RUM JUNGLE REHABILITATION PROJECT

Water Treatment Plant Options Assessment

Prepared for:

NTG Department of Industry, Trade & Tourism
Level 5, Paspalis Centrepoint, 48 Smith Street, Darwin NT 0800

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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 NTG Department of Industry, Trade & Tourism (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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EXECUTIVE SUMMARY

SLR Consulting Australia Pty Ltd (SLR) was engaged to deliver the Rum Jungle rehabilitation strategy design works over the period 2020 to 2021 (Project Stage 2A). This was used to support the draft Environmental Impact Statement (EIS) submitted by Northern Territory Government Department of Industry, Tourism and Trade (DITT) to the Australian Government Department Agriculture, Water and the Environment (the Department) for approval of the rehabilitation project under the Environment Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act).

Based on the review of the EIS, the Department issued a request for additional information associated with the Water Treatment Plant (WTP) options and discharges, specifically:

"Please provide either a finalised Wastewater Treatment Plant (WTP) design or a shortlist of design options. This information should include a description of the chemicals to be used, the quality and quantity of water to be discharged, and the quantity, composition and methods to be implemented for disposal of sludge.

The Department is of the view that, without this information, the WTP in itself may pose a potential and additional environmental and chemical risk to the Finniss River."

The proposed WTP has 2 functions:

- Treat highly contaminated groundwater, which would be extracted at low flow rates for an extended period (planned 10 years, subject to groundwater monitoring)
- Treat lowly contaminated water from the Main and Intermediate Pits for a short period (approx. 3 years). The extraction from the Main Pit would be at a high rate to match the displacement caused by backfilling of the Main pit with potentially acid forming (PAF) waste rock. The extraction from the Intermediate Pit would initially be at a high rate to create a sink to the conveyance of surrounding ground and surface water and then at a moderate rate to maintain the supressed water level.

At the conclusion of Main Pit backfilling and other site earthworks activities, the WTP would be downsized to maintain the groundwater treatment program. The decommissioning of the groundwater abstraction and WTP would occur at a time agreed by the Proponent and appropriate Regulators but would be subject to the groundwater monitoring results.

Under both scenarios the WTP would discharge treated water into the East Branch Finniss River (EBFR) in a condition suitable to meet the Locally Derived Water Quality Objectives (LDWQO) set for the Project.

A reference treatment concept design was prepared by SLR. The detailed design was avoided with the intention to encourage supplier innovation and economies in the treatment process without compromising the treated water quality. The reference design is a well proven process for Acid and Metalliferous Drainage (AMD). It consists of a high density sludge (HDS), two stage lime precipitation process in combination with Greensands Filtration and Ion-exchange Resins (Geco). The large volumes of sludge would be dewatered via high pressure screw presses and buried in the Waste Storage Facilites (WSF) to be constructed as part of the project.

Including the above, the following summarises the treatment processes that could successfully meet the requirements:

- A High-Density Sludge (HDS), two-staged 'Geco' system.
- Electrocoagulation.
- Membrane technology.
- Anaerobic Sulphate Reducing Bacteria (SRB) Wetlands.

EXECUTIVE SUMMARY

Each have pros and cons which should be taken into consideration with knowledge of the remoteness of the site, the availability of power, the available footprint, waste production, required chemicals and the cultural significance of the land. In order to prepare this report a worst case scenario water quality was assumed to develop the calculations in this report (sludge volumes, reagent use etc.). The following table summarises the key aspects of the four processes.

Description	Ability to meet Zone 2 LDWQOs	Input Reagents	Power Input	Sludge Volume	Plant Mobilisation	Skill Set	Precedence	Human health/ Environmental Risks
HDS 'Geco' with Ion exchange resins and Greensands/DMI65 catalytic filtration media	Yes.	Lime. Flocculant. Carbon dioxide. Hydrochloric acid. Chlorine. Sodium bisulphate. Ion exchange resin. Greensands/DMI65 media.	Diesel = 2,764kL. Supplemented by solar / batteries.	107,700 m^3 wet OR 54,400 m^3 if dry pressed. No further treatment required to stabilise sludge.	Complex pipe and control network, significant earthworks.	1 skilled operator (remote). 2 support staff (site based), plus redundancy.	Proven technology and practiced world wide.	Low to high risks associated with reagents and diesel.
Electrocoagulation	Possibly, pilot testing necessary for design.	None required.	Diesel = 227kL. Supplemented by solar / batteries.	141 m^3. Dry powder that can be stored in the WSFs with no further treatment. Sludge could be on sold.	Self contained units mobilised to site.	Low skilled staff for plate replacement during operation. Local industry could cut plates.	Proven in other settings and applications, however not yet proven in treating high density AMD. Would require Pilot testing.	Moderate risks associated with diesel. Low voltage power.
Reverse osmosis	Yes, pilot testing necessary for design.	Sulphuric acid. Caustic soda.	Diesel = 227kL. Significant mains power required. Supplemented by solar / batteries.	3,799 ML. An evaporation pond with a surface area of 70Ha is required.	Compact plant but requires a 70 Ha evaporation pond.	1 highly skilled operator. 2 moderately skilled operators.	Proven technology in this application but requires pilot testing to verify if secondary RO will achieve the LDWQO otherwise it needs to be coupled with another process.	High risk with sulphuric acid.
SRB wetland	Unlikely.	Organics (no limestone). Organics (with crushed limestone and seeded bacteria). Limestone cobble.	Diesel = 227kL. Supplemented by solar / batteries.	325 m^3. Can be on sold, stored in the WSFs or encapsulated locally with no further treatment.	Significant earthworks, requires 90 Ha footprint for treatment cells and settlement ponds which may not be available.	1 moderately skilled operator permanent. 1 highly skilled operator occasional.	Is often used as a cost effective means to mining metals, however at Rum Jungle it may not provide the required performance. Required footprint may also not be available.	Moderate risks associated with diesel. Low voltage power.

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1 Introduction

1.1 Background

The former Rum Jungle Uranium Mine, located approximately 100 km south of Darwin, operated between 1954 and 1971 and underwent rehabilitation from 1983 to 1986. Historic mining activities have led to a highly disturbed system both onsite (terrestrial) but more so within the East Branch Finniss River. The rehabilitation addressed significant environmental impacts caused by Acid Metalliferous Drainage (AMD) and achieved objectives related to aesthetic improvements and reducing public health hazards. Recent studies documented that the original rehabilitation works do not meet modern standards meaning further rehabilitation work would be required to support future land use.

Since 2009, the Northern Territory and Australian Governments have undertaken investigative works to develop an improved rehabilitation strategy consistent with the views and interests of stakeholders and contemporary environmental and mined-land rehabilitation standards.

SLR Consulting Australia Pty Ltd (SLR) was engaged to deliver the rehabilitation strategy design works over the period 2020 to 2021 (Project Stage 2A). This was used to support the draft Environmental Impact Statement (EIS) submitted by Northern Territory Government Department of Industry, Tourism and Trade (DITT) (formerly DIPR) to the Australian Government Department Agriculture, Water and the Environment (the Department) for approval of the rehabilitation project under the Environment Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act).

Based on the review of the EIS, the Department issued a request for additional information associated with the Water Treatment Plant (WTP) options and discharges, specifically:

"Please provide either a finalised Wastewater Treatment Plant (WTP) design or a shortlist of design options. This information should include a description of the chemicals to be used, the quality and quantity of water to be discharged, and the quantity, composition and methods to be implemented for disposal of sludge.

The Department is of the view that, without this information, the WTP in itself may pose a potential and additional environmental and chemical risk to the Finniss River."

This report has been prepared to address the above request.

1.2 Project Water Quality Objectives

Hydrobiology was engaged by DITT to undertake a downstream impact assessment on the aquatic ecosystems within the EBFR (Hydrobiology, 2016). Assessment confirmed the view that the East Branch Finniss River is a highly disturbed system as evidenced by water quality monitoring over decades and aquatic ecology monitoring over the last decade. This disturbance is due to historic mining activities over the 19502 to 1970s. The conclusions showed a pattern of increased metal concentrations in the isolated pools in the EBFR immediately downstream of the mine in the dry season as compared to baseline and upstream sites. There were consistent patterns of reduced biodiversity and abundance of flora and fauna in this zone – to the point that within the East Branch Finniss River, current water quality offers less than 1% species protection. 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. In response to these findings, site Locally Derived Water Quality Objectives **LDWQO**s were formulated in accordance with the methodologies of the ANZECC/ARMCANZ guidelines to establish rehabilitation goals for the highly disturbed system and to establish a basis for water release limits from the site during the rehabilitation process. **Table 1** shows the Project LDWQO prepared by Hydrobiology for Zone 2 of the EBFR.

