Resin Filter. Injection of sodium hypochlorite (chlorine) as an oxidising agent and sodium bisulphate to convert sulphites to sulphates would be required albeit in very small quantities. The reagents in the filters are very efficient with up to 150ML of treated water achieved per m^3 of resin. The spent resin can either be disposed of or regenerated on site.

7.9 Sump collection and storage

The treated water is stored in a HDPE lined pond for use as dust suppression, process water within the plant or direct discharge to the EBFR upstream of the monitoring point. The following submersibles pumps are required in the sump:

- A 27.5 kW submersible pump with a duty of 100L/s @ 14m head is required to discharge treated effluent directly to the EBFR.
- A 6kW duty/standby pump with a duty of 5.6L/s at 50m head to pressurise the process water network

7.9.1 Discharge to the EBFR

Discharge to the EBFR would be via a DN315 PE100 PN10 HDPE pipeline. The recommended discharge point is onto the rocks on the downstream side of the iron bridge crossing the EBFR.

7.9.2 Water truck fill tank

A tank volume of 100kL has been designed for to rapidly fill four water trucks in quick succession. A submersible pump mounted in a sag in pond 1 (drawing 680.10421.WTP) would top up the tank. An 8kW submersible with a duty of 40L/s at 10m head would refill the tank in 40 minutes.

8 Chemicals Used

8.1 Flocculant Praestol

Praestol 2540 is used in the treatment of surface and ground waters after treatment with hydroxide formers. It involves the flocculation of very fine to colloidal solid particles suspended in neutral to alkaline slurries with inorganic solids. The mode of action is based on charge exchange between the electrical charges along the polymer chains, which are present in aqueous solution, and the surface charges of the suspended solid particles. The charge of the particle surfaces is neutralized and then a coagulation or flocculation of the particles is possible. Preastol 2620 is to be dosed at 25g/tonne.

8.2 Lime

Lime represents the most economical and efficient alternative for the neutralization of cations dissolved in water, either as hydroxides or complex anions, due to its low cost and insensitivity to temperature fluctuations. Either hydrated or quick lime may be used for this purpose however the preparation requires a different process.

Bulk hydrated lime is delivered by trucks. These are equipped with blowers and 100mm camloc hoses to feed the lime to a silo on site. The silo needs to be equipped with an exhaust fan and a dust collector. The silo may be mild steel. The storage facility must be airtight to prevent slaking and re-carbonation. The hopper bottom requires a minimum bottom slope of 60 degrees and mechanical or aeration intrusion is required to discharge the lime from the bins. Sufficient lime storage is required for 3 weeks or 50% larger than the delivery truck whichever is larger. Alternatively, a truck dog could be left on site which is replaced along with the refill of the hopper at the time of delivery.

Dry hydrated lime is delivered to a dilution tank that may be fitted directly onto the feeder. Compressed air, water jets, or impeller type mixers may be used to agitate the tank. The lime slurry is then transferred to the sludge-lime blending tank.

This transfer operation is the most troublesome operation in the lime handling process. The milk-of-lime reacts with atmospheric CO_2 or carbonates in the dilution water to form hard, tenacious $CaCO_3$ scales, which, with time, can plug the transfer line. Because the magnitude of this problem is in direct proportion to the distance over which the slurry must be transferred, lime feeder facilities must be located as close as possible to the lime/sludge mixing tanks. Pumping of the lime slurry should be avoided (if possible, gravity transfer should be used), and all apparatus should be accessible for cleaning. Hydrochloric acid has been included on site for this purpose.

Feeding of quicklime is similar to for hydrated lime, except that there is an additional step, slaking, in which the quicklime reacts spontaneously with water to form hydrated lime. Bagged quicklime can be slaked in batches by simply mixing one-part quicklime with two to three parts water in a steel trough while blending with a hoe. Proportions should be adjusted so that the heat of the reaction maintains the temperature of the reacting mass near 200°F (93°C). The resulting thin paste should be held for 30min after mixing to complete hydration. Manually operated batch slaking is a potentially hazardous operation and should be avoided if possible. Uneven distribution of water can produce explosive boiling and splattering of lime slurry. Use of protective equipment should be mandatory. For small plants, the advantage of a using the lower-priced quicklime is smaller, because lime consumption is smaller. Use of slaked lime is safer, simpler, and requires less labour. Quicklime is slaked with 15% wt/v which takes about 5 minutes to produce hydrolyzed lime $Ca(OH)_2$. A quicklime slaker with a capacity of 450kg/h is recommended for this site.

