# Water Treatment Study

*Bendigo-Ophir Gold Project*

*9 October 2025*

*J-NZ0464-002-R-Rev2*

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Prepared for:

*Matakanui Gold Limited*

15a Chardonnay Street, Cromwell, 9310

Prepared by:

*Mine Waste Management Limited*

5 Sir William Pickering Drive, Burnside, Christchurch 8053, New Zealand

+64 3 242 0221

www.minewaste.com.au

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# EXECUTIVE SUMMARY

Mine Waste Management Limited (MWM) has been engaged by Matakanui Gold Limited (MGL) to provide guidance on water treatment for Mine Impacted Water (MIW) for the proposed Bendigo-Ophir Gold Project (BOGP).

**Objectives of this Study**

The objectives of this report are to:

- Review the expected water treatment requirements during the Active Closure and Post Closure Phases of the BOGP when treated MIW will be released from site.
- Provide guidance on the Water Treatment Plant (WTP) that will be operational during the Active Closure Phase of the BOGP.
- Provide guidance on the Passive Treatment System(s) (PTS) that will be required during the Post Closure Phase of the BOGP.

**Findings**

The water and load balance model (WLBM) and other studies indicate that the BOGP needs to focus on the management and treatment of MIW that will contain potential constituents of concern (PCOC). Specifically:

- Water management to minimise the amount of water that requires treatment during the closure phases.
- Treatment of MIW by a WTP within the Shepherds Creek catchment during the active closure phase until PTS can be successfully established after a number of decades (~ 50 years).
- Partial passive treatment of the SRX Pit Lake overflow in the Rise and Shine catchment.
- PTS are likely to be operational for many decades once installed.

The following PCOC may require treatment by the WTP and PTS to achieve the proposed water quality limits for the BOGP (Ryder, 2025):

- Nitrogenous compounds (N) that include nitrate ($NO_3$) and ammoniacal-N (Amm-N).
- Sulfate ($SO_4$).
- Metals and metalloids that may include Aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), uranium (U), and zinc (Zn)
- Cyanide (CN) within the tailings water.

**Management**

Water management during the Operational Phase of the BOGP will involve discharge of only episodic runoff from haul roads and ELF surfaces. All other MIW (e.g., landform seepage) will be collected, used, and stored on site within the TSF. In the Active Closure Phase and Post Closure Phase, MIW will be treated and discharged to the receiving environment.

Order of magnitude (OoM) studies indicate that active and passive water treatment can achieve closure water quality objectives as defined by Ryder (2025), although further feasibility studies are required to confirm treatment performance and the ability to transfer from active to passive treatment.

**Project Description**

MGL is proposing to establish the BOGP, which comprises gold mining operations, processing operations, ancillary facilities and environmental mitigation measures on Bendigo and Ardgour Stations in the Dunstan Mountains of Central Otago. The project site is located approximately 20 km north of Cromwell and will have a maximum disturbance footprint of 550 hectares.

The total Mineral Resource Estimate for the BOGP using a 0.5 g/t cut-off for open pit and 1.5 g/t for underground is 34.3 Mt at 2.1 g/t for 2.34 M oz (MGL, 2025). The Bendigo-Ophir resources occur in four deposits: Come in Time (CIT), Rise and Shine (RAS), Srex (SRX), Srex East (SRE). The majority of identified mineral resources are located within the RAS deposit. Three primary geological units are recognised at site:

- RSSZ – Rise and Shine Shear Zone
- TZ3 – Lower Greenschist facies Textural Zone 3 rocks of the Otago Schist
- TZ4 – Upper Greenschist facies Textural Zone 4 rocks of the Otago Schist

The proposed BOGP will include the following components:

- Open pits targeting the RAS, SRX, SRE, and CIT deposits.
- An underground mine targeting the RAS deposit.
- Three ex-pit engineered landforms (ELFs) – Shepherds ELF, SRX ELF, and West ELF (WELF).
- Two in-pit landforms (backfill) – CIT and SRE[1].
- Plant and processing area, where CIL extraction technologies will be used as part of the ore recovery process. This includes the Shepherds Creek Fill (SCK Fill).
- A tailings storage facility (TSF) and TSF Embankment.
- Other ancillary support services / structures (e.g., roads, water management infrastructure, water treatment plants, etc).

[1] *Note: SRE Pit is backfilled by the SRX ELF.*

**Water Treatment**

During the Active Closure Phase, water treatment is required by a WTP once the project switches from a process of internal water management for MIW (during operations) to discharge of MIW from site after closure of the mine. WLBM results indicates that the WTP can be replaced by PTS within decades of mining cessation, which then defines the commencement of the Post Closure Phase.

Flow Rates

Flow rates that require treatment are presented in Table E1. Flow rates are based on a net percolation (NP) rate of 20% of rainfall. It is proposed that a NP rate of 20% may be achievable, with appropriate engineering controls (i.e., an engineered cover system).

Table E1: Estimated average water quantity per mine domain.

| MINE DOMAIN | WTP DESIGN CRITERIA (L/s) | PTS (L/s) | COMMENTS |
|---|---|---|---|
| Shepherds ELF | 4 | 4 | 20% Net percolation (MWM, 2025b) |
| SRX ELF [1,2] | - | 1 | 20% Net percolation (MWM, 2025b) |
| West ELF [2] | 1 | 1 | 20% Net percolation (MWM, 2025b) |
| Shepherds TSF | 13.4 | 3 | Flow is expected to be ~13.4 L/s decreasing to 3 L/s after 5 years (MWM, 2025c). |
| RAS Underground Portal | 6 | 6 | Flow from the RAS Underground is not expected for 20-30 years after closure (MWM, 2025c). |
| CIT Pit Backfill | 1.5 | 1.5 | Further details are available in MWM (2025c). |
| SRX Pit | - | 8 | Further details are available in MWM (2025c). It is assumed this water will not require active treatment. Passive treatment is required. |
| SCK Fill [2] | 1 | 1 | 20% Net percolation (MWM, 2025b) |
| Non-NMD impacted water | - | - | Managed for TSS separate to the active WTP. At closure rehabilitated surfaces are assumed to be suitable for discharge with TSS management. |

1. *Active treatment for SRX ELF and SRX Pit is not anticipated.*
2. *Flow rates rounded up to 1 L/s*

Active Water Treatment

Active treatment is expected for a number of decades (~ 50 years). During this period, the BOGP processing plant would be disestablished and the passive treatment system established. Process Flow (2025) note that the WTP will include the following processes:

- Surge sump
- Pontoon mounted pumps for plant feed
- Metal hydroxide precipitation and settling
- Gypsum precipitation and settling

- Ettringite precipitation and settling
- Carbonation and pH trimming
- Treated water sump
- Sludge management

Other processes that will likely be needed in addition to the active WTP are:

- Cyanide destruct on the Shepherds TSF influent stream.
- Potential additional nitrate removal after WTP via biological processes.

Process Flow (2025) indicate that the proposed water quality objectives (Ryder, 2025) can be achieved, although further work is required to develop the OoM study to a feasibility study (FS) level. Further details are provided in Appendix B. The WTP will operate until passive treatment systems can be installed to successfully treat MIW.

Passive Treatment System

Based on the identified PCOC for the BOGP a multi-stage passive treatment system is expected. This would include:

- Sediment management to mitigate any residue sediment and prevent the PTS from being overwhelmed with sediment.
- Oxidation to encourage $Fe(OH)_3$ precipitation and adsorption of metals such as As and V.
- Anaerobic treatment to remove nitrate, reduce sulfate concentrations, and precipitate metals as sulfides.
- A polishing pond to remove secondary contaminants generated in the anaerobic treatment stage (e.g., sulfide ($HS^-$), ammoniacal nitrogen, and low dissolved oxygen).

Preliminary treatment efficiencies for the PTS are provided in Table E2. These efficiencies will require validation once mining commences, and MIW is available for trials. Data highlighted in yellow have lower confidence and further work is needed to confirm the passive treatment systems will be appropriate.

Table E2: PTS Treatment Efficiencies

| PARAMETER | REMOVAL EFFICIENCIES [1] |
|---|---|
| Calcium | -43.2% |
| Magnesium | 8% |
| Aluminium | 83.3% |
| Arsenic | 99% [2] |
| Iron | 99.1% |
| Nickel | 97.9% |
| Zinc | 99.8% |
| Manganese | 86.4% |
| Cadmium | 85.2 [3] |

| PARAMETER | REMOVAL EFFICIENCIES [1] |
|---|---|
| Cobalt | 98.4% |
| Copper | 85.6 [3] |
| Uranium | 74% [3] |
| Vanadium | 90% [8] |
| Other metals | 98% [4] |
| Sulfate | 30% [5] |
| Nitrate nitrogen | 99% |
| Ammoniacal nitrogen | 99% [6] |
| Cyanide | 90% [7] |

*1. – where data are taken from Table 9 for MSR and limestone is assumed to be part of the treatment media.*

*2. – where data are taken from Hayton et al. (2022) = 95% removal with additional Fe to increase As removal to 99% (e.g., Raven et al., 1998).*

*3. – where data are obtained from Trumm et al. (2024).*

*4. – where data are assumed to be comparable to other metals removed by a MSR (Table 9).*

*5. – Based on 30% removal as determined from literature (Figure 21).*

*6. – Assumed to be 99% to be in alignment with nitrate removal efficiencies. Further work is required.*

*7. – Based on studies by Álvarez et al. (2004).*

*8. – Zhang et al. (2022).*

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# 1 INTRODUCTION

Mine Waste Management Limited (MWM) has been engaged by Matakanui Gold Limited (MGL) to provide guidance on water treatment for Mine Impacted Water (MIW) for the proposed Bendigo-Ophir Gold Project (BOGP).

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- PTS are likely to be operational for many decades once installed.

## 1.1 Background

MGL is proposing to establish the BOGP, which comprises gold mining operations, processing operations, ancillary facilities and environmental mitigation measures on Bendigo and Ardgour Stations in the Dunstan Mountains of Central Otago. The project site is located approximately 20 km north of Cromwell and will have a maximum disturbance footprint of 550 hectares.

The total Mineral Resource Estimate for the BOGP using a 0.5 g/t cut-off for open pit and 1.5 g/t for underground is 34.3 Mt at 2.1 g/t for 2.34 M oz (MGL, 2025). The Bendigo-Ophir resources occur in four deposits: Come in Time (CIT), Rise and Shine (RAS), Srex (SRX), Srex East (SRE). The majority of identified mineral resources are located within the RAS deposit. Three primary geological units are recognised at site:

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- Two in-pit landforms (backfill) – CIT and SRE[2].
- Plant and processing area, where CIL extraction technologies will be used as part of the ore recovery process. This includes the Shepherds Creek Fill (SCK Fill).

[2] *Note: SRE Pit is backfilled by the SRX ELF.*

- A tailings storage facility (TSF) and TSF Embankment.
- Other ancillary support services / structures (e.g., roads, water management infrastructure, water treatment plants, etc).

## 1.2 Mine Plan

The proposed mine plan is shown in Table 1 as a schedule of activities. The transition from active treatment to passive treatment is expected to be in the order of decades and will require further studies during the operational phases of the proposed BOGP.