Table 1 Water Quality Objectives

Analyte	Zone 2 Project LDWQOs (mg/L) (Hydrobiology, 2016)
Arsenic	0.14
Aluminium	0.236
Cadmium	0.0043
Cobalt	0.089
Copper	0.0602
Iron (2+ and 3+)	0.300
Manganese	0.759
Nickel	0.1304
Magnesium	86.6
Lead	0.0129
Zinc	0.2105
EC (µS/cm)	2,985
Sulphates	1,192
pH	None[1]

ID – Insufficient data, ND – no data
1 Targeting 7 to 8.5 for WTP design purpose

Robertson GeoConsultants (RGC) were engaged by the DITT to develop a calibrated integrated surface water and groundwater model that accurately represented the existing contaminant flow processes on the Rum Jungle property. The purpose of this model was to modify and gain confidence in contaminant sources, transport and flows. RGC prepared a MODFLOW/MT3D groundwater model to simulate groundwater flow across site and the interactions of ground and surface waters (RGC, 2019). The model was enhanced through calibration with real observed data over a period of 9 years. Copper was identified as the contaminant of concern from the Rum Jungle property therefore the project team sought to identify a solution which would reduce copper loads in the EBFR downstream to levels practicably achievable and in line with the established Project LDWQOs. The rehabilitation plan targets source reduction.

The Project established a rehabilitation plan as presented with in the EIS documentation (established by the Project's Contaminated Sites Auditor as suitable for a Remediation Action Plan). The rehabilitation plan includes establishment of a network of groundwater extraction bores in strategic locations that would capture impacted water to reduce volume of this impacted water entering the EBFR (as is currently the case) by drawing impacted groundwater from a depth of up to 30m at a rate between 1 and 2L/s on a 24-hour basis for a planned period of 8 to 10 years (subject to ongoing water quality monitoring). The groundwater and mine affected surface storages would be treated to meet the Project LDWQOs before release or used within the construction project (NT-DPIR, December 2019).

The LDWQO's for Zone 2 (on the mine site) were developed with a 70% species protection target following a detailed assessment of the aquatic ecosystems within the EBFR to derive these LDWQO. The LDWQO therefore defines the minimum for the standard of water treatment prior to release from the Water Treatment Plant.

1.3 Physical and Chemical Process Requirements of the Treatment Process

The treatment technology is required to be developed in response to the following site conditions and constraints:

- Has the capability to treat a variable low flowrate of highly concentrated aqueous metals from groundwater sources with a pH as low as 3.5. The groundwater flow would vary from approximately 17L/s in the dry season (5 months) to 34L/s in the wet season (7 months). Groundwater simulations predict the concentration would diminish over time but may require continual operation for 10 years to achieve the LDWQO.
- Has the capability to process a variable but high flowrate of lowly concentrated aqueous metals with a pH down to 5 from surface water storages, groundwater recharge and captured surface runoff. The displaced water during backfilling would vary between 100L/s in the wet season (5 months) to 180L/s in the dry season (7 months). The groundwater recharge and surface water contribution would vary between 12L/s in the dry season to 59L/s in the wet season. The treatment of this water would need to continue for approximately 3 years.
- At the conclusion of Main Pit backfilling and other site earthworks activities, the WTP is to be downsized to just maintain the groundwater treatment program. The decommissioning of the groundwater abstraction and WTP would occur at a time agreed by the Proponent and appropriate Regulators but would be subject to the groundwater monitoring results.
- Is constructed of materials which can withstand a very low pH but has a lifespan which is compatible with the operational demands and timeframes.
- Be modular and temporary in construction with components which are readily available 'off the shelf' and can be easily removed from site at decommissioning.

- Requires chemicals which are readily available, cost effective and can be managed with minimal OHS requirements.
- Produces a water quality which meets or exceeds the LDWQOs.
- Release treated water on the downstream side of the iron bridge crossing of the EBFR at the western extreme of the site.
- May release water to the EBFR in the dry season during the backfilling operation but only during the dry season during the extended groundwater management program.
- Is proven technology in the field of metalloid removal.

1.4 Reference WTP Design Intent

Management technologies of metal Mine Influenced Water (MIW) is a specialised industry. With an increased community awareness of the potential consequences of environmental and human contact with MIW comes an increase in water quality regulations. More stringent regulations drive technological advancements in the industry. The goal is to encourage innovation to achieve economies in the capital costs, operating costs and minimising sludge volumes without compromising the treatment flow rates and the treated water quality discharged to the EBFR over and above that which could be achieved by the reference design.

1.5 Comparison Time Period

For the purposes of comparison of the options, the following time periods have been adopted, to allow a "like-for-like" comparison:

- Treatment during Main Pit backfilling and Intermediate Pit treatment – 3 years.
- Groundwater and remaining surface water treatment - 10 years.

2 Potential Treatment Options Description

2.1 Shortlist of Design Options

There are several MIW operational WTP design options that meet the physical and chemical requirements and are understood by SLR, however it is important to note that new technologies are always emerging, including refinement to those listed below. To this end, it is important that the WTP detailed design is undertaken by industry specialists to meet the site requirements and constraints set out by the Project in accordance with LDWQOs. This will be established during the procurement process which will include a competitive engineering process to ensure a best fit solution is procured for the Project.

The reference design consists of a High Density Sludge (HDS) two stage lime precipitation process in combination with Greensands/DMI65 catalytic filtration media and ion-exchange resins. The process is commercially referred to as the 'Geco' process.

For the purposes of understanding likely input and operational requirements and output data, SLR will compare the reference design with three other processes currently available commercially, i.e.:

- Electrocoagulation
- Membrane Technology
- Anaerobic Sulphate Reducing Bacteria (SRB) Wetlands

Each process has pros and cons which must be taken into consideration with knowledge of the remoteness of the site, the availability of power, the available footprint, sludge production and safe management, availability and safe handling of chemicals, available budget and the cultural significance of the land.

2.2 'Geco' HDS with Polishing (Reference Design)

2.2.1 Description

A High-Density Sludge (HDS) two-staged 'Geco' hydroxide precipitation with oxidation, Ion exchange resins and Greensands/DMI65 catalytic filtration media water treatment process is a proven option to satisfy the LDWQOs. 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 resins and catalytic filtration.

The system would be installed centrally near the Main Pit and surface and groundwater pumped to the WTP for treatment as a combined flow.

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. 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% dry solids 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 or high pressure screw press to dewater. A polishing phase by passing the treated water through Ion exchange resin and Greensands/DMI65 catalytic filtration media before release ensures the LDWQO can be met. **Table 2** summarises the expected treated water quality for each analyte compared to the LDWQA.

Table 2 Treatment Capability of the Geco process with polishing

Analyte	Zone 2 Project LDWQOs (mg/L) (Hydrobiology, 2016)	Geco HDS + Ion exchange + Greensands/DMI65 treated water results (mg/L)
Arsenic	0.14	0.003
Aluminium	0.236	0.0009
Cadmium	0.004	0.0001
Cobalt	0.089	0.0002
Copper	0.0602	0.0004
Iron (2+ and 3+)	0.300	0.002
Manganese	0.759	0.1
Nickel	0.1304	0.002
Magnesium	86.6	2

Analyte	Zone 2 Project LDWQOs (mg/L) (Hydrobiology, 2016)	Geco HDS + Ion exchange + Greensands/DMI65 treated water results (mg/L)
Lead	0.0129	0.001
Zinc	0.2105	0.04
EC (µS/cm)	2,985	<3000
Sulphates	1,192	1000-2000[1]
pH	None[2]	7.5

1 When sulphate concentration exceeds 10,000 mg/L the treated water may have slightly elevated levels.
2 WTP design to target 7 to 8.5

Essentially, individual units would be 'plug and play' and would be 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 1** shows a schematic of the primary high pH stream and **Figure 2** the secondary neutral pH stream before discharge to the EBFR via a temporary storage system.