Continuous slaking is accomplished in automated machines that also dilute and de-grit the lime slurry. Several types of continuous shakers are available. They vary mainly in the proportion of lime to water mixed initially. A volumetric or gravimetric dry chemical feeder is used to measure quicklime as it is moved from bulk storage to the shaker. Since quicklime is available in a wide range of particle sizes, it is important to match the dry feeder with the type of quicklime to be used in the particular application.

8.3 Carbon Dioxide

Carbon dioxide is required for pH correction. It exhibits greater storage capacity than acid which makes it possible to store up to twice as much neutralizing agent in the same amount of storage space. It requires no handling costs. CO_2 cylinders should always be stored in a specified area. The storage area should be well ventilated. CO_2 gas in small concentrations, as little as 15%, can cause unconsciousness in less than one minute.

The cylinder should be protected from areas of high traffic. To prevent an accident occurring. Be a continuously cool place. Safety relief devices of CO_2 cylinders are designed to operate when the pressure of the cylinder exceeds 2800 – 3000 psi (depending on the design of the safety relief device). A properly charged CO_2 cylinder could vent through its safety relief device at approximately 65^{o}C. A slightly overfilled CO_2 cylinder could vent through its safety relief device when exposed to a much lower temperature. Empty CO_2 cylinders should be stored with the valve tightly closed.

Cylinders can be stored standing on their base or lying on their side. Catalina Cylinders recommends that the cylinders be stored as designed, standing on their flat base. Cylinders should not be stored where they might become part of an electrical circuit.

Cylinders, which have been manufactured to accommodate a valve protective carrying handle or a protective cap, should be stored with these accessories in place.

8.4 Hydrochloric Acid

Hydrochloric acid has been included on site for the purpose of cleaning the lime slaking pipeline and lime feed tank to prevent blockages.

8.5 Chlorine

Sodium hypochlorite solution (13% w/v) is to be used as an oxidising agent of treated water prior to the Greensands filter.

8.6 Sodium Bisulphate

Sodium bisulphate (13% w/v) is required post Greensands Filter to de-chlorinate prior to the Ion Exchange Filter.

9 Optioneering

9.1 Electrocoagulation MTECH Water

A recent invention has shown extreme promise for the Rum Jungle site. An Australian Company MTECH Water Treatment System has been inundated with engagements following recent successes. The company intends to focus on site rehabilitation rather than mining so has turned down many offers to implement the process in the mining sector.

The process uses electrified Titanium Oxide plates 8 to 14mm apart which applies a charge to the metals in the water when they pass which then coagulates and drops out of solution. The process does not use chemicals, apart from pH correction, and runs on very little power. Most installations are solar powered due to the remote locations. The process even works in biological treatment.

The benefits of such a treatment system over the traditional hydroxide or sulphide precipitation, absorption and adsorption methods include:

- The simple operation could utilise local Indigenous employment to build, manufacture, maintain & service equipment over the 10-year period.
- Replacement of the plates is only required four times per annum

- The volume of sludge produced would be less than 5% of that generated in a traditional hydroxide HDS WTP
- Small footprint, mobile and containerised
- Run in wet and dry season
- No chemicals required (aside from pH balancing) therefore OH&S is minimised in cost & handling of chemicals
- Carbon offsite footprint
- Mobility of the unit – infrastructure easily set up
- Infrastructure can be implemented in stages and 50% faster than traditional water treatment systems
- We can implement satellite systems around project site if required
- Remote monitoring & support of the system whilst using local workers on site
- All machines powered on solar
- The removed sludge could be sold as it is not contaminated with chemicals

Figure 17 Installation at a quarry

Figure 18 Before and after results

MTECH Water Treatment System has offered to run the Rum Jungle groundwater through a pilot plant to test the performance and determine the size of the plant and solar system required to satisfy the Main Pit displacement demands and the groundwater treatment demands. The solar farm required could be reused to supply the Batchelor township or feed to the grid with proceeds to the Indigenous communities in the area.

9.2 Treatment options prior to placement of the cap in the Main Pit

The methodology to treat the remaining water in the Main Pit prior to the capping is yet to be defined. It is imperative the water in the pit satisfy the LDWQO prior to the placement of the cap. The following is a list of suggestions.