Table 1. BOGP Mine Plan

| MONTH | YEAR | MINING PHASE | DESCRIPTION OF PHASE |
|---|---|---|---|
| | | **Pre-startup** | Detailed design phase |
| 0 to 6 | 0 to 0.5 | **Startup** | Pioneering / RAS Pre-Strip, Initial Jean Creek Silt Pond, earthworks at process plant. |
| 6 to 24 | 0.5 to 2 | **Project Development** | Construction of process plant, TSF, Shepherds Silt Pond, North Diversion Channel, Commissioning, mining RAS pre-strip (Pre-strip ends month 19). |
| | | **Operations** | |
| 25 to 54 | 3 to 4.5 | RAS pit mining on its own | Operations (pit ore production in month 20. UG Development begins month 54) |
| 54 to 72 | 4.5 to 5 | RAS pit with UG development | Operations (UG Ore production begins month 70) |
| 72 to 132 | 6 to 11 | RAS pit plus RAS UG | Operations (UG Ore production months 70 to 150) |
| | | RAS Pit plus RAS UG plus CIT Pit | Operations (CIT Pit mined months 102 to 114) |
| | | RAS Pit plus RAS UG, plus CIT backfilled, plus Srex | Operations (Srex Pit mined months 145 onwards) |
| 120 - 160 | 10 to 13.3 | RAS UG continues on its own with CIT and Srex open pit feeds | Operations (all mining halted month 160) |
| | | **Closure** | |
| 160 - 372 | 11 to 31 | **Active Closure** [1] | All mining halted. Active closure of pits, TSF, and wider site, plus setup of active water treatment plant (option). |
| 372 - | 31 onwards | **Post-Closure** | Passive treatment and maintenance |

*TSF = Tailings Storage Facility; UG = Underground*

*1. Presented as two decades as part of the Pre-feasibility Mine Plan*

## 1.3 Report Objectives

The objectives of this report are to:

- Review the expected water treatment requirements during the Active Closure and Post Closure Phases of the BOGP when treated MIW will be released from site.

- Provide guidance on the Water Treatment Plant (WTP) that will be operational during the Active Closure Phase of the BOGP.
- Provide guidance on the Passive Treatment System(s) (PTS) that will be required during the Post Closure Phase of the BOGP.
- Provide recommendations to advance the current studies from an order of magnitude (OoM) desktop assessment to a feasibility Study (FS) stage.

# 2 PROJECT DESCRIPTION

This section provides an introduction to the BOGP.

## 2.1 Introduction

MGL is proposing to establish the BOGP (Figure 1), which comprises gold mining operations, processing operations, ancillary facilities and environmental mitigation measures on Bendigo and Ardgour Stations in the Dunstan Mountains of Central Otago. The project site is located approximately 20 km north of Cromwell and will have a maximum disturbance footprint of 550 hectares.

The total Mineral Resource Estimate for the BOGP using a 0.5 g/t cut-off for open pit and 1.5 g/t for underground is 34.3 Mt at 2.1 g/t for 2.34 M oz (MGL, 2025). The Bendigo-Ophir resources occur in four deposits: Come in Time (CIT), Rise and Shine (RAS), Srex (SRX), Srex East (SRE). The majority of identified mineral resources are located within the RAS deposit. Three primary geological units are recognised at site:

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The resources will be mined by open pit methods at each deposit within the project site, with underground mining methods also proposed to be utilised at RAS to access the deeper gold deposits. The majority of the mining activities, ancillary facilities and associated infrastructure will be located in the Shepherds Valley with non-operational infrastructure located on the adjoining Ardgour Terrace. The BOGP also involves the taking of groundwater from the Bendigo Aquifer for use in mining-related activities and the realignment of Thomson Gorge Road via Ardgour Station.

The following mine facilities are proposed (Figure 2):

- Open pits targeting the RAS, SRX, SRE, and CIT deposits.
- An underground mine targeting the RAS deposit.
- Three ex-pit engineered landforms (ELFs) – Shepherds ELF, SRX ELF, and West ELF (WELF).
- Two in-pit landforms (backfill) – CIT and SRE[3].
- Plant and processing area, where CIL extraction technologies will be used as part of the ore recovery process.
- A tailings storage facility (TSF) and TSF Embankment.
- Other ancillary support services / structures (e.g., roads, water management infrastructure, water treatment plants, etc).

These facilities will be placed in the catchment of Shepherds and Bendigo creeks. Understanding baseline water quality (surface and groundwater) is important to enable the establishment of site-specific water quality compliance criteria for any resource consent that may be granted in the future.

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[3] *Note: SRE Pit is backfilled by the SRX ELF.*

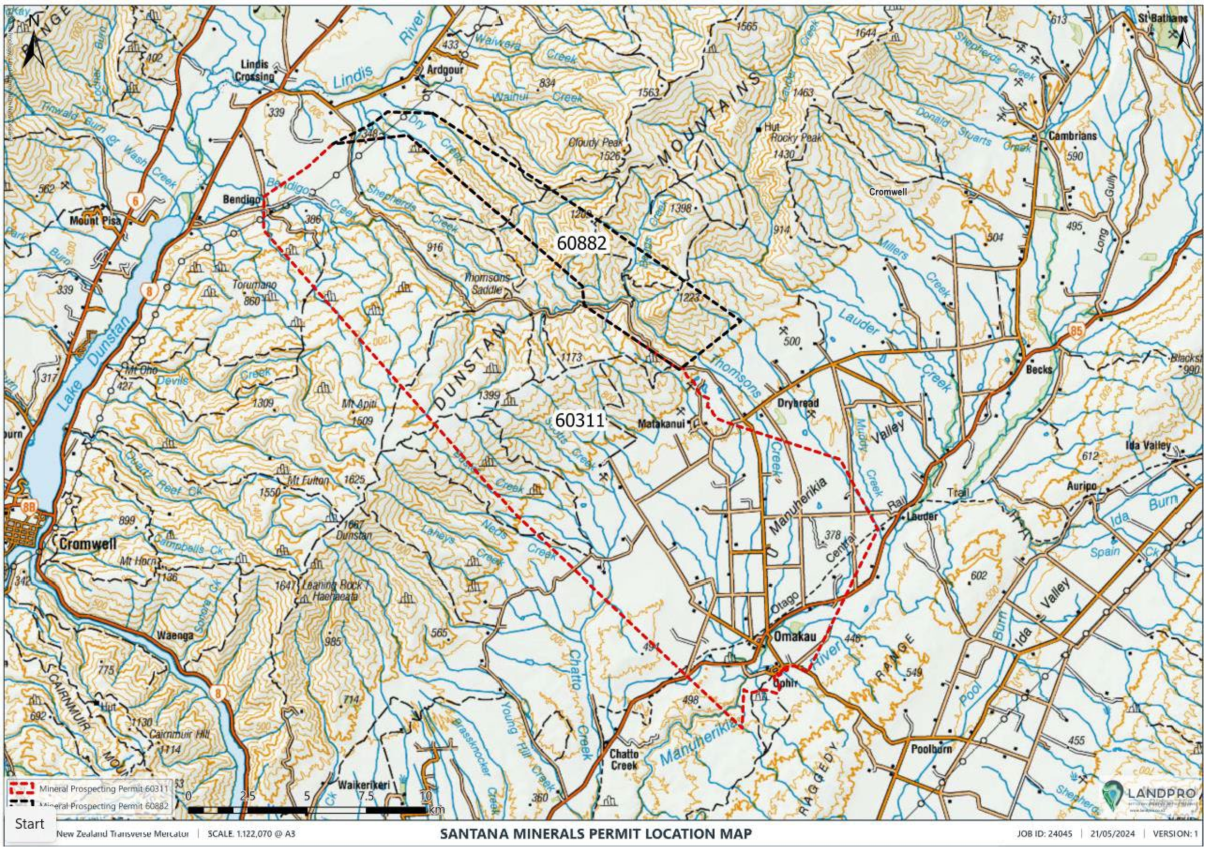


Figure 1. BOGP mineral permit boundaries showing MEP60311 and PEP60882.

## 2.2 Surface Water

The project area covers several catchments and sub-catchments (Figure 2), including:

- Shepherds Creek: This creek runs permanently through the project area and then intermittently from the Ardgour Terrace towards the Lindis River. An irrigation water-take on Shepherds Creek (RM17.301.15) downstream of SC1 monitoring site takes all available surface water in normal flow conditions, which is supplied to an irrigation dam, so the creek does not flow past this point. There is potential for groundwater to flow past this point via a thin layer of alluvial gravels along the creek bed.
- Jean Creek: This creek is an intermittent tributary to Shepherds Creek.
- Rise and Shine Creek: This creek joins Clearwater Creek south-east of the Come in Time Battery and flows into Bendigo Creek.
- Clearwater Creek: Flows into Bendigo Creek.
- Bendigo Creek: Several irrigation water-takes are in place on this creek (RM20.079.01 and RM20.079.02).

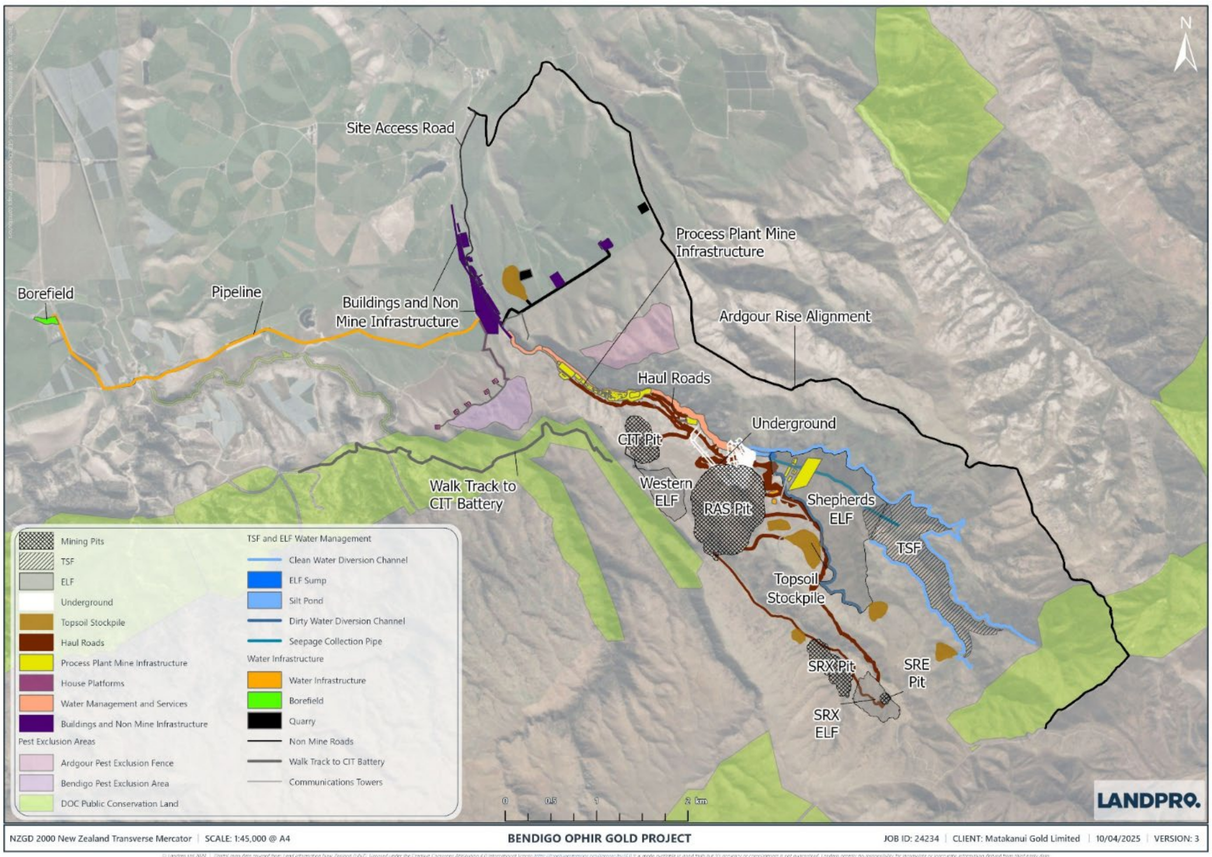


Figure 2. Bendigo-Ophir Gold Project area and water quality monitoring sites.