Figure 1 The primary stream of the 'Geco' Process

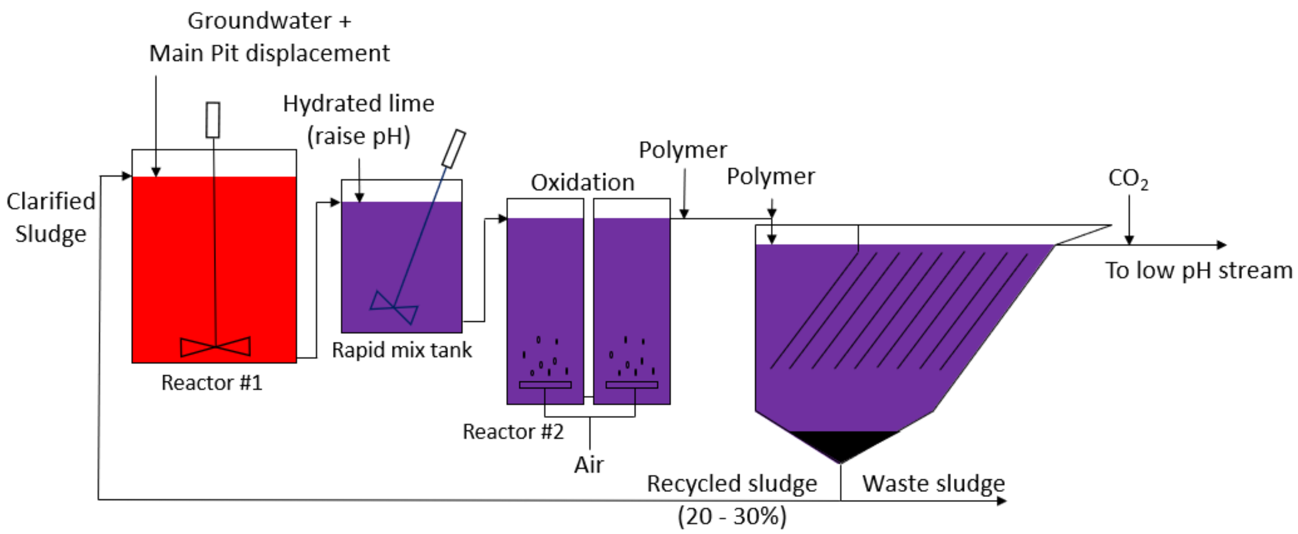
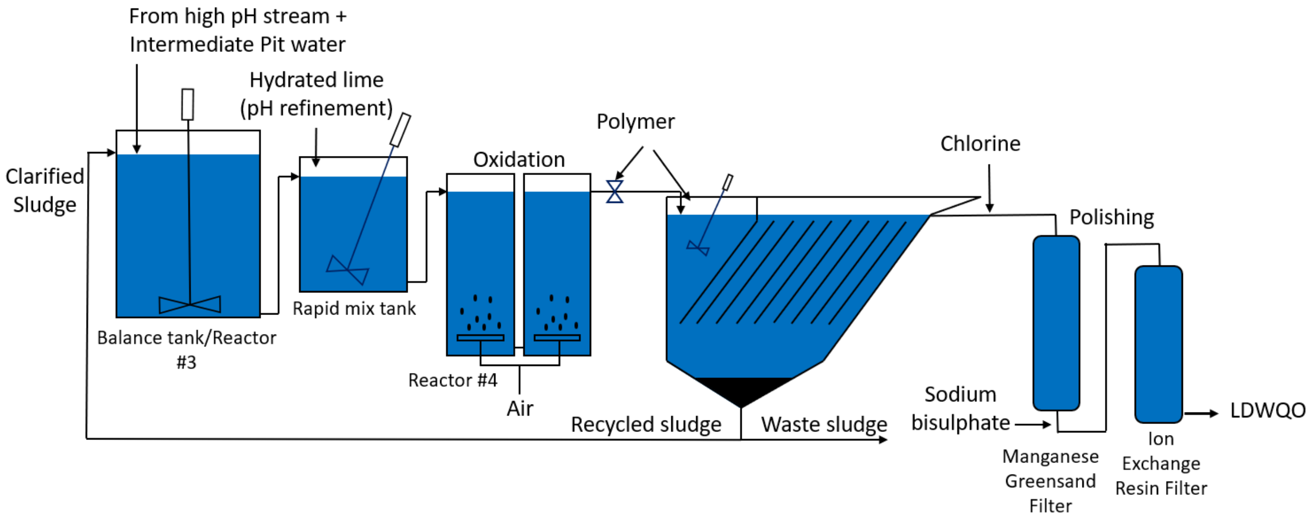


Figure 2 The secondary stream of the 'Geco' process



2.2.2 Consumables

The following chemicals and reagents are required to operate the Geco process. They would be delivered to site either via Darwin or directly from the Eastern seaboard. Most will be stored and batched on site.

2.2.2.1 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.

Delivery

Bulk hydrated lime is sourced from either Western Australia or Indonesia. It is shipped to Darwin and delivered to site by trucks. The trucks are equipped with blowers and 100mm Camloc hoses to feed the lime to a silo on site. The silo will be equipped with an exhaust fan and a dust collector.

Storage

The lime will be stored on site in a mild steel silo. The storage facility is airtight to prevent slaking and re-carbonation. Sufficient lime storage would be 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. The hopper bottom has a bottom slope of 60 degrees and mechanical or aeration intrusion to discharge the lime from the bins.

Handling

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 is required 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. Continuous slaking is accomplished in automated machines that also dilute and de-grit the lime slurry. A volumetric or gravimetric dry chemical feeder is used to measure quicklime as it is moved from bulk storage to the shaker.

Dose rate

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 would be recommended for this site.

The consequence of a spillage or delivery accident

Lime is a non-flammable and nontoxic powder. It can irritate the skin, may cause eye damage and can irritate the lungs.

If spilt, it can be scrapped off the ground and reused.

If accidentally released to the EBFR it will rapidly increase the alkalinity to between 8.5 and 11 depending on dilution. It will not bioaccumulate and will neutralise over time by absorption of carbon dioxide, dilution and reaction with the PAF soils.

The environmental hazard is considered low.

Volume required

Approximately 930 to 1,550 tonnes of hydrated lime will be required annually with a greater quantity required upfront during the backfilling operation.

2.2.2.2 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.

Storage

It is delivered as a bulky bagged powder and is made into a solution on site. The volumes required are small.

Dose rate

Preastol 2620 is to be dosed at 25g/tonne.

The consequence of a spillage or delivery accident

Polymer is a white powder that is non-flammable but can irritate the skin, eyes and lungs. If spilt on the ground it can be scrapped off and reused. Hard surfaces must be thoroughly cleaned as it will make the surface slippery.

If accidentally released to the EBFR it must be contained as it is toxic to microfauna that live in soils in high doses such as earthworms. As it is transported as a solid this is easily achieved.

The environmental hazard is considered moderate.

Volume required

Approximately 37 to 72 tonnes of polymer will be required annually with a greater quantity required upfront during the backfilling operation.

2.2.2.3 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. CO_2 cylinders should always be stored in a specified area.

Storage

Carbon dioxide is stored in cylinders standing on their base or lying on their side. Cylinders should not be stored where they might become part of an electrical circuit.

Dose rate

Dosage depends on the pH correction required but overdosing is not possible.

The consequence of a spillage or delivery accident

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 and be in 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°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.

Volume required

Approximately 90 to 123 tonnes of carbon dioxide will be required annually with a greater quantity required upfront during the backfilling operation.

2.2.2.4 Hydrochloric Acid

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

Storage

HCl is stored in 1,000L IBC containers inside a cool sheltered bund away from incompatible materials.

Dose rate

HCl is diluted and used to remove lime scale in the lime dosing system pipework. The dose rate is proportional to the alkalinity in the pipeline to achieve neutrality and will vary across the WTP.

The consequence of a spillage or delivery accident

This is a Class 8 chemical requiring handling by trained personnel. It can cause severe skin, eye, and digestive tract burns. It is harmful if swallowed. The mist or vapour is extremely irritating to eyes and the respiratory tract.

If a rupture of the IBC occurs it is contained within a lined bund.

Transport to site is via truck with IBC units protected with a steel frame. A truck accident could release HCl to the environment which is neutralised with lime. If released to the EBFR it will affect the acidity (pH) of the water with risk of harmful effects to aquatic organisms. Lime should be added to neutralise the acid.

Volume required

Approximately 1kL will be required annually.

2.2.2.5 Chlorine

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

Storage

Chlorine is stored in 1,000L IBC containers inside a cool sheltered bund away from incompatible materials.

Dose rate

The dose rate is approximately 0.5mg/L.

The consequence of a spillage or delivery accident

This is a Class 8 chemical requiring handling by trained personnel. It can cause severe skin, eye, and digestive tract burns. It is harmful if swallowed. The mist or vapour is extremely irritating to eyes and the respiratory tract.

If a rupture of the IBC occurs it is contained within a lined bund.

Transport to site is via truck with IBC units protected with a steel frame. A truck accident could release chlorine to the environment which is harmful to aquatic organisms and should be rapidly contained.

Volume required

Approximately 800L will be required annually.

2.2.2.6 Sodium Bisulphate

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

Volume required

Approximately 620L will be required annually.

2.2.2.7 Ion exchange resin

Volume required

Approximately 12.2m^3 will be required annually and used at a rate of 1m^3/150ML of water.