1. Recirculate the treated water whilst maintaining the operating level. This may require two to three Main Pit volume cycles. The treated water should be discharged to the opposite side of the lake to the intake which is taken at depth. That is a diagonal from intake to discharge to prevent short circuiting. This process could be hastened by turning off the groundwater inflow and running the WTP as parallel systems with a throughput of 160L/s. (63 days)

2. Install a floating curtain in the Main Pit to further limit mixing and treat as per option 1. One to 1.5 cycles are likely. (51 days)
3. Use a siphon pipe(s) to transfer untreated Main Pit water to the Intermediate Pit. Pump from the Intermediate Pit to the WTP and refill the Main Pit to a minimum level to place the cap with treated water. (45 days)
4. Pump the Main Pit water to the Intermediate Pit and allow upstream EBFR waters to refill the pit to the desired level. A penstock would be required on the inlet pipe to control the refill. (potentially 10 days)
5. Aerial broadcast with hydrated lime including in pit aeration, flocculation and pH correction with sulphuric acid. (potentially 10 days)
6. Recirculate the treated water whilst maintaining the operating level. This may require two to three Main Pit volume cycles. The treated water should be discharged to the opposite side of the lake to the intake which is taken at depth. That is a diagonal from intake to discharge to prevent short circuiting. This process could be hastened by turning off the groundwater inflow and running the WTP as parallel systems with a throughput of 160L/s.
7. Install a floating curtain in the Main Pit to further limit mixing and treat as per option 1. One to 1.5 cycles are likely.
8. Use a siphon pipe(s) to transfer untreated Main Pit water to the Intermediate Pit. Pump from the Intermediate Pit to the WTP and refill the Main Pit to a minimum level to place the cap with treated water.
9. Pump the Main Pit water to the Intermediate Pit and allow upstream EBFR waters to refill the pit to the desired level. A penstock would be required on the inlet pipe to control the refill.
10. Aerial broadcast with hydrated lime including in pit aeration, flocculation and pH correction with sulphuric acid.
11. Treat the remaining water in the Main Pit and discharge to the Intermediate Pit. Install a penstock on the inlet to the Main Pit and allow the pit to fill to the desired level from flows in the EBFR during the wet season.

9.3 Initial pump down of the Pits

Transferring the water from the pits to the EBFR could be aided by pumping out through the inlet on the Main and outlet of the Intermediate Pit. The static pumping head, and therefore power requirements of the pumps within the pits during pump down, could be substantially reduced by installing duck bills valves on the inlet to the Main Pit and the outlet to the Intermediate Pit (refer Figure 19). The head loss through a duck bill valve is approximately 0.3m compared with the additional 6m head to pump over the embankment. Approximately 4.7 and 4.4 MWh in power could be save at the Main and Intermediate Pits respectively by this technique.

Figure 19 Recommended duck bill valve for the inlet of the Main Pit

10 List of Supporting Documentation

10.1 Design Reports

This report is intended as a standalone report however it forms part of a wider rehabilitation strategy for Rum Jungle and it is recommended that it be read in conjunction with the documentation listed in the Bibliography. Particular reference should be made to the overarching Detailed Engineering Design Report (SLR, 2020).

10.2 Design Drawings

A summary of drawings associated with these design works is given in Table 30.

Table 30 Supporting Design Drawings

Drawing No.	Title
GENERAL	
680.10421.GEN.D00	Locality Plan and Schedule of Drawings
680.10421.GEN.D01	Existing Site Conditions
680.10421.GEN.D02	Site Construction Works Layout
WATER TREATMENT PLANT	
680.10421.WTP.D01	Water Treatment Plant Layout
680.10421.WTP.D02	Water Treatment Plant Plan
680.10421.WTP.D03	Water Treatment Plant Schedule

11 Bibliography

Aubé, B. (2009). *Treatment and Monitoring of Pit Lakes. Securing the Future & 8th ICARD, Sweden, Cd, 1–10.*

Aubé, B., & Zinck, J. (1999). *Comparison of AMD Treatment Processes and their Impact on Sludge Characteristics. Proceedings for Sudbury '99, Mining and the Environment II.*

Aubé, B., & Zinck, J. (2003). *Lime Treatment of Acid Mine Drainage in Canadá. Brazil-Canada Seminar on Mine Rehabilitation, March, 1–12.*

Balladares, E. J. (2018). *Neutralization and co-precipitation of heavy metals by lime addition to effluent from acid plant in a copper smelter. Minerals Engineering, 122(April), 1.*

Hydrobiology. (2016). *Rum Jungle Impact Assessment, Final Report (Issue June).*

Lewis, A. (2010). *Review of metal sulphide precipitation. Hydrometallurgy, 104(2), 222–234. https://doi.org/10.1016/j.hydromet.2010.06.010.*

NT-DPIR. (December 2019). *Northern Territory Government, Department of Primary Industry and Resources - Draft Envirionmental Impact Statement.*

ProChemTech International. (2015). *Innovation in Water Management. www.prochemtech.com.*

RGC. (November 2019). *Robertson GeoConsultants Inc. Groundwater and Surface Water Modelling Report, Rum Jungle.*

SLR. (2020). *Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design - Design Report (under Construction).*

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