Baseline water quality data indicates that PCOC are elevated in the BOGP area due to historic mining activities and natural mineralisation (MWM, 2024a).

# 3 MINE IMPACTED WATER

The BOGP is located within the Otago Schist and is associated with the mineralised Rise and Shine Shear Zone (RSSZ) which juxtapose lower greenschist facies Textural Zone 3 (TZ3) and mid to upper greenschist facies Textural Zone 4 (TZ4) schists in their hanging walls and footwalls respectively. This mineralisation is dominated by sulfur (S) and arsenic (As) (e.g., the mineral arsenopyrite) with other trace metals also being potentially elevated but at much lower concentrations (e.g., cobalt, (Co), copper (Cu), chromium (Cr), antimony (Sb), and zinc (Zn)).

## 3.1 Baseline Studies

The proposed BOGP water quality compliance limits (Ryder, 2025) are used as a screening tool to determine whether baseline water quality is elevated. The assessment (MWM, 2025a) indicated that:

- Shepherds Creek is elevated in copper (Cu).
- Bendigo Creek is elevated in arsenic (As), cobalt (Co), Cu, and iron (Fe).
- Groundwater is elevated in As, Cu, Fe, zinc (Zn), and on occasion strontium (Sr) within the project area. Thallium (Tl) was elevated on one occasion (although this appears anomalous).

## 3.2 Geoenvironmental Hazards

All BOGP materials are classified as non-acid forming (NAF), with circum-neutral pH drainage expected from mine domains that contain the materials. However, neutral metalliferous drainage is likely to occur with elevated levels of arsenic (As), sulfate ($SO_4$), trace metal, and nitrogenous compounds. The most significant AMD source hazard for waste rock relates to the TZ4 and RSSZ materials, some of which will be waste rock, and some will be processed (to extract gold) producing tailings.

Data for waste rock indicates that the TZ4 and RSSZ lithologies contain ~95.3% of arsenic and 21.9% of sulfur yet represents only 9.3% of the waste rock that will be disturbed. Hence, appropriate management of TZ4 and RSSZ materials to reduce sulfide mineral oxidation is a critical step to minimise deleterious effects, i.e., manage 9.3% of the waste rock well to mitigate 95.3% of the arsenic risk in the engineered landforms (ELFs) that will contain the waste rock.

The key PCOC that are likely to be associated with MIW include: aluminium (Al), As, Co, Cu, chromium (Cr), Fe, manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), strontium (Sr), uranium (u), zinc, (Zn), cyanide (CN), ammoniacal nitrogen (Amm-N) and nitrate nitrogen ($NO_3$-N).

## 3.3 MIW Summary

It is expected that mining of the BOGP will affect waters within the project area including:

- Elevated total suspended solids (TSS).
- Neutral metalliferous drainage (NMD) with elevated sulfate ($SO_4$) and the certain PCOCs such as As, Fe, and potentially lesser amounts of trace metals.
- Nitrate-rich drainage due to the use of ANFO and cyanide.

Collectively these waters are referred to as MIW to acknowledge the different contributions to poor water quality within the project area.

# 4 PROPOSED COMPLIANCE MONITORING

This section summarises the proposed water quality limits for the BOGP.

## 4.1 Mine Impacted Water

Studies completed by MWM indicate that the following PCOC may be elevated and require treatment:

- Nitrogenous compounds (N) that include nitrate ($NO_3$) and ammoniacal-N (Amm-N).
- Sulfate ($SO_4$).
- Metals and metalloids that may include Aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), uranium (U), and zinc (Zn)
- Cyanide (CN) within the tailings water.

## 4.2 Proposed Water Quality Limits

PCOC that have been identified for the BOGP based on baseline water quality studies, environmental geochemistry studies, and proposed water quality compliance limits are shown in Table 3. Limits are based on:

- Ecotoxicity assessments developed by Ryder (2025) for the proposed surface water compliance sites
- Groundwater limits are based on New Zealand Drinking Water Standards (MoH, 2022).

The proposed compliance monitoring locations are shown in Figure 2 for surface waters and groundwaters.

For conceptual desk-top studies, it is proposed that the WTP and PTS design should be based on the more stringent water quality criteria (i.e., the lower compliance value) for surface and groundwaters to ensure that treated waters comply with both criteria.

These proposed water quality criteria for the BOGP (Ryder, 2025) are summarised in Table 2 for surface water and Table 3 for groundwater.

Table 2. Proposed surface water quality compliance limits for the BOGP.

| PARAMETER (units are mg/l unless stated otherwise) | COMPLIANCE LIMIT |
|---|---|
| pH (unitless) | 6.5 - 9.0 |
| Turbidity (NTU) | 5 (over a 5-year rolling period, 80% of samples, when flows are at or below median flow, are to meet the limit) |
| Ammoniacal-nitrogen ($NH_3$-N) | ≤0.24 (annual median)<br><0.4 (annual 95$^{th}$ percentile) |
| Nitrate-nitrogen ($NO_3$-N) | <2.4 (annual median)<br><3.5 (annual 95$^{th}$ percentile) |
| Cyanide (CN) | 0.011 (un-ionised HCN, measured as [CN], ANZG, 2018) |

| PARAMETER (units are mg/l unless stated otherwise) | COMPLIANCE LIMIT |
|---|---|
| Sulfate ($SO_4$) | A. If hardness is <100 mg/L ($CaCO_3$), the sulfate compliance limit = 500 mg/L.<br>B. If chloride is <5 mg/L, the sulfate compliance limit = 500 mg/L<br>C. If the hardness is 100–500 mg/L AND if chloride is 5–<25 mg/L, the sulfate compliance limit is (in mg/L):<br>[-57.478 + 5.79*(hardness mg/L $CaCO_3$) + 54.163*(chloride mg/L)] * 0.65<br>D. If hardness is between 100 and 500 mg/L AND if chloride is between ≥25 and ≤500 mg/L, the sulfate limit is (in mg/L):<br>[1276.7+5.508*(hardness mg/L $CaCO_3$) +1.457*(chloride mg/L)] * 0.65<br>A minimum of 12 samples must be collected over any rolling 12-month period.<br>For compliance limits in A to D, no more than 20% of samples collected over a rolling 12-month period may exceed the relevant compliance limit.<br>E. An acute compliance limit = 1,000 mg/L averaged over 4 days and not to be exceeded more than once in a one-year period, OR in more than 10% of samples over a one-year period. |
| Aluminium (Al) (dissolved) | ≤0.08 |
| Antimony (Sb) (total) | 0.074 (chronic, the average of 5 (monthly) samples over a 5-month period)<br>0.250 (acute, not to be exceeded at any time) |
| Arsenic (As(V)) (dissolved) | ≤0.042 |
| Cadmium (Cd) (dissolved) | ≤0.0004<br>See below for adjustment algorithm |
| Chromium (Cr) (dissolved) | ≤0.0033 (CrIII)<br>≤0.006 (CrVI)<br>See below for adjustment algorithm |
| Cobalt (Co) (dissolved) | 0.001 (chronic)<br>0.11 (acute, not to exceed)<br>See below for adjustment algorithm |
| Copper (Cu) (dissolved) | ≤0.0018 |
| Molybdenum (dissolved) | ≤0.034 |
| Zinc (Zn) (dissolved) | 0.015<br>See below for adjustment algorithm |
| **Adjustments** | |
| Cd (dissolved) | HMTV = TV $(H/30)^{0.89}$, where hardness-modified trigger value (HMTV) = (µg/L), trigger value (TV) (µg/L) at a hardness of 30 mg/L as $CaCO_3$; H, measured hardness (mg/L as $CaCO_3$) of a fresh surface water. |
| Cr (dissolved | HMTV = TV $(H/30)^{0.82}$, where hardness-modified trigger value (HMTV) = (µg/L), trigger value (TV) (µg/L) at a hardness of 30 mg/L as $CaCO_3$; H, measured hardness (mg/L as $CaCO_3$) of a fresh surface water. |
| Co (dissolved) | Cobalt (µg/L)= exp{(0.414[ln(hardness CaCO3 mg/L)] – 1.887} |
| Sb (total) | (chronic) the average of 5 (monthly) samples over a 5-month period (acute) not to be exceeded at any time |
| Zn (dissolved) | HMTV = TV $(H/30)^{0.85}$, where hardness-modified trigger value (HMTV) = (µg/L), trigger value (TV) (µg/L) at a hardness of 30 mg/L as $CaCO_3$; H, measured hardness (mg/L as $CaCO_3$) of a fresh surface water. |

*Source: MGL (2025)*

*HMTV = hardness modified toxicity value.*

*TV = toxicity value.*

*H = hardness.*

Table 3: Proposed groundwater quality compliance limits for the BOGP.

| PARAMETER (units are mg/L unless stated otherwise) | COMPLIANCE LIMIT |
|---|---|
| Nitrate-nitrogen ($NO_3$-N) | 11.3 (MAV)* |
| Cyanide (CN-) | 0.6 (MAV) |
| Sulfate ($SO_4$) | ≤250 (taste threshold) |
| Aluminium (Al) | 1 (MAV) |
| Antimony (Sb) | 0.02 (MAV) |
| Arsenic (As(V)) | 0.01 (MAV) |
| Cadmium (Cd) | 0.004 (MAV) |
| Chromium (Cr) | ≤0.05(MAV) |
| Cobalt (Co) | <1 (livestock drinking water) |
| Copper (Cu) | ≤0.5 |
| Iron (Fe) | ≤0.3 |
| Lead (Pb) | 0.01 (MAV) |
| Manganese (Mn) | 0.4 (MAV) |
| Molybdenum (Mo) | <0.01 |
| Strontium (Sr) | 4 |
| Uranium (U) | 0.03 (MAV) |
| Zinc (Zn) | ≤1.5 |

*Source: MGL (2025)*

*MAV = maximum acceptable value – from NZ drinking water standards*

The PCOC presented in Table 2 and Table 3 were identified from the baseline studies, source hazard assessment, geochemical modelling, and the water and load balance modelling to understand potential effects of the BOGP.

# 5 FLOW RATES

This section summarises the long-term average flow rates for each mine domain that may require treatment during the Active Closure and Post Closure phases of the BOGP.

## 5.1 Average Flow Rates

Average flow rates are estimated from the Water and Load Balance Model (MWM, 2025c). It is assumed that the use of average flow rates is suitable for the WTP OoM Study and the PTS Concept Study. Peak flows may require either a larger capacity plant or a surge pond prior to any treatment. Further work is required to advance the designs to a FS level including understanding the treatment requirements for peak flow rates.

Table 4 provides a summary of flow rates for the various mine domains that require treatment. These flow rates are preliminary and are intended to provide guidance for the OoM study on the WTP design. For the OoM WTP Study it is recommended that the design include suitable contingency for variable flow rates. Active treatment is not required for SRX Pit - It is expected that the water quality from this mine domain will be acceptable for release to the receiving environment (e.g., Rise and Shine Creek / Bendigo Creek) with passive treatment.