2.2.2.8 Greensands/DMI65

Volume required

Approximately 12.2m^3 will be required annually and used at a rate of 1m^3/150ML of water.

2.2.2.9 Diesel

Diesel is required to run pumps, generators as well as plant on site.

Storage

Diesel is stored in bunded fuel cells adjacent to generators and pumps.

The consequence of a spillage or delivery accident

Transport to site is via tanker and will be required to refuel other plant during the remediation. In the case of small spills relating to transportation and operation a fuel spill kit would be carried on the tanker and adjacent to plant.

A spill as a result of an overturned tanker would be harmful to the environment. Containment measures using large plant and pumps would be required.

Volume required

Approximately 380kL/annum when backfilling (first 3 years) and 232kL/annum with just groundwater extraction (years 4 to 10).

If supplemented with solar then approximately 129kL/annum when backfilling (first 3 years) and totally reliant on solar/batteries (years 4 to 10).

2.2.3 Sludge Production

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. 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 3 summarises the expected volume of sludge generated by the WTP.

Table 3 Sludge volumes and management options

Stage	Raw daily sludge volume	Total	Rotary Screw Compacted (daily vol)	Total
First 3 Years	$33m^3$	$36,100m^3$	$17m^3$	$18,600m^3$
Years 4-10	$28m^3$	$71,500m^3$	$14m^3$	$35,800m^3$

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

The sludge produced is chemically stable and will not breakdown or interact once placed and covered in the WSFs.

2.2.4 Power

An NPV calculation has confirmed it is more cost effective to implement a combination of solar/batteries and diesel power. Diesel power would be used to maintain the required water levels in the Main and Intermediate pits and to supplement the WTP during the backfilling operation. Solar/batteries would power the borefield pumping and the reduced size treatment plant when the backfilling is complete.

Table 4 Power Requirements

Source	Size	Comments
Solar Array	690kW (approx. 2300 panels)	Main array adjacent to WTP Solar banks adjacent to groundwater bores
Battery storage/ inverters/ MCC	2500 kWh	Container mounted next to WTP Garden shed style adjacent to groundwater bores
Diesel generator	63kVA	Main pit drawdown, WTP supplement
Diesel generator	30kVA	Intermediate pit drawdown

2.2.5 Skill sets

The WTP will require trained personnel to establish and program the control. Two moderately trained operators would be required to maintain the plant on day shift with two on call at other times when alarms sound. One highly skilled operator should be available on call with telemetered access to the control panels. This Operator could be located remotely.

2.2.6 Precedence and confidence in technology

Significant precedence since the late 90's. There are many companies that supply and operate this plant in a package format.

2.2.7 Input / Output / Risk Summary

Table 5 summarises the input requirements and output data for the HDS 'Geco' system.

Table 5 HDS 'Geco' Input / Output Summary

Material	Input Quantity Per annum	Output Quantity Total	Comment
Lime	930-1,550 t		Environmental / human impact risk is low.
Flocculant Praestol	37-72 t		The environmental / human impact risk is considered moderate.
Carbon dioxide	90-123 t		Human impact risk is considered moderate.
Hydrochloric acid	1 kL		Environmental / human impact risk is low.
Chlorine	0.8 kL		Environmental / human impact risk is moderate.
Sodium Bisulphate	0.62 kL		Environmental / human impact risk is moderate.
Ion exchange resin	12.2 m^3		Environmental / human impact risk is low.
Greensands/DMI65	12.2 m^3		Environmental / human impact risk is low.
Diesel	• 380 kL (0 - 3 yrs) • 232 kL (3-10 yrs)		Environmental / human impact risk is moderate. Supplemented by solar / batteries.
Sludge		a) 107,700m^3 b) 54,400m^3	a) Conventional: Deposit to Main Pit during backfill. Deposit to WSF post backfill. b) Dry press: Deposit to WSF. No further treatment required to stabilise sludge.
Skill set	1 skilled operator (remote). 2 support staff (site based), plus redundancy.		24-7 operation.
Reliance			Proven technology and practiced worldwide.

2.3 Electrocoagulation

2.3.1 Description

Electrocoagulation is a compact, low maintenance, low power solution to the removal of contaminants in water. It is a well-known process and has been commercialised for industrial treatment on a large scale in the US and Europe. It was first discovered when miners realised the water discharging from rusty pipes was cleaner than new pipes. It still operates on the same principle but on a significantly larger scale.

The treatment system has no moving parts and consists of charged parallel plates of aluminium, iron, sometimes stainless steel and titanium (if disinfection is required) submerged in batch reactor. It relies on the reduction of water to form hydrogen and hydroxyl (OH-) ions. The free hydroxyl (OH-) ions attach to aqueous metals and salts in the water to form a precipitate. The waste hydrogen bubbles formed in the process float the coagulated precipitates to the surface to form a scum which is periodically scraped off into a hopper. Heavier precipitates drop to the bottom however this will not occur at Rum Jungle as fats and oils are not present in the water.

The metal plates require replacement every 3 to 6 months depending on the treatment demand, plate thickness, current, gap, arrangement etc. It does not require any chemicals and can generally operate solely on solar energy. Voltages vary between 10 and 40 volts so lowly skilled operators can be used. Currents are between 1 and 100 Amps which is varied to achieve cyclic cleaning.

2.3.2 The science of electrocoagulation

The following simple reactions occur in the process:

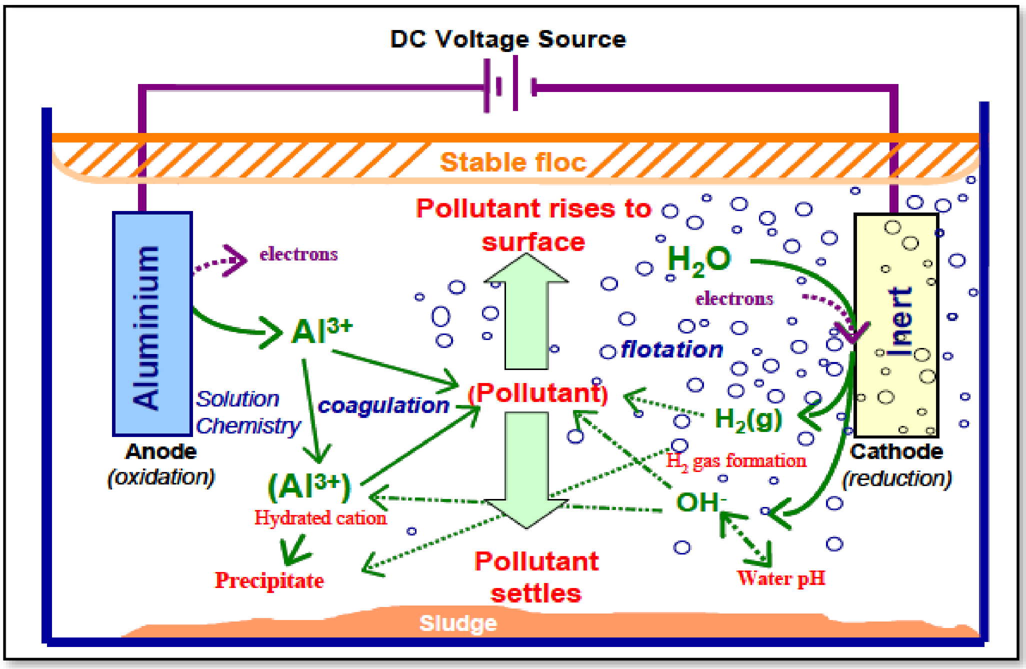
$$\mathbf{Al \longrightarrow Al^{3} + 3e^{-}}$$

$$\mathbf{Fe \longrightarrow Fe^{3} + 3e^{-}}\ \textbf{anode}$$

$$\mathbf{2\,H_2O + 2e^{-} \longrightarrow 2\,(OH)^{-} + H_2}\ \textbf{cathode}$$

The oxidation of the water at the anode causes the formation of H+ ions which, due to their charge, are attracted to the cathode. On the cathode, the reduction of water to form hydrogen causes the formation of hydroxyl (OH-) ions which, due to their charge are attracted to the anode. A series of processes take place in the reaction namely ionisation, destabilisation, oxidoreduction, electrolysis, free radical formation, electromagnetic field formation, emulsion breaking and separation.

Figure 6 The science of the electrocoagulation reactor



Due to the free ions in the water the influent becomes a conductor, allowing the DC current to pass freely throughout the chamber. The electrodes react to the current by releasing charged metal ions into the influent at a rate of 0.04kg/m³ treated. The flooding of electrons into the influent neutralises charged particles, causing them to be pulled out of suspension.