Table 4: Estimated average water quantity per mine domain.

| MINE DOMAIN | WTP DESIGN CRITERIA (L/s) | PTS (L/s) | COMMENTS |
|---|---|---|---|
| Shepherds ELF | 4 | 4 | 20% Net percolation (MWM, 2025b) |
| SRX ELF [1, 2] | - | 1 | 20% Net percolation (MWM, 2025b) |
| West ELF [2] | 1 | 1 | 20% Net percolation (MWM, 2025b) |
| Shepherds TSF | 13.4 | 3 | Flow is expected to be ~13.4 L/s decreasing to 3 L/s after 5 years (MWM, 2025c). |
| RAS Underground Portal | 6 | 6 | Flow from the RAS Underground is not expected for 20-30 years after closure (MWM, 2025c). |
| CIT Pit Backfill | 1.5 | 1.5 | Further details are available in MWM (2025c). |
| SRX Pit | - | 8 | Further details are available in MWM (2025c). It is assumed this water will not require active treatment. Passive treatment is required. |
| SCK Fill [2] | 1 | 1 | 20% Net percolation (MWM, 2025b) |
| Non-AMD impacted water | - | - | Managed for TSS separate to the active WTP. At closure rehabilitated surfaces are assumed to be suitable for discharge with TSS management. |

*1. Active treatment for SRX ELF and SRX Pit are not anticipated.*

*2. Flow rates rounded up to 1 L/s*

Flow rates (Table 4) are based on a net percolation (NP) rate of 20% of rainfall. It is proposed that a NP rate of 20% may be achievable, with appropriate engineering controls (i.e., an engineered cover system), which would halve the flow rates (MWM, 2025c).

### 5.2 Model Flow Rates

The section summarises the flow rates for the mine domains presented in Table 4 to provide a visual guide to the flow variance.

#### *5.2.1 ELF and TSF Flows*

Model results for seepage flow rates from the ELFs and TSF are shown in Figure 3:

- Average flow rates for the Shepherds and other ELFs of approximately 4 and 1 L/s respectively.
- TSF seepage decays through the draindown period as the system equilibrates to lesser influent water (e.g., no process water, only rainfall), with average long term seepage flow rates of approximately 2 L/s. Flow rates typically vary between 1 and 3 L/s in the long term. Further details are provided in EGL (2025).

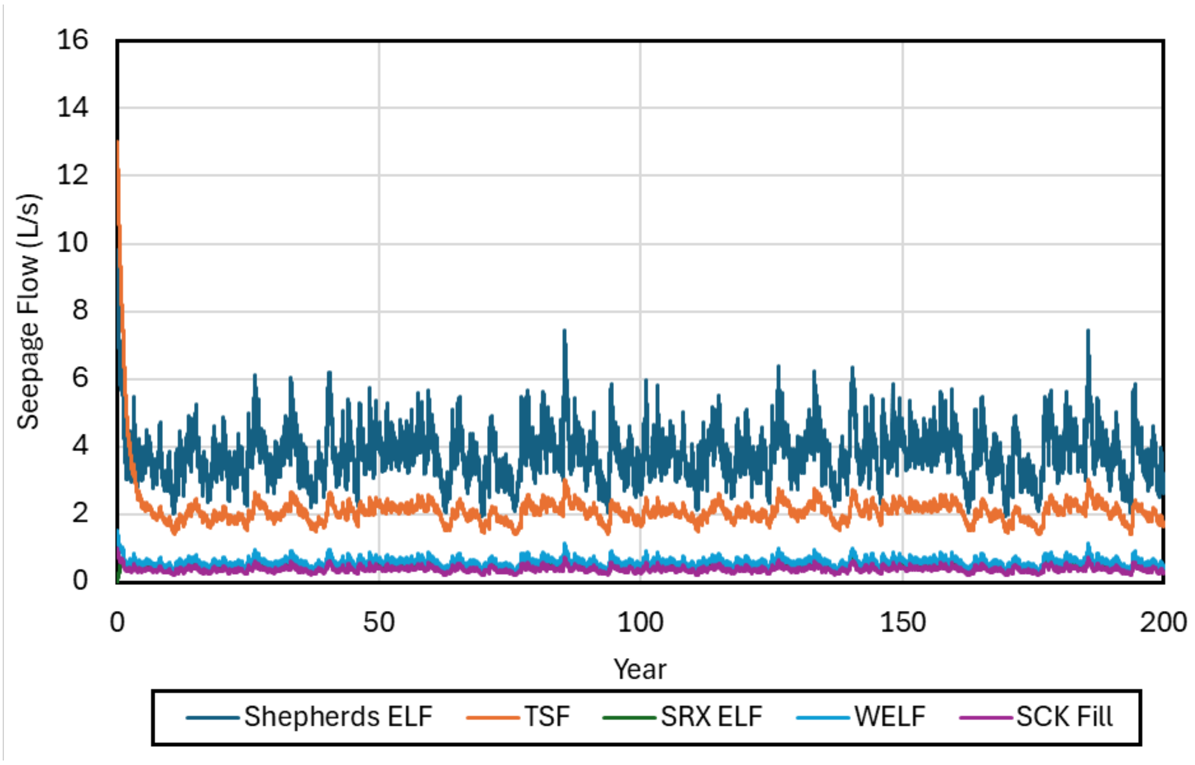


Figure 3: ELF and TSF seepage flow rates.

#### *5.2.2 RAS Pit and RAS Underground*

Model results for RAS Pit Void are shown in Figure 4 and Figure 5, and suggest:

- Stabilisation of the pit lake rebound in approximately 25 years, with a water level around 492 m asl (slightly above the adopted portal elevation of 490 m asl).
- Model results do not suggest the pit lake will spill over the pit crest low point (565 m asl).
- Discharge of pit lake water via the underground portal will start once the pit lake water level is above 490 m asl, and typically range between 4 to 7 L/s, with an average of about 6 L/s.

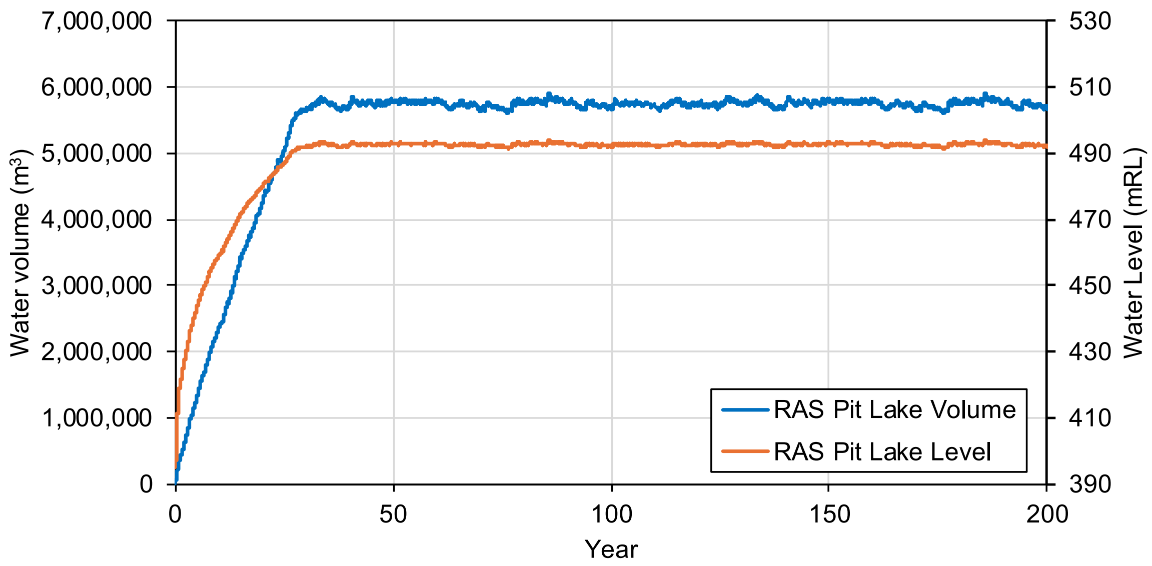


Figure 4: RAS Pit Void model results – water volume and level.

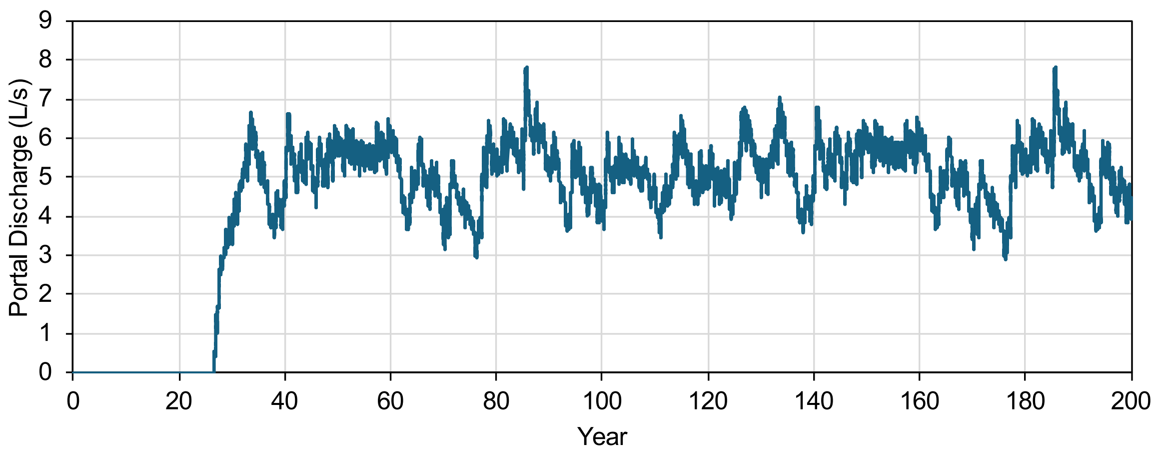


Figure 5: RAS Pit Void model results – underground portal discharge.

### *5.2.3 SRX Pit Void*

Model results for SRX Pit Void are shown in Figure 6 and Figure 7, and suggest:

- The pit void will fill and spill quickly (~ 6 months) owing to the low pit crest elevation and high groundwater inflow rate.
- The variability in overflow rate from the pit lake is higher than other pit voids due to the contribution of runoff from undisturbed areas reporting to the pit. Periodic high outflow rates are predicted, 140 L/s or higher, but average outflow rate is approximately 8 L/s.

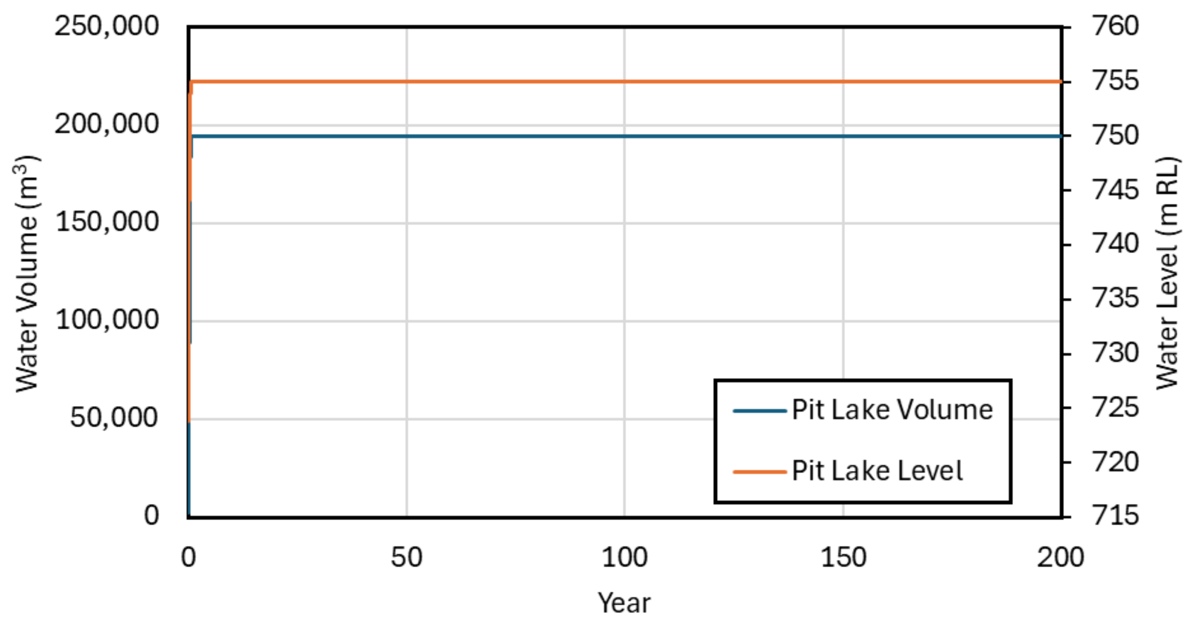


Figure 6: SRX Pit Void model results – water volume and level.