2.3.3 Construction

The reactors are constructed of epoxy coated mild steel frame with a HDPE lined cell with separated chambers which target different metals and pH progression. The standard dimension is approximately 7m x 2.1m x 1.8m but this can be customised to the project needs. The roof is a dual use solar panel. A battery bank is designed to power the machine at night and several days without solar gain. Refer **Figure 3**.

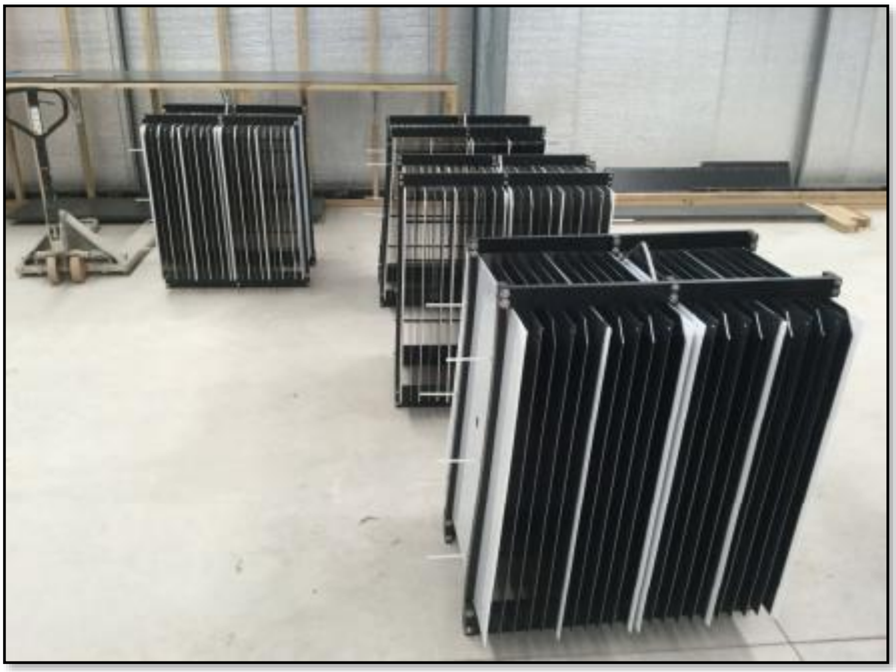
The electrodes are fixed at designed distances apart according to the metals to be targeted and the concentration. They a mix of alternating Aluminium, Iron, Stainless Steel and sometimes Titanium depending on the influent composition and required quality. Refer **Figure 4.** The electrodes decay as they liberate metal ions and need to be replaced every three to six months depending on the voltage applied and required demand.

An automatic scraper periodically scrapes the floating foam to a launder which discharges to a skip. The foam is the aerated metal precipitates which dry and compact in the skip which is periodically removed for disposal or on-sale (in the case of metals).

It is recommended for this option that the systems be installed at each of the main groundwater extraction areas as well as at the Main and Intermediate Pits.

Figure 3 Replacement of reactor plates and elevation view of solar powered electrocoagulation reactor

Figure 4 Prepared electrodes ready for installation



2.3.4 Operation on the Rum Jungle Site

The capacity of each reactor is between 150 and 4,000 kL/d depending on the concentration of influent and level of treatment required. Water passes through the units under gravity. The operation is most efficient with a constant flowrate. This water treatment option would suit a discharge from groundwater bore pumps which discharge between 1 and 2L/s each so several groundwater bores could discharge to the one reactor in a clustered arrangement. This clustered arrangement would be utilised in preference to a centralised Water Treatment Plant arrangement. For the Main Pit surface water treatment – this plant would only be required for the duration of Pit Backfilling and this module could be decommissioned in its entirety once no longer required. This may require several units in line to keep up with the inputs required to ensure continuity of Main Pit Backfilling rates.

Reactors are placed on a flattened ground or elevated on footings to allow flood waters to pass under. The source is connected to the inflow and the treatment process is active when power is applied.

It is feasible for treated effluent to gravitate directly to the EBFR diversion channel from each reactor and discharge compliance monitoring could be carried out from each clustered reactor's discharge point rather than from a centralised Water Treatment Plant. If treated effluent is to discharge to the regulated point of discharge on the EBFR west of the site, then the reactors would need to be elevated to provide sufficient head to gravitate by pipe otherwise it would need to be pumped in a rising main.

2.3.5 Treatment capability of Electrocoagulation

The performance of a project of a similar nature was sourced as an example of the capability of Electrocoagulation, however Pilot plant trials are absolutely critical in the design of the Electrocoagulation electrodes for a particular influent. They are designed to target particular metals and associated concentrations. It should be noted that the Rum Jungle site, particularly target groundwater, is heavily contaminated and the concentrations from the sample site are likely to be very different to the Rum Jungle site.

Table 6 summarises the indicative treated water concentrations with a comparison to the required LDWQO concentrations. Note that the water quality presented here is to demonstrate that the technology could be used in a clustered arrangement with different achieved output qualities based on the different source water qualities for each cluster.

Table 6 Estimated treatment capability using Electrocoagulation. Performance based on a similar project against the highest concentration recorded at each location between 2008 and 2013.

Analyte	Zone 2 LDWQO (mg/L)	Removal Rate [1]	Main Pit SW (mg/L)	Main WRD East GW (mg/L)	Main WRD West GW (mg/L)	Int Pit WRD GW (mg/L)	Old Tailings GW (mg/L)	Leach Heap GW (mg/L)
Arsenic	0.14	97.12%	0.000	nd	nd	nd	nd	nd
Aluminium	0.236	99.69%	0.002	0.063	0.057	0.118	0.000	0.117
Cadmium	0.004	98.40%	0.000	0.000	0.001	0.001	0.000	0.000
Cobalt	0.089	82.71%	0.031	0.821[2]	2.006[2]	3.458[2]	1.651[2]	20.748[2]
Copper	0.0602	99.75%	0.001	0.010	0.039	0.050	0.021	2.142[2]
Iron (2+ and 3+)	0.300	99.72%	0.006	0.210	0.059	0.406	0.000	0.176
Manganese	0.759	98.27%	0.039	0.732	0.879[2]	0.604	0.124	4.100[2]
Nickel	0.1304	99.96%	0.000	0.002	0.004	0.006	0.002	0.037
Magnesium	86.6	99.66%	0.044	0.014	8.976	9.758	0.677	3.910
Lead	0.0129	99.46%	0.000	0.000	0.000	0.000	0.000	0.000
Zinc	0.2105	99.90%	0.000	0.004	0.020	0.029	0.006	0.017
EC (µS/cm)	2,985	99.49%	1	91	68	72	15	49
Sulphates	1,192	78.00%	37	3740[2]	2486[2]	2552[2]	299	1687[2]

1 Based on one project of a similar nature.

2 These exceedances would be addressed during the critical pilot plant testing, most likely by the addition of extra electrolysis cells, reducing the gap and voltage of the electrodes.

2.3.6 Chemicals

Electrocoagulation does not require chemicals. The process operates most efficiently with an influent at a pH between 5 and 6. If the pH is lower than 5 then pre-treatment is performed either on the suction side of the pump by charging the raw water with an electrode which releases hydroxide ions or passing the raw water through a primary cell running at a higher voltage to release hydroxide ions. Both processes raise the pH before entering the reactor. The operation is computer controlled with feedback loops. The treated water is released with a pH between 7 and 8.

As this technology has not yet been demonstrated for highly impacted acid mine drainage, pre-treatment and subsequent chemical use may be required.

2.3.7 Sludge

The sludge produced in the Electrocoagulation process is a stable metal precipitate. It is captured in a skip bin as a dried powder. This material could be on sold or stored safety in the WSFs with no further treatment.

Table 7 Anticipated annual solids production using Electrocoagulation reactors

Location/source	Annual Solids Production (m^3)	Total solids productions (m^3)
Main and Intermediate Pits surface water (first 3 years)	2.19	6.56
Main WRD east (10 years)	2.35	23.5
Main WRD west (10 years)	1.56	15.6
Intermediate WRD (10 years)	1.07	10.7
Leach Heap area (10 years)	8.25	82.5
Old Tailings (10 years)	0.17	1.7
Totals	**16**	**141**

2.3.8 Power

Power consumption is approximately 5kWh per day per reactor. In relative terms the consumption of four reactors is equivalent to an average household power consumption. Each reactor has its own 8 to 10kW solar array mounted above the reactor which also serves as a roof. A Li-Ion battery bank and management system ensures operation 24hours. Three days without solar gain is generally allowed for in the battery sizing. The units can be powered on mains or diesel generation if available.

The power management, monitoring and control can be performed remotely via a 4G remote connection to a mobile phone.

Table 8 Power Requirements

Source	Size	Comments
Solar Array for groundwater bores	295kW	Solar banks adjacent to groundwater bores (10 years)
Battery storage/ inverters/ MCC for groundwater bores	1050 kWh	Garden shed style adjacent to groundwater bores (10 years)
Diesel generator	63kVA	Main pit drawdown (3 years)
Diesel generator	30kVA	Intermediate pit drawdown (3 years)
Solar Array for EC reactors (approx. 46 reactors[1] required to year 3 then 20 reactors to year 10)	460kW	Solar banks on EC reactors (10 years)
Battery storage/ inverters	690 kWh	Attached to EC reactor (10 years)

1 Reactors can be leased for short term operations.

2.3.9 Skill sets

Lowly skilled operators would need to attend the site every three to six months to replace the plates otherwise the reactors would operate automatically. Each reactor has 4G connection and remote monitoring and control. A highly skilled operator located remotely would need to check on and respond to alarms when required. This may involve shedding of the plates by varying voltages or monitoring plate loss rates remotely or responding to spikes in analyte concentrations.

Local staff could be trained to manufacture the replacement electrodes in Darwin or Batchelor. The electrodes would need to be transported to site on a tabletop top truck and lifted into place with a jib crane on the back of the truck. The electrodes have Anderson plug connectors so the wrong polarity does not occur on site.

2.3.10 Precedence and confidence in technology

There are several companies marketing electrocoagulation. One company based in Sydney NSW has successfully implemented electrocoagulation plants in the following industries:

- Borg Manufacturing (MDF sheeting, formaldehydes, wood chip, tannins).
- Coca Cola (sugars, food colours).
- Ibuprofen (pharmaceutical industry).
- Dayco (Metal machining, cutting compounds, aqueous metalloids).
- Blue metal quarry (colloidal particles, dispersive clays).
- Peppies abattoirs (biological matter).
- under negotiation with South 32 underground mine goaf (dissolved metals, coal fines).
- under negotiation with McDonalds (biological matter, high in fats and oils).

This operator indicated the technology is readily used in the US and Europe and internet searches verify this claim. Pilot trials would be required to verify the claim of this supplier as the noted list of applications above do not include demonstrated treatment capacity for acid mine drainage at this time.

2.3.11 Input / Output / Risk Summary

Table 9 summarises the assumed input requirements and output data for the Electrocoagulation system.

Table 9 Electrocoagulation Input / Output Summary

Material	Input Quantity Per annum	Output Quantity Total	Comment
Chemicals	Not required		
Diesel	227 kL		Environmental / human impact risk is moderate. Supplemented by solar / batteries.
Sludge		141 m^3	Dry powder that can be stored in the WSFs with no further treatment. Sludge could be on sold.
Skill set	Low skilled staff for plate replacement during operation. Local industry could cut plates.		24-7 operation.
Reliance			Proven in some settings and applications, however requires Pilot Plant testing

2.4 Membrane Technology

2.4.1 Description

Reverse Osmosis (RO) is a membrane technology in which high pressure is applied to the seepage water within a vessel to force the water through a semi permeable membrane and concentrate the contaminants in a remnant concentrate. RO works by applying enormous pressures (typically 3 to 10MPa = 306 to 1,020m head), greater than the osmotic pressure, that forces water through the membrane while the metal ions and salts are rejected. This process creates two steams:

1. A clean water steam that passes through the membrane (permeate).
2. A stream that contains the metals rejected by the membrane (concentrate).

The waste concentrate stream is typically 25% of the incoming flow. Management of this material will require careful consideration, as typically when desalinating water the concentrate is released back to sea but at Rum Jungle it will not be feasible to reinject the permeate into the ground water.

RO is very compact and discrete but requires a considerable amount of power.

The system would be installed centrally near the Main Pit and surface and groundwater pumped to the WTP for treatment as a combined flow.

2.4.2 Treatment Capability of Membranes

Typical metal concentrations in the permeate are 2% of the feed stream. This level of treatment is inadequate for some analytes to satisfy the LDWQO. One technique is to recirculate the primary treated permeate through a secondary stream. Another technique is to compliment RO with another process up front. The former will be investigated further.

Table 10 summarises the expected treated water concentrations with a comparison to the required LDWQO concentrations for a single pass through RO. The data columns are calculated output water qualities based on averaged input water qualities from various surface water and groundwater sources across site.

Table 10 Estimated treatment capability using a single pass of Reverse Osmosis. Performance based on a similar project against modelled input water quality.

Analyte	LDWQO (mg/L)	Year 1 to 3 (Main Pit SW and GW) - treated water quality results (mg/L)	Year 4 to 10 (GW) – treated water quality results (mg/L)
Arsenic	0.14	0.001	0.000
Aluminium	0.236	0.104	0.514[1]
Cadmium	0.004	0.001	0.001
Cobalt	0.089	0.168[1]	0.628[1]
Copper	0.0602	1.003[1]	3.254[1]
Iron (2+ and 3+)	0.300	0.294	1.318[1]
Manganese	0.759	0.354	1.517[1]
Nickel	0.1304	0.131[1]	0.501[1]
Magnesium	86.6	5.9	36
Lead	0.0129	0.000	0.001

Analyte	LDWQO (mg/L)	Year 1 to 3 (Main Pit SW and GW) - treated water quality results (mg/L)	Year 4 to 10 (GW) – treated water quality results (mg/L)
Zinc	0.2105	0.064	0.357[1]
EC (µS/cm)	2,985	34	261
Sulphates	1,192	28	223

1 A pilot test will verify if a second stage RO will mitigate the exceedances

Initial calculations indicate that a single pass through an RO process would not achieve the LDWQO in the groundwater but would in the Main Pit. The groundwater permeate would need to recycle through a secondary RO.

2.4.3 Chemicals

Due to the high concentrations of potential analytes at Rum Jungle, the RO will require chemical additions to prevent the fouling of the membranes, which occurs through oxidation of the contaminates before it enters the RO. Typically, oxidation of Fe^{2+} to Fe^{3+} and sulphates can occur which foul the membranes unless chemicals are added to prevent precipitation. This can be achieved by lowering the pH to approximately 3.5 before the membrane and then correcting the pH before discharge. This process can be achieved with sulphuric acid to lower the pH and caustic soda to raise the pH. The volumes required in the project are as follows.

Table 11 Chemical needed to assist the RO process

	Annual Volume (kL)	Total Volume (kL)
Sulphuric acid (lower pH)	58 (first 3 years) 13 (3 to 10 years)	265
Caustic soda (raise pH)	55 (first 3 years) 13 (3 to 10 years)	256

It should be noted that operating the membrane with a lower pH than neutral does degrade the membrane faster than normally would be experienced so the operational life would be compromised.

Caustic soda

Caustic Soda (sodium hydroxide) is a Dangerous Class 8 chemical requiring strict management requirements. It is a liquid and delivered to site in 1,250L plastic Intermediate Bulk Container (IBC) with a mild steel frame to provide structural support and enable stacking. When in operation it must be stored in a sealed capture bund with a volume of 110% of the chemical volume.

In the event of a major spill in the vicinity of the EBFR it must be cleaned up immediately. Response personnel must wear protective equipment to prevent skin and eye contamination and the inhalation of vapours. The ground surface will be slippery so response personnel must be aware of potential slips and falls. To minimize discharge to the environment, run off into the drainage path and waterways must be prevented with absorbent material such as soil or sand or other inert material. The contaminated material could be blended with the waste rock as it will increase the pH and lock in PAF material.

This material has been classified as non-hazardous in terms of long-term aquatic hazard as it is rapidly degradable. It is hydrolyzed in soil and does not bioaccumulate and the mobility depends upon water content in soil. Direct contact Caustic terrestrial species is corrosive.

Sulphuric acid

Sulphuric acid is a strong mineral acid present as a colourless and odourless oily liquid when pure but may appear yellow to dark brown when impure. It is extremely corrosive to all body tissues, causing rapid tissue destruction and serious chemical burns. Skin or eye contact requires immediate first aid. Sulphuric acid decomposes at high temperatures, forming toxic gases such as sulphur oxides. It is non-flammable but reacts violently with water, generating large amounts of heat with potential for spattering of the acid. Sulphuric acid reacts with combustible materials to generate heat and ignition. It reacts with most metals, particularly when diluted with water, to form flammable hydrogen gas which may create an explosion hazard.

If spilt in transit to site it must be prevented from entering the drainage systems and bodies of water. It is necessary to dike the spill and pump uncontaminated acid back to process if possible. The spill must be neutralised with sodium carbonate, sodium bicarbonate, soda ash, lime or limestone granules. If neutralized with lime rock or soda ash, good ventilation is required during neutralization because of the release of carbon dioxide gas. Allow to stand for 1-2 hours to complete the neutralization, then absorb any liquid in solid absorbent such as bentonite. If it enters the EBFR then it must be neutralized immediately with one of the alkali chemicals.