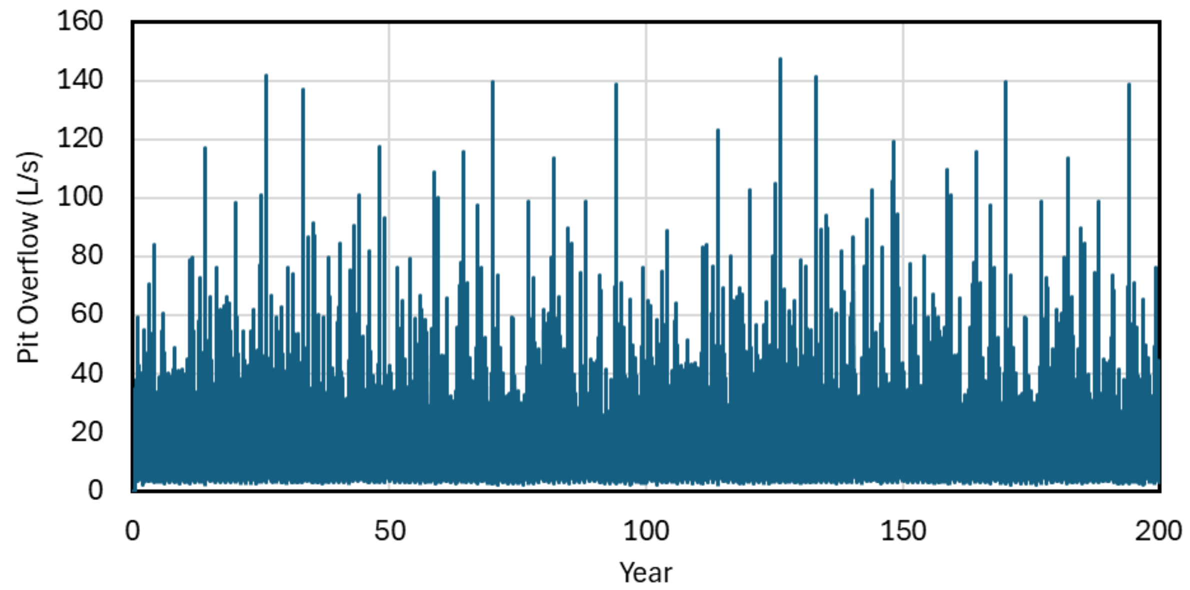


Figure 7: SRX Pit Void model results - overflow rate.

### *5.2.4 CIT Backfill Pit*

Model results for CIT Pit Void are shown in Figure 8 and Figure 9, and suggest:

- The backfilled pit void will fill and spill at around 3.5 years.
- Outflow rates via groundwater pathways are low <0.1 L/s, with the majority of outflow via spilling at the pit crest at an average of approximately 1.5 L/s.

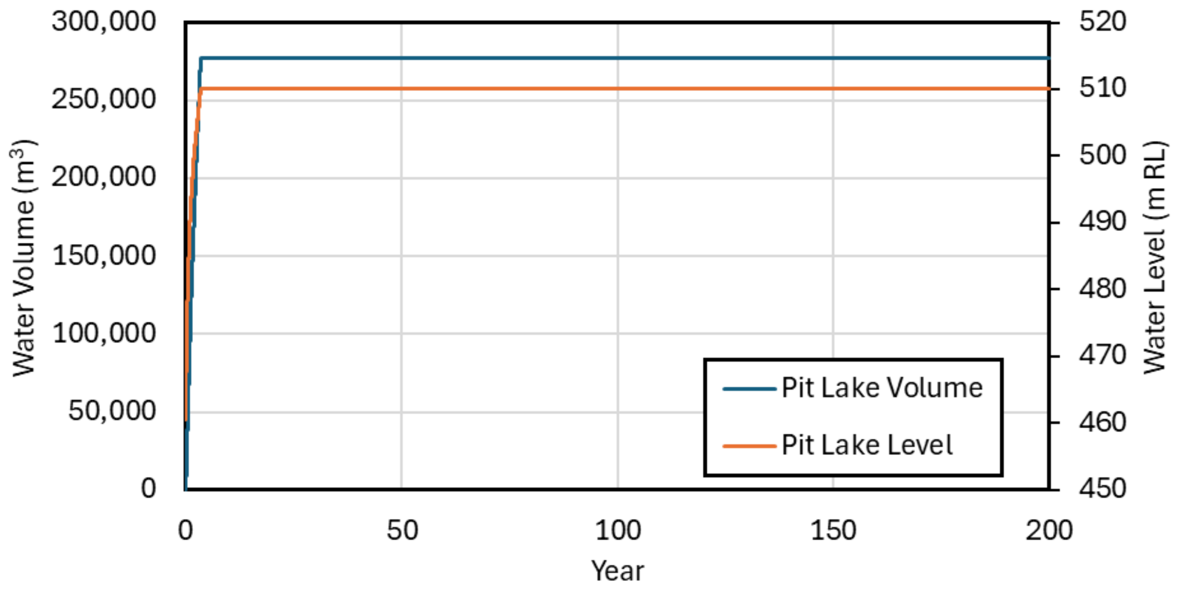


Figure 8: CIT Pit Void model results – water volume and level.

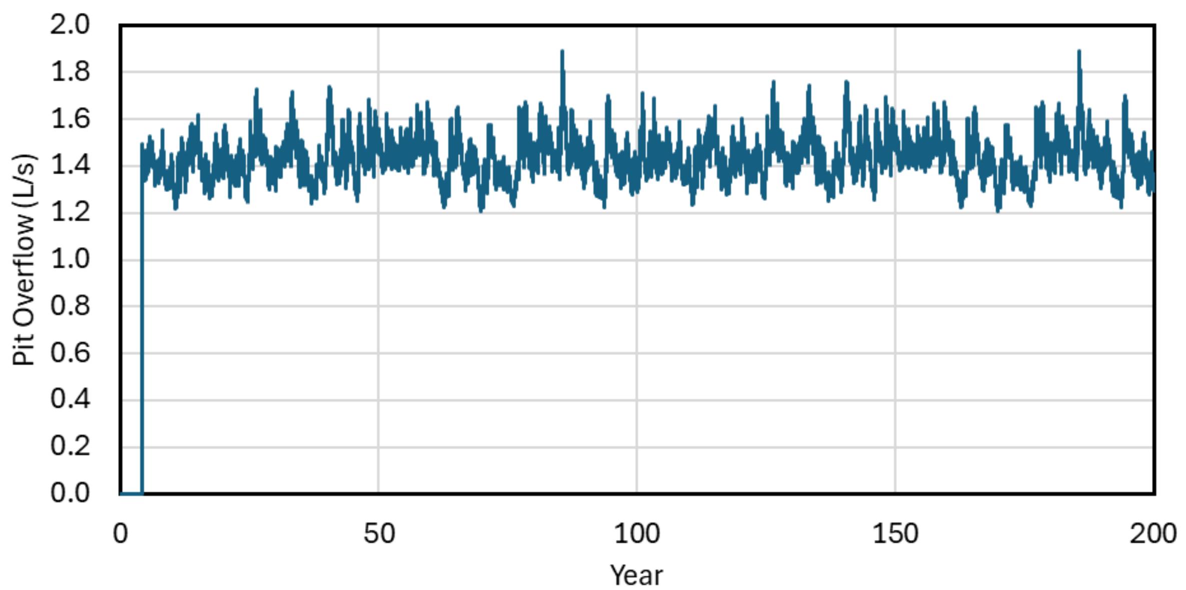


Figure 9: CIT Pit Void model results – outflow rates.

# 6 WATER QUALITY: ACTIVE WATER TREATMENT

This section summarises the water quality from the various mine domains that require treatment at closure of the BOGP by the active water treatment plant.

## 6.1 Shepherds TSF Water Quality

TSF seepage water quality at mine closure (Year 11) is presented in Table 5. Further details on how the water quality was derived are provided in MWM (2025e). Constant concentration is assumed.

Table 5: TSF seepage water quality (Closure).

| PARAMETER | CLOSURE TSF SEEPAGE WATER QUALITY |
|---|---|
| Alkalinity (mg $CaCO_3$/L) | 73.21 |
| pH (pH units) | 6.41 |
| EC (µS/cm) | 4,121 |
| Ca | 297 |
| Cl | 804 |
| F | 1.93 |
| Mg | 99 |
| Na | 847 |
| K | 50.8 |
| TOC | - |
| Al | 0.01 |
| Ag | 0.0068 |
| As | 2.05 |
| B | 0.825 |
| Cd | 0.0002 |
| Co | 0.053 |
| Cr | 0.0055 |
| Cu | 0.001 |
| Fe | 15.3 |
| Mn | 0.59 |
| Mo | 0.14 |
| Ni | 0.678 |
| Pb | 0.0275 |
| Sb | 0.18 |
| Se | 0.003 |
| Sr | 4.4 |
| Tl | 0.001 |
| U | 0.028 |
| V | 0.004 |
| Zn | 0.0296 |
| Cyanide - WAD | 0.35 |
| Sulfate | 954 |
| Ammoniacal-N | 2 |
| Nitrate-N | 0.005 |

*Note: All units in mg/L unless otherwise stated. Green data are LOR*

*WAD – Weakly Acid Dissociable cyanide; If no data are provided these are identified by ' - '.*

### 6.2 ELF and CIT Backfill Water Quality

Water quality for the ELFs is provided in Table 6 , which shows the water quality for Year 27, when maximum loads are being derived from the Shepherds ELF to provide peak concentration data for the design of the WTP.

Constant concentrations are assumed for As (0.2 mg/L) and Fe (7.6 mg/L) based on empirical data for sub-oxic conditions (e.g., Globe Progress Waste Rock Stack, Hayton et al., 2022). These concentrations are above the proposed water quality reference limit (Ryder, 2025) and will require management. The SCK Fill assumes full oxidation, which results in low Fe concentrations.