It is highly toxic to aquatic organisms and plant life. It has the potential to pose ecological risks to organisms in both aquatic and terrestrial environments.

2.4.4 Sludge

The waste concentrate stream is typically 25% of the incoming flow. **Table 12** summarises the expected concentrate volumes.

Table 12 Sludge production from the RO process

Source	Annual Volume (ML)	Total Volume (ML)
Concentrate Main Pit	633 (3 years)	1,900
Concentrate Groundwater	189 (10 years)	1,899
Total	823	3,799

Management of this material would require evaporation on site and an appropriate storage method for the evaporites. The following summarises the net evaporation on the Rum Jungle site.

Table 13 Net evaporation at the Rum Jungle site

Season	Evaporation (mm)	Rainfall (mm)	Net (mm)
Wet	1167	1422	-256
Dry	1633	200	1434
Annual	2800	1622	1178

The pond area required to evaporate the concentrate is approximately 70Ha. This could be accommodated north northwest of the Main Pit in a stepped evaporation pond. The dried material would be transferred to the WSF or the pond lining wrapped over the dried sludge and capped at the conclusion of the project.

2.4.5 Power

To achieve the enormous pressures required by an RO plant requires a significant amount of energy, typically, 3kWh of power is needed to treat one kL of water. **Table 14** identifies the power requirements.

Power is needed to move water around the site in addition to operating the RO plant. Due to the huge power demands it may be more economical to establish mains power from the 22kW line supplying Brown Oxide.

It is assumed that a combination of solar/batteries and diesel power is used to move water around the site then diesel power would be used to maintain the required water levels in the Main and Intermediate pits and solar/batteries would power the borefield pumping and control valves with mains power to supply the RO.

Table 14 RO Power Requirements

Source	Size	Comments
Solar Array	295kW	Solar banks adjacent to groundwater bores (10 years)
Battery storage/ inverters/ MCC	1050 kWh	Garden shed style adjacent to groundwater bores (10 years)
Diesel generator	63kVA	Main pit drawdown (3 years)
Diesel generator	30kVA	Intermediate pit drawdown (3 years)
Mains power to supply the RO plant	9,878 MWh annually (years 1 to 3)	Pit water and groundwater
Mains power to supply the RO plant	2,280 MWh annually (years 3 to 10)	Groundwater only

2.4.6 Skill sets

Highly skilled operators are required to manage an RO plant. The antifouling chemicals are Class 8 and require specialist training to manage the safety. A highly skilled Operator would need to attend on a day shift and be on call at other times. Two moderately skilled operators would be required to maintain the membranes at other times.

2.4.7 Precedence and confidence in technology

There is significant precedence for using RO in metalloid removal and mining.

2.4.8 Input / Output / Risk Summary

Table 15 summarises the input requirements and output data for the membrane technology system.

Table 15 Membrane Input / Output Summary

Material	Input Quantity Per annum	Output Quantity Total	Comment
Sulphuric acid	265 ML		High Environmental Risk
Caustic soda	256 ML		Low Environmental Risk

Material	Input Quantity Per annum	Output Quantity Total	Comment
Diesel	227 kL		Environmental / human impact risk is slightly hazardous. Supplemented by solar / batteries.
Mains Power	12,200 MWh		Only option requiring mains power
Sludge		823 ML	Evaporated and the waste product stored in the WSF or on sold for metals processing
Skill set	1 highly skilled operator 2 moderately skilled operators		24-7 operation.
Reliance	Significant precedence		Will require two stage RO to deliver LDWQOs.

2.5 Anaerobic Sulphate Reducing Bacteria (SRB) Wetlands

2.5.1 Description

Constructed anaerobic wetlands rely on various bacteria to remove aqueous metal ions from solution. The bacteria are supported and fed by an environment of organic and inorganic materials such as wood waste, hay, composted manure, limestone and bacteria. Anaerobic wetlands work in unison with the accompanying limestone to precipitate aqueous metals as sulphides, hydroxides and carbonates. The SRB use the decay products of the organic substrate (i.e., the fermenting cellulose) and sulphate as nutrients. The bacteria convert sulphates to hydrogen sulphide to reduce the metalloids. SRB cells work most efficiently on slightly acidic water (pH 5) but will still operate up to a pH of 9. Successful operation has been reported to pH 2 (Gusek, 1998, 2009).

These systems are very efficient at removing aqueous metals. Some of the metals are removed as sulphides i.e., PbS, CdS, CuS, ZNS, FeS, some as hydroxide precipitates i.e., $Al(OH)_3$, $Cr(OH)_3$ and others as carbonates $FeCO_3$. Arsenic is removed but the mechanism is unknown. In the bacterial conversion of sulphate to hydrogen sulphide, bicarbonate alkalinity is produced.

Typically, ARB cells will operate successfully for a period of approximately 30 years. Replenishment of the reservoir of organic and inorganic material is required after this period to maintain the bacteria.

The volume of substrate that is required to achieve the sulphate reduction is a function of:

- Flow rate.
- Concentration of divalent metals (i.e., Fe^{2+}, Cu^{2+} etc).
- Concentration of trivalent metals (i.e., Fe^{3+}, Al^{3+} etc).
- pH of the influent.
- Rate of sulphate reduction.

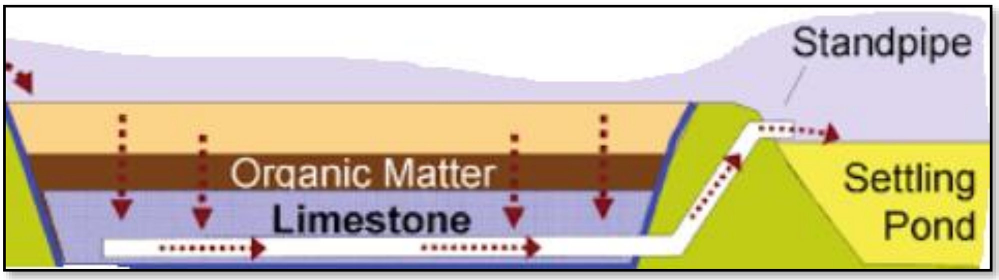
As there is no mixing in the substrate, if the acidity is too low (i.e., less than pH 5) the influent will need to be spread over a very large area to avoid removing the neutralisation capacity in the top of the substrate which will cause the sulphate reduction process to cease. The loading can range between 70 and 360 L/min/m^2 depending on the incoming acidity. Blending with treated water or water from other sources can also achieve this aim. This will require the wetland to be increased in size to cater for the larger flow.

After the anaerobic cells the treated water passes through aeration /settlement basin where precipitates settle. Based on Stokes calculations a 4.5 day settlement period is required to separate precipitates before the treated water is pumped to the EBFR with Aluminium Hydroxide requiring the longest settling time.

2.5.2 Construction

The system would be installed centrally near the Main Pit and surface and groundwater pumped to the WTP for treatment as a combined flow. The cells are often compartmentalised to manage operational issues. The cells are lined with welded HDPE sheets. It is important the top 0.5m layer is rich organic matter consisting of cow manure, sawdust, bark chips, and hay to strip dissolved oxygen and reduce ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}) which prevents plugging in the layers below. Below this layer is filled with a mixture of composted cow manure, sawdust, bark chips, hay, alfalfa, seeded bacteria and inert limestone. The depth of media is approximately 2 to 3m. A geonet separates the media from the limestone cobles below. 0.5m to 1m limestone cobbles underline the layer of organic material. The collection and distribution pipes are perforated HDPE and dendritic in arrangement. The pipes are sleeved with geofabric.

Figure 5 Construction of the SRB anaerobic cell and settling pond



The drainage pipes convey the water into an aerobic pond where the metals are precipitated and settle under gravity. This process can be accelerated with Lamella clarifier which reduces the plan area of the settlement pond by 80%.

2.5.3 SRB Cell Dimensions and Location on Site

The SRB cells required would be at a centralised location and would be of the order 44 Ha. A 50% safety factor is recommended when sizing and has been included.

The important requirement is an even distribution of influent across the surface of the cell as the flow path is vertical through the media.

2.5.4 Settlement Pond Dimensions and location of site

The settlement ponds could be adjacent to or downstream of the SRB cells. Flow from one to the other would be via gravity so the elevation between cells would need to suit the local topography. An approximate area of 46 Ha would be required, assuming a 50% safety factor. A depth of 1.5m has been assumed to promote solids accumulation. Settlement could be aided with a corresponding 80% reduction in sizing with the use of mobile lamella clarifiers.

The combined 90 Ha footprint may not be available at the Rum Jungle site.