Table 6. Water Quality Data (Year 27) for WTP design – 20 m Oxygen Exclusion Model

| STATION | TSF SEEPAGE | SHEPHERDS ELF SEEPAGE | WELF SEEPAGE | CIT PIT BACKFILL | SCK FILL SEEPAGE | MIW COMBINED[1] |
|---|---|---|---|---|---|---|
| Acidity | 0.01 | 0 | 0 | 0 | 0 | 0.03 |
| Al | 0.011 | 0.003 | 0.003 | 0.005 | 0.003 | 0.013 |
| Alkalinity | 73 | 189 | 183 | 190 | 158 | 160 |
| As | 2.06 | 0.20 | 0.20 | 0.08 | 0.20 | 0.61 |
| B | 0.83 | 0.87 | 0.10 | 0.09 | 0.01 | 0.59 |
| Ca | 297 | 51 | 51 | 39 | 36 | 107 |
| Cd | 0.0002 | 0 | 0 | 0.0001 | 0 | 0.0001 |
| Cl | 806 | 63 | 37 | 12 | 8 | 223 |
| Co | 0.053 | 0.109 | 0.023 | 0.004 | 0.003 | 0.061 |
| Cr | 0.00636 | 0.00020 | 0.00019 | 0.00040 | 0.00007 | 0.00170 |
| Cu | 0.00100 | 0 | 0 | 0.00021 | 0 | 0.00049 |
| DOC | 0 | 0 | 0 | 0.206 | 0 | 0.038 |
| F | 1.94 | 6.30 | 6.12 | 1.39 | 2.37 | 3.90 |
| Fe | 15.3 | 7.6 | 7.6 | 2.4 | 7.6 | 8.7 |
| Hg | 0 | 0 | 0 | 0.00014 | 0.00000 | 0.00003 |
| K | 51 | 683 | 672 | 84 | 159 | 372 |
| Mg | 100 | 38 | 37 | 20 | 24 | 49 |
| Mn | 0.594 | 0.819 | 0.774 | 0.103 | 0.182 | 0.567 |
| Mo | 0.140 | 1.005 | 0.672 | 0.119 | 0.157 | 0.535 |
| NO3-N | 2.01 | 49.64 | 9.54 | 0.73 | 1.33 | 22.89 |
| Na | 848 | 922 | 734 | 127 | 170 | 673 |
| Ni | 0.6784 | 0.0121 | 0.0010 | 0.0013 | 0.0001 | 0.1652 |
| Pb | 0.0276 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0068 |
| Sb | 0.1802 | 2.9986 | 3.2208 | 0.3622 | 0.7601 | 1.6317 |
| Se | 0.0030 | 0.1544 | 0.1649 | 0.0196 | 0.0388 | 0.0826 |
| SO4 | 954 | 957 | 888 | 110 | 208 | 730 |
| Sr | 4.40 | 16.15 | 15.91 | 3.77 | 10.89 | 10.12 |
| Tl | 0 | 0 | 0 | 0.00021 | 0.00000 | 0.00005 |
| CN | 0.35 | 0 | 0 | 0 | 0 | 0.08238724 |
| U | 0.0280 | 0.2751 | 0.2225 | 0.0299 | 0.0515 | 0.1468 |
| V | 0.0040 | 0.1200 | 0.1155 | 0.0135 | 0.0269 | 0.0633 |

| STATION | TSF SEEPAGE | SHEPHERDS ELF SEEPAGE | WELF SEEPAGE | CIT PIT BACKFILL | SCK FILL SEEPAGE | MIW COMBINED[1] |
|---|---|---|---|---|---|---|
| Zn | 0.0296 | 0.0098 | 0.0021 | 0.0014 | 0.0003 | 0.0117 |
| pH (pH unit) | 6.41 | 7.93 | 7.92 | 8.03 | 7.92 | 6.72 |
| Hardness | 1,151 | 285 | 280 | 179 | 190 | 469 |

*Units in mg/L unless stated otherwise: DOC = dissolved organic carbon*

*1. weighted average*

### 6.3 RAS Underground

As discussed in MWM (2025e) seepage from the RAS Underground will be comparable to the RAS Pit Lake. The RAS Underground is not expected to commence discharge until Year 26. Water Quality for Year 26 is provided in Table 7.

Table 7. RAS Underground water quality (Year 27)

| PARAMETER | RAS UNDERGROUND |
|---|---|
| Acidity | 0.44 |
| Al | 0.100 |
| Alkalinity | 182 |
| As | 0.09 |
| B | 0.05 |
| Ca | 59 |
| Cd | 0.0001 |
| Cl | 14 |
| Co | 0.000 |
| Cr | 0.00058 |
| Cu | 0.00302 |
| DOC | 0.090 |
| F | 0.23 |
| Fe | 7.9 |
| Hg | 0.00006 |
| K | 34 |
| Mg | 37 |
| Mn | 0.014 |
| Mo | 0.020 |
| NO3-N | 4.35 |
| Na | 42 |
| Ni | 0.0009 |
| Pb | 0.0035 |
| Sb | 0.0234 |
| Se | 0.0008 |
| SO4 | 141 |
| Sr | 0.79 |

| PARAMETER | RAS UNDERGROUND |
|---|---|
| Tl | 0.00031 |
| CN | 0 |
| U | 0.0094 |
| V | 0.0006 |
| Zn | 0.0022 |
| pH (pH unit) | 5.91 |
| Hardness | 299 |

*Units in mg/L unless otherwise stated*

# 7 PRINCIPLES OF WATER TREATMENT

This section discusses the principles of water treatment for the BOGP.

## 7.1 Overview

Water treatment should be the last option evaluated to manage mine water discharges (INAP, 2021) and a hierarchy of controls are proposed to minimise the requirements for water treatment (Figure 10). As noted by the Australian Commonwealth (DFAT, 2016) "*It makes good business sense, in addition to being leading practice, to avoid and minimise the production of acid mine drainage (AMD), and to treat AMD only as a last resort if other approaches have failed*."

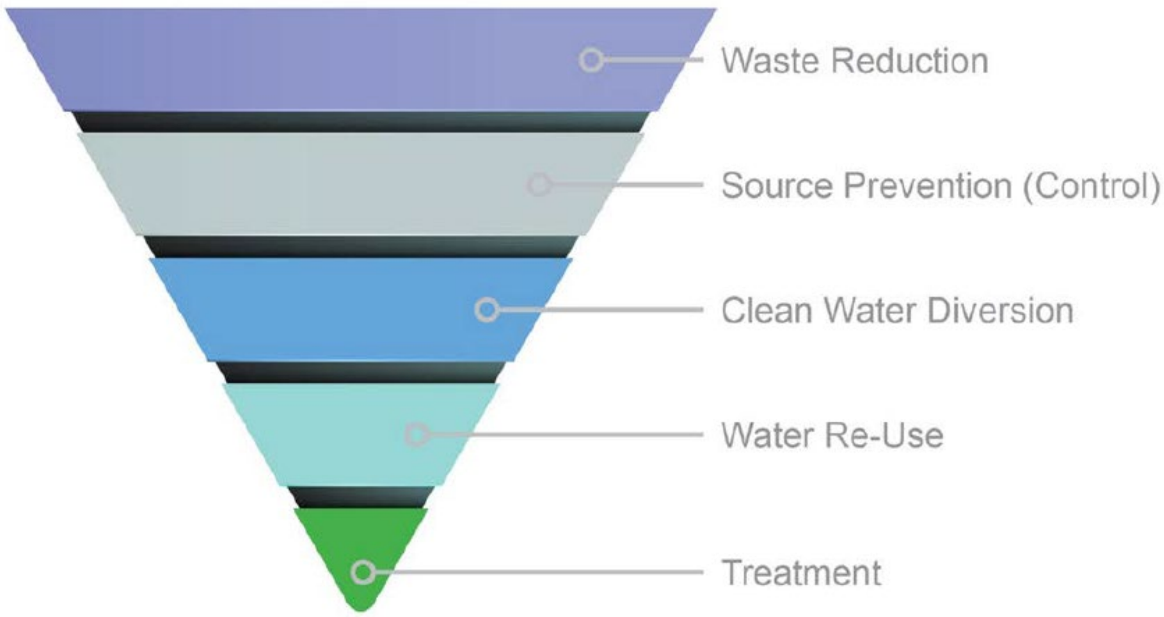


Figure 10. Hierarchy of MIW Treatment Controls
*Source: INAP (2021).*

Previous studies completed as part of an assessment of environmental effects for the BOGP have already considered these hierarchy of controls:

- Source control technologies for the proposed engineered landforms are proposed, which are expected to significantly reduce contaminant loads in the longer term (MWM, 2025d). Further discussion on source control is provided in Section 10 – Further Work that recommends additional studies to assess the options to reduce net percolation rates (which mobilises PCOC).
- Clean water diversion is part of the overall water management philosophy including minimising water ingress into the engineered landforms (MWM, 2025f).
- Water reuse is proposed during the operational phase where MIW is reused for process water and possibly dust suppression (MWM, 2025c).

This report discusses water treatment.

### 7.2 Treatment Technology Selection: Active Treatment versus Passive Treatment

Estimates of flow rates (Table 4) suggest that active treatment using a WTP is required for up to ~20 L/s during the Active Treatment Phase and up to 25 L/s for the PTS (split over two PTS) during the Post Closure Phase.

Passive systems, in general, can only handle relatively small flows (usually less than 50 L/s) unless a significant area is available for passive treatment to be successful (INAP, 2021). A common reference document (Taylor et al., 2005) provides general criteria for passive treatment (Table 9). However, INAP (2021) note that '*Under neutral to slightly acidic conditions, much higher flows can be treated through passive treatment, especially where sufficient real estate is available and where the concentrations of iron, which is often the largest problematic dissolved constituent, can be decreased through aeration*.' MIW at BOGP will be circum-neutral, hence PTS limitations on flow rates are unlikely given the flows proposed in Table 4.

INAP (2021) also note that "*most successful passive treatment projects are treating less than 1,000 m$^3$ per day*", however there are two examples where treatment of 6,500 m$^3$ per day (~75 L/s) was maintained for up to 19 years.

Table 8. General Guidelines for Selection Active versus Passive Treatment

| TREATMENT SYSTEM | AVERAGE ACIDITY RANGE (mg $CaCO_3$/L) | AVERAGE ACIDITY LOAD (kg $CaCO_3$/day) | AVERAGE FLOW RATE (L/s) | TYPICAL pH RANGE | MAX pH ATTAINABLE |
|---|---|---|---|---|---|
| Passive | 1 - 800 | 1 – 150 | < 50 | >2 | 7.5 – 8.0 |
| Active | 1 – 10,000 | 1 – 50,000 | No defined limit | No defined limit | 14 |
| BOGP | <50 [1] | ~50 [2] | ~30 | Circum-neutral | - |

*Source: Taylor et al. (2005).*

1. *Based on 7.6 mg/L as Fe(iii) converted to acidity mg $CaCO_3$/L).*
2. *Based on 30 L/s (see Table 4) – Active = 27 L/s; passive = 32 L/s.*

Based on this review, it is anticipated that the flow rates expected for the BOGP in the Active Phase and Post Closure Phase can be managed by both active and passive treatment technologies.

### 7.3 MIW Redox Geochemical Characteristics

MIW can be summarised into three broad geochemical groups:

- Oxic waters - waters that contain measurable dissolved oxygen.
- Suboxic waters - waters that lack measurable oxygen or sulfide but contain significant dissolved iron (> ~0.1 mg/L).
- Reducing waters (anoxic) - waters that contain both dissolved iron and sulfide.

Mine impacted water at BOGP are likely to have a number of different redox states:

- TSF seepage is likely to be suboxic or be reduced.
- ELF seepage is likely to be suboxic with elevated Fe.

- Pit lakes are likely to be oxic.
- RAS Underground is likely to be suboxic/oxic (e.g., may contain some elevated iron that has not hydrolysed by interaction with air as water seeps from the portal).

The various mine waters will be mixed prior to treatment through the WTP and PTS. The mixing will be optimised to encourage beneficial geochemical reactions that include, for instance, Fe hydrolysis with As and trace metal removal (via adsorption).