2.5.5 Chemicals

There are no additional reagents required to operate SRB anaerobic cells apart from those used in the construction as shown in **Table 16**. The projected life is approximately 30 years based on carbon depletion from pilot trials (Gusek, 1998, 2009).

The 'reagents' used during construction include:

- Rich organic matter composed of composted cow manure, sawdust, hay
- SRB substrate composed of composted cow manure, sawdust, hay, alfalfa, Seeded *Desulfovibrio* and *Dessulfotomaculum* Bacteria and crushed limestone
- Limestone cobbles

Table 16 Reagent input at construction

Rich organic matter (no limestone) (m^3)	Rich organic matter with seeded bacteria & crushed limestone (m^3)	Limestone cobbles (m^3)
21,939	131,635	43,878

2.5.6 Water Quality Results

Table 17 summarises the expected treated water concentrations with a comparison to the required LDWQO concentrations for a single pass through RO. The data columns are calculated output water qualities based on averaged input water qualities from various surface water and groundwater sources across site.

Table 17 Estimated treatment capability using a single pass of Reverse Osmosis. Performance based on a similar project against modelled input water quality

Analyte	LDWQO (mg/L)	Year 1 to 3 (Main Pit SW and GW) - treated water quality results (mg/L)	Year 4 to 10 (GW) – treated water quality results (mg/L)
Arsenic	0.14	0.005	0.000
Aluminium	0.236	0.037	0.184
Cadmium	0.004	0.015	0.012
Cobalt	0.089	2.097	7.844
Copper	0.0602	2.712	8.795
Iron (2+ and 3+)	0.300	0.586	2.622
Manganese	0.759	2.162	9.251
Nickel	0.1304	0.203	0.775
Magnesium	86.6	36	222
Lead	0.0129	0.001	0.006
Zinc	0.2105	0.489	2.728
EC (µS/cm)	2,985	208	1,592
Sulphates	1,192	170	1,360

The results indicate it is **unlikely** the SRB system can achieve the required LDWQOs.

2.5.7 Sludge

Sludge is generated which is captured in the settling pond, however some of the precipitates will remain in the media. The ponds have been sized to accommodate the total solids load. At the conclusion of the project the supernatant is recycled through and forced evaporated, and the sludge either on sold, transferred to the WSFs as a sludge or could be encapsulated by HDPE in the operating locations and buried. No further treatment is required to stabilise the sludge material.

Table 18 Anticipated annual solids production

Years 1 – 3 Annual Solids Production (m^3)	Years 4 – 10 Annual Solids Production (m^3)	Total Solids Production (m^3)
29.2	33.7	325

2.5.8 Power

Power is needed to move water around the site, but the SRB cells are designed to utilise gravity in the movement of water through the cells.

An NPV calculation has confirmed it is more cost effective to implement a combination of solar/batteries and diesel power to move water around the site. Diesel power would be used to maintain the required water levels in the Main and Intermediate pits and solar/batteries would power the borefield pumping and control valves. **Table 19** summarises the power requirements.

Table 19 Power Requirements

Source	Size	Comments
Solar Array	295kW	Solar banks adjacent to groundwater bores (10 years)
Battery storage/ inverters/ MCC	1,050 kWh	Garden shed style adjacent to groundwater bores (10 years)
Diesel generator	63kVA	Main pit drawdown (3 years)
Diesel generator	30kVA	Intermediate pit drawdown (3 years)

2.5.9 Skill sets

A moderately skilled Operator would be required to take weekly samples to ensure the cells are operating as designed. A highly skilled Operator would be required to analyse the results and attend site and determine solutions if issues are identified periodically.

2.5.10 Precedence and confidence in technology

There is significant precedence worldwide on mining sites. SRB cells and settlement ponds and are often constructed ahead of the mining operation.

2.5.11 Input / Output / Risk Summary

Table 20 summarises the input requirements and output data for the SRB wetlands system. Note that the significant area of land required to operate this system may contribute additional environmental harm to the project and would require a full engineering risk assessment to decide suitability.

Table 20 SRB Wetlands Input / Output Summary

Material	Input Quantity Per annum	Output Quantity Total	Comment re: Environmental Risk
Organic matter (no limestone)	21,940 m^3		No risk
Organic matter (with crushed limestone and seeded bacteria)	131,635 m^3		Considered a low risk but a bacterial infestation unknown
Limestone cobbles	43,878 m^3		No risk
Diesel	227 kL		Environmental / human impact risk is slightly hazardous. Supplemented by solar / batteries.
Sludge		325 m^3	Can be on sold, stored in the WSFs or encapsulated locally with no further treatment.
Skill set	1 x moderately skilled operator permanent 1 x highly skilled operator occasional		
Reliance	Significant precedence		Is often used as a cost effective means to mining metals, however at Rum Jungle it may not provide the required performance. Required footprint may also not be available.

3 Summary and Conclusions

Table 21 summarises the comparison of the proposed options, including commentary on:

- Reagent inputs.
- Sludge output volumes and treatment.
- Power requirements.
- Plant mobilisation.
- Skill set requirements.
- Technology precedence.
- Hazardous compounds.

The Department question is as follows:

"Please provide either a finalised Wastewater Treatment Plant (WTP) design or a shortlist of design options. This information should include a description of the chemicals to be used, the quality and quantity of water to be discharged, and the quantity, composition and methods to be implemented for disposal of sludge.

The Department is of the view that, without this information, the WTP in itself may pose a potential and additional environmental and chemical risk to the Finniss River."

In response the following is noted:

- A shortlist of 4 possible design options is presented:
    - Traditional high density sludge method that can **meet LDWQOs**.
    - Electrocoagulation is a more recent development and **may meet LDWQOs**.
    - Reverse Osmosis (RO), a traditional technology, that **may meet LDWQOs** but requires significant power to run the process and footprint to accommodate the evaporation ponds. Pilot testing is recommended to verify the effectiveness of the second stage RO to meet LDWQO.
    - SRB wetlands, a traditional technology that **may not meet LDWQOs** and requires significant footprint.
- Treatment of mine impacted water is evolving constantly and there may be more cost-effective solutions available in the market that can meet the LDWQOs.
- A combination of the processes may also provide the highest value approach for the Project. Market sounding and Expression of Interest from the market will determine what options are available.

Table 21 Option Comparison Summary

Description	Ability to meet Zone 2 LDWQOs	Input Reagents	Power Input	Sludge Volume	Plant Mobilisation	Skill Set	Precedence	Human health/ Environmental Risks
HDS 'Geco' with Ion exchange resins and Greensands/DMI65 catalytic filtration media	Yes.	Lime. Flocculant. Carbon dioxide. Hydrochloric acid. Chlorine. Sodium bisulphate. Ion exchange resin. Greensands/DMI65 media.	Diesel = 2,764kL. Supplemented by solar / batteries.	107,700 m^3 wet OR 54,400 m^3 if dry pressed. No further treatment required to stabilise sludge.	Complex pipe and control network, significant earthworks.	1 skilled operator (remote). 2 support staff (site based), plus redundancy.	Proven technology and practiced world wide.	Low to high risks associated with reagents and diesel.
Electrocoagulation	Possibly, pilot testing necessary for design.	None required.	Diesel = 227kL. Supplemented by solar / batteries.	141 m^3. Dry powder that can be stored in the WSFs with no further treatment. Sludge could be on sold.	Self contained units mobilised to site.	Low skilled staff for plate replacement during operation. Local industry could cut plates.	Proven in other settings and applications, however not yet proven in treating high density AMD. Would require Pilot testing.	Moderate risks associated with diesel. Low voltage power.
Reverse osmosis	Yes, pilot testing necessary for design.	Sulphuric acid. Caustic soda.	Diesel = 227kL. Significant mains power required. Supplemented by solar / batteries.	3,799 ML. An evaporation pond with a surface area of 70Ha is required.	Compact plant but requires a 70 Ha evaporation pond.	1 highly skilled operator. 2 moderately skilled operators.	Proven technology in this application but requires pilot testing to verify if secondary RO will achieve the LDWQO otherwise it needs to be coupled with another process.	High risk with sulphuric acid.
SRB wetland	Unlikely.	Organics (no limestone). Organics (with crushed limestone and seeded bacteria). Limestone cobble.	Diesel = 227kL. Supplemented by solar / batteries.	325 m^3. Can be on sold, stored in the WSFs or encapsulated locally with no further treatment.	Significant earthworks, requires 90 Ha footprint for treatment cells and settlement ponds which may not be available.	1 moderately skilled operator permanent. 1 highly skilled operator occasional.	Is often used as a cost effective means to mining metals, however at Rum Jungle it may not provide the required performance. Required footprint may also not be available.	Moderate risks associated with diesel. Low voltage power.

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