# 8 ACTIVE CLOSURE PHASE: WATER TREATMENT PLANT

The Active Closure Phase of the BOGP commences once mining is complete (i.e., no further ore processing) and the MIW management at site transitions from water retention to treat and release.

## 8.1 Introduction

Active closure of the site commences in Year 11 (Table 1) with final rehabilitation of mine domains and transition from water storage to water treatment by an active water treatment plant. An OoM design has been developed by Process Flow (2025) for active treatment of MIW. This is included as Appendix C.

As noted by INAP (2021) "*Surge ponds may be a valuable feature in the case of highly variable mine drainage flows and pollutant loads as this will afford some protection against surcharging the treatment system. It is typically not economically feasible to build very large raw water retention ponds nor is it economical to build small ponds and very large treatment plants*". The surge pond capacity will be considered during the BOGP detailed design stage when peak flow rates will be considered. For this study, the average flow rates presented in Table 4 are used.

## 8.2 Location

The proposed location for the Active WTP is located within the Shepherds Creek catchment. Process Flow note the size and footprint requirements for the WTP and Surge and Treated water ponds is as follows.

- WTP Footprint – An area approximately 100 m x 60 m is recommended to be located near the surge and treated water ponds.
- WTP Surge Pond – 14,000 $m^3$
- WTP Treated Water Pond – 2,000 $m^3$

## 8.3 Technology Selection

Process Flow (2025) note that the selected process involves:

- Surge sump
- Pontoon mounted pumps for plant feed
- Metal hydroxide precipitation and settling
- Gypsum precipitation and settling
- Ettringite precipitation and settling
- Carbonation and pH trimming
- Treated water sump
- Sludge management

Other processes that will likely be needed in addition to the active WTP are:

- Cyanide destruct on the Shepherds TSF influent stream

- Potential additional nitrate removal after WTP via biological processes.

### 8.4 Summary

Process Flow indicate that the proposed water quality objectives (Ryder, 2025) can be achieved, although further work is required to develop the OoM study to a FS level. Further details are provided in Appendix B. The WTP will operate until passive treatment systems can be installed.

# 9 POST CLOSURE PHASE: PASSIVE TREATMENT SYSTEMS

The Post Closure Phase for the BOGP commences once MIW can be treated by passive treatment system technology. Based on the WLBM (MWM, 2025c) and expected sulfate concentrations at SC01, it is expected that transition from active to passive treatment can occur within a few decades depending on water management processes.

This section discusses passive treatment technologies. Passive treatment technologies for treatment of MIW are defined as biological and/or chemical processes that neutralise acidity and precipitate metals via oxidation or reduction using natural processes that do not require regular human intervention or maintenance (INAP, 2021). In general, a passive system should function for many years without a major retrofit to replenish materials and should operate with no or low electrical power.

## 9.1 Introduction

Based on the contaminants of concern identified at the BOGP a multi-stage passive treatment system is expected. This would include:

- Sediment management to mitigate any residue TSS and prevent the PTS from being overwhelmed with sediment.
- Oxidation to encourage $Fe(OH)_3$ precipitation and adsorption of metals such as As.
- Aerobic treatment of tailings seepage waters for cyanide.
- Anaerobic treatment to remove nitrate, reduce sulfate concentrations, and precipitate metals as sulfides.
- A polishing pond to remove secondary contaminants generated in the anaerobic treatment stage (e.g., sulfide ($HS^-$), ammoniacal nitrogen, and low dissolved oxygen).

Gusek and Waples (2009) developed a periodic table of elements for passive treatment (Figure 11), which demonstrates the applicability of oxic and anaerobic treatment systems to PCOC identified at BOGP. Figure 11 provides useful context but does not cover all elements. For instance, Trumm et al (2024) noted that a mussel shell anaerobic bioreactor at Echo Mine, Reefton removed 96% of Cs; 82% of Rb, and 98% of La, which is not shown in Figure 11.

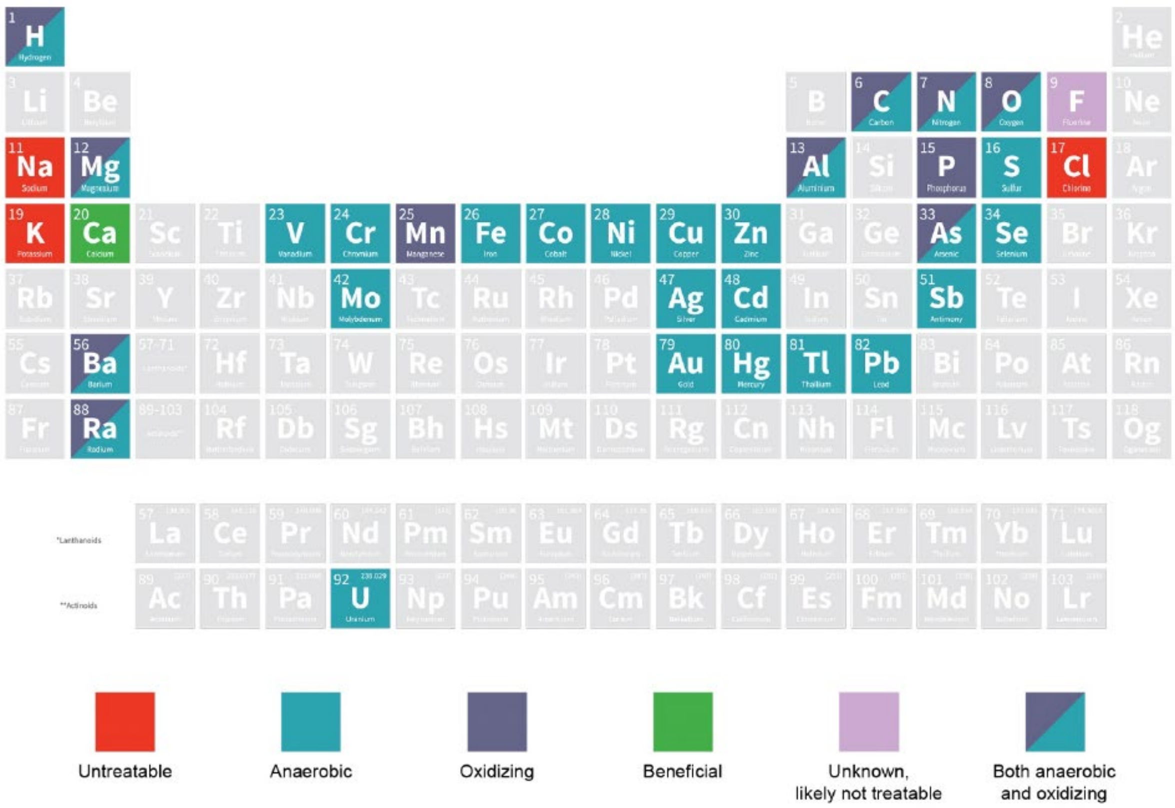


Figure 11. Periodic table for passive treatment.

*Source: INAP (2021).*

The following locations are potentially available for the construction of PTS at the BOGP after closure of the mine:

- Shepherds Sediment Pond footprint.
- SRX ELF toe seepage pond and/or SRX Pit.
- BOGP Infrastructure area to treat seepage from the Shepherds ELF, Shepherds TSF, RAS underground, WELF, and the CIT Backfill Pit.

Passive treatment during the operational phase of the mine is generally not viable due to the MIW being affected by significant sediment loads (TSS). However, the Operational Phase is an ideal time to test and confirm PTS technologies can achieve water quality objectives.

## 9.2 Oxidation of Suboxic Waters

Oxidation is a common approach for the treatment of waters discharging from suboxic / reduced environments (e.g., seepage from the ELF, underground workings, etc.) impacted by iron (Fe) and arsenic (As). The oxidation treatment process involves aerating water (to increase the dissolved oxygen content), which allows $Fe^{2+}$ to oxidise to $Fe^{3+}$ and form insoluble ferric hydroxide, $Fe(OH)_3$ precipitates. Arsenic is removed through this process by co-precipitation / adsorption to the ferric hydroxide.

### *9.2.1 Aeration*

Aeration is a common technology used to remove sulfide from water. This is demonstrated by the fact that hydrogen sulfide gas escapes (volatilizes) rapidly from water and can be identified by its distinct odour[4]. Aeration can also be used to remove ammoniacal nitrogen and is common for wastewater treatment.

The following physical aeration systems are available to increase aeration of the PTS effluent to increase dissolved oxygen and remove ammoniacal N and un-ionised hydrogen sulfide.

9.2.1.1 Trompe

A trompe (Figure 12) utilises falling water to compress air, drawing air into a vertical downpipe as water flows through an airhead (Leavitt et al., 2015)[5]. The high velocity of the falling water carries entrained air down the pipe, which is then separated from the water in a chamber located below the discharge elevation. To generate air pressure, a drop of approximately four feet is required between the inlet head and discharge pipe, and the height of the discharge pipe controls the pressure generated (Leavitt and Danehy, 2011; Leavitt et al, 2015). Trompes can be installed in series for sites with multiple flow rates, and multiple airheads and downpipes.

The Curley passive treatment site in Pennsylvania installed a trompe to assist in the treatment of mine-impacted drainage. The mine drainage had Fe concentration of 23 mg/L (Dorman, 2019). The study found that the trompe added over 3 mg/L of dissolved oxygen, which was sufficient to oxidise 82 – 97% of the Fe present in the influent water (Dorman, 2019).

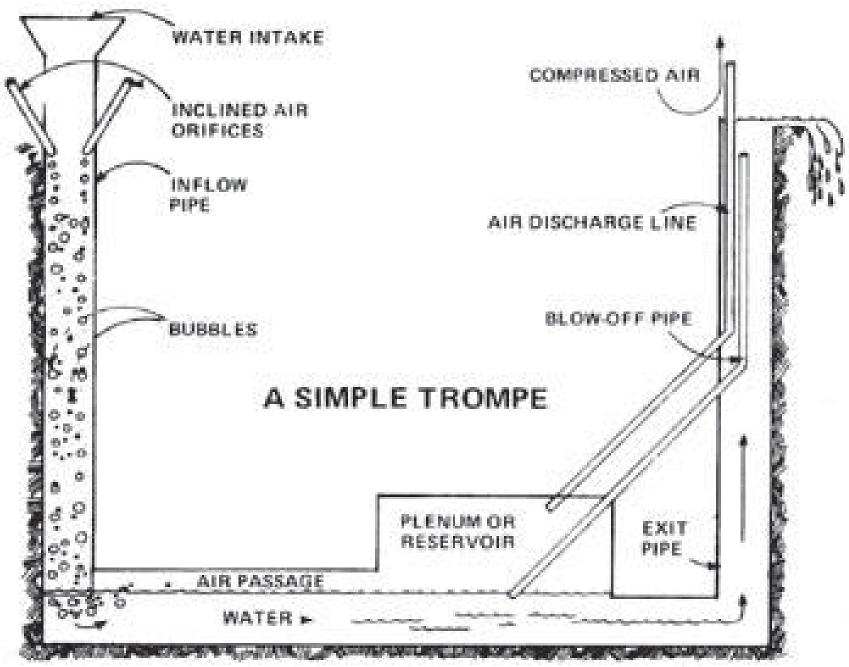


Figure 12. A simple trompe schematic

*Air entrained in the water is compressed in the plenum, or reservoir, and delivered via pipeline*

*Source: Trumm 2013*

9.2.1.2 Mechanical Aeration

Powered mechanical aeration systems are available for wastewater treatment systems (e.g., agitators), however, the electricity requirements are likely to be prohibitive once power is removed from the site in

[4] *Further details are available: https://extension.uga.edu/publications/detail.html?number=C858-15.*

[5] *Further details are available from the U.S. Department of the Interior: https://www.osmre.gov/node/794.*

the Post Closure Phase. Alternatively, solar options are available to generate compressed air (e.g., CWS, 2023).

#### 9.2.1.3 Bubble Diffusers

Bubble diffusers or similar generate high surface area air particles to allow sufficient chemical oxidation of sulfide and ammoniacal nitrogen. Fine bubble diffusers create fine bubbles by pushing air through tiny holes in the diffuser plate, resulting in a large water-air interface and high oxygen transfer rate (Dorman, 2019).

Fine bubble diffusers may not be suitable for waters with high suspended solids like a mine drainage oxidation pond due to fouling from metal hydroxides or biofilm layers (Dorman, 2019; Schmidt 2004). However, the proposed polishing pond will have low dissolved metal content. Trials during the detailed design phase will confirm if fouling is a problem.

### *9.2.2 Ferric Treatment of High Arsenic MIW*

Where waters are aerated but retain elevated As concentrations the addition of Fe to trigger further ferric hydroxide formation and remove As by co-precipitation / adsorption is a common treatment approach, and is used in many active treatment systems. Passive treatment systems can also use $FeCl_3$ addition. For instance, OceanaGold treated the Globe Pit Lake with $FeCl_3$ to reduce elevated arsenic concentrations (Navarro et al., 2022). This is shown in Figure 13 which demonstrates significant decreases in As following the addition of Fe.

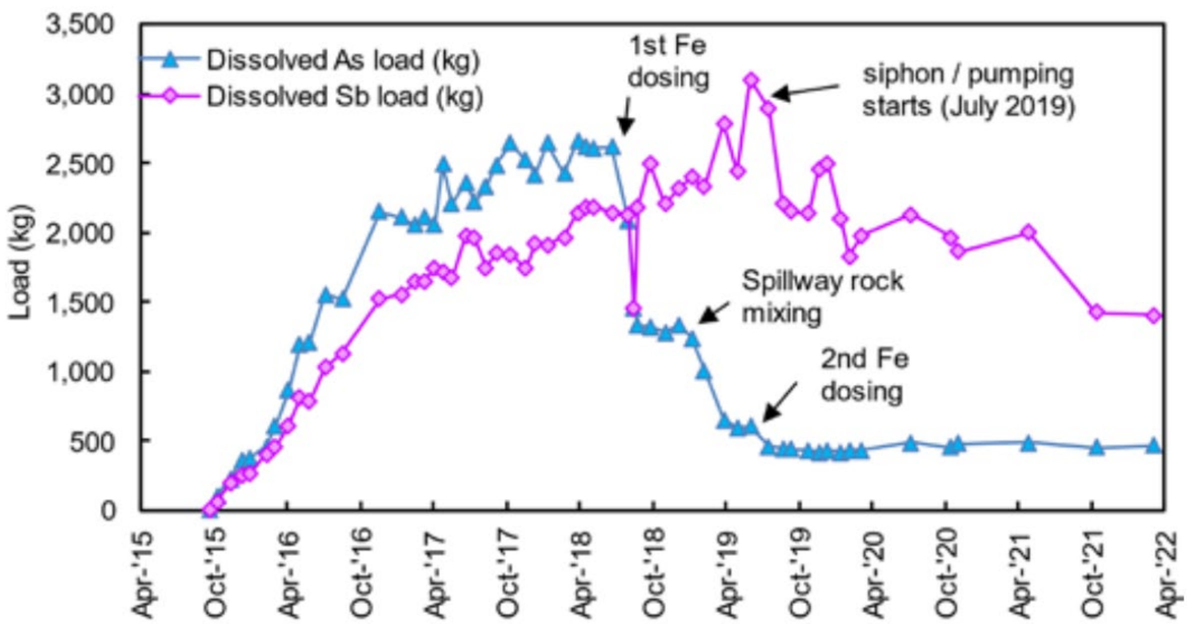


Figure 13. Arsenic and antimony loads – Globe Pit Lake, Reefton.
*Source: Navarro et al. (2022)*

### *9.2.3 Vertical Flow Reactor Technologies*

Work completed by Hayton (2022) demonstrated that one option to treat arsenic and iron was a vertical flow reactor (VFR). A full-scale VFR has subsequently been constructed at the Globe-Progress Mine. The following link provides further information on the system:

- https://oceanagold.com/2021/01/27/delivering-innovative-passive-water-treatment-at-reefton/

The Globe-Progress Mine VFR aerates Fe- and As- rich waters from the waste rock stack seepage and tailings storage facility underdrains and then filters (downwards flow) the Fe-precipitates (with As adsorbed to the Fe-floc) through a gravel-bed. Treated waters are then discharged from site.

The use of Fe hydroxides to co-precipitate / adsorb and treat As-impacted mine waters is a proven technology for As treatment and could be applied at the BOGP where required. This could include seepage from the TSF, ELFs, and RAS Underground, etc. If Fe is limited in the influent water stream, this could be added by a simple $FeCl_3$ dosing system.

#### *9.2.4 Summary*

The precipitation of iron as hydroxide minerals may also assist in the removal of additional pollutants. Several ionic species, such as arsenic and molybdenum, coprecipitate or adsorb onto ferric hydroxide (INAP, 2021), which will help with these PCOC if they are elevated in MIW.

### 9.3 Aerobic Passive Treatment of TSF seepage: Cyanide

Aerobic passive treatment of TSF seepage may be required following active treatment for residual cyanide that may be present in concentrations up to 0.35 mg/L.  This could be co-incidental with the passive oxidation and removal of Fe and As.

Studies state that that cyanide move only a short distance through soil before being biologically converted under aerobic conditions to nitrates via microbial attenuation to ammonia and then to nitrate (Mudder et al., 2001). It was also found that cyanides are immobilized after reacting with trace metals through chelation processes (Mudder et al., 2001). Álvarez et al (2004) indicated that passive treatment of cyanide is viable with 90.36% removal of $\text{Cyanide}_{\text{WAD}}$.

### 9.4 Anaerobic Passive Treatment of Mine Impacted Water

Anaerobic passive treatment can be used to mitigate the effects of poor water quality during the Post Closure Phase, which might be impacted by:

- Metals
- Nitrogenous compounds
- Sulfate

#### *9.4.1 Anaerobic Treatment of MIW*

There are numerous types of anaerobic treatment system for sulfate-rich waters, however all anaerobic PTS rely on Equation 1 to convert sulfate to sulfide, which can then be removed as either metal sulfides (e.g., pyrite that can also contain other trace elements, e.g., As, Zn, Ni, Pb, etc) or be converted to elemental sulfur. This process can only occur under anoxic conditions when there is a labile source of carbon to provide electrons and sulfate is available to receive the electrons (assuming microbes will naturally be present).

*Equation 1:* $$SO_4^{\ 2-} + 2CH_2O \xrightarrow{SRB} 2HCO_3^{\ -} + H_2S \quad \text{Where } SRB = \text{sulfate reducing bacteria.}$$

$H_2S$ is a common anaerobic degradation by-product where sulfate is present.  $H_2S$ can be found in natural sediments and is found in industrial wastes and landfill leachates (ANZECC, 2000). Mine-impacted waters can also be elevated in sulfate that can be converted to hydrogen sulfide under anoxic conditions where labile organic carbon is available. This process is driven by microbes seeking energy to drive metabolic activity where energy is obtained from the transfer of electrons from electron-rich (reduced) substrates (e.g., organic matter) to electron-deficient (oxidised) species (e.g., nitrate, sulfate, etc). This is shown schematically in Figure 14 and an explanation of relative oxidation-reduction potential (Eh) for these reactions is shown in Figure 15.

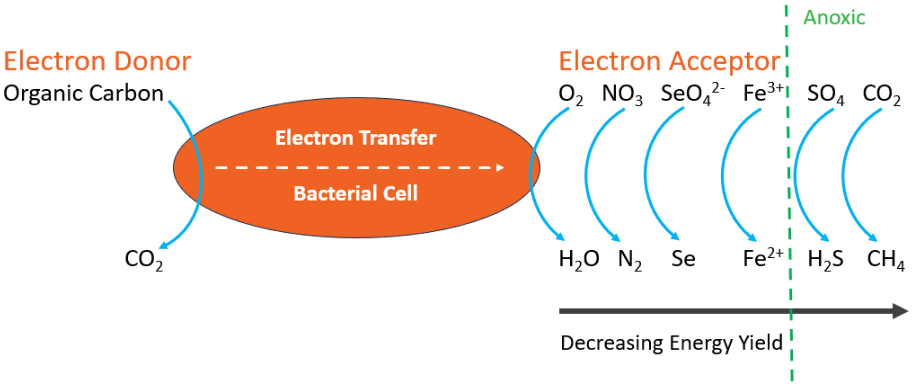


Figure 14. Energy yield and common oxidation-reduction (redox) sensitive species.

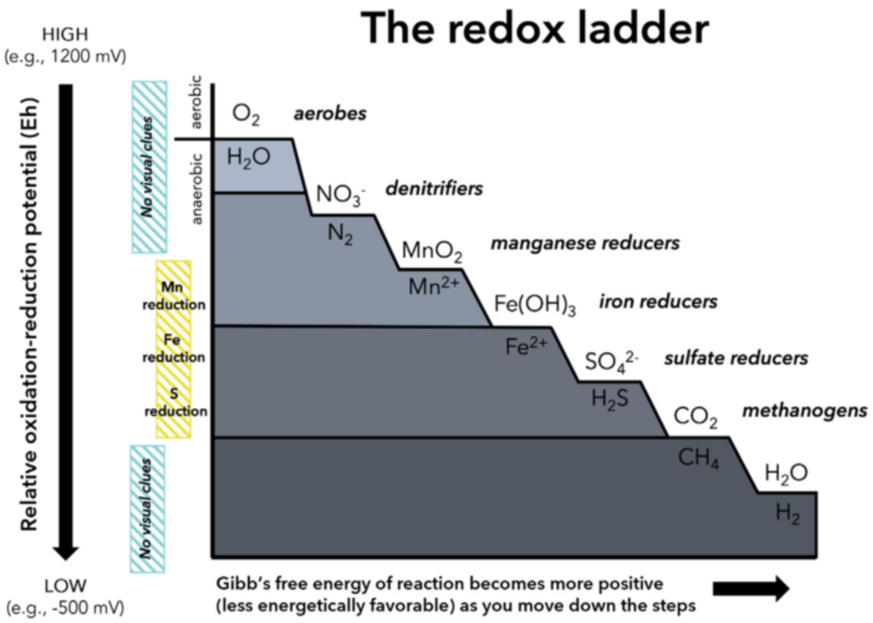


Figure 15. The Redox Ladder

*Source: Sapkota et al. (2022)*

As shown in Figure 14 and Figure 15, anaerobic passive treatment systems can also treat nitrate impacted waters.

A number of options for As-Fe-$SO_4$ impacted waters were assessed for OceanaGold's Globe Progress Mine (bioreactors and vertical flow reactors) (Hayton et al., 2022). The bioreactors included 4 different substrates:

- B-LC: Biosolids with less compost.
- M-LC: mussel shells with less compost.
- B-MC: biosolids with more compost.

- M-MC: mussel shells with more compost.

Data (Hayton et al., 2022) indicated that for a hydraulic residence time (HRT) of 50 hours there was a significant reduction in As in mine-impacted waters. The bioreactors were fed water from the sites combined underdrains (median chemistry: 28.5 mg Fe/L, 1.7 mg As/L and 425 mg $SO_4$/L). Results are shown graphically in Figure 16 and Figure 17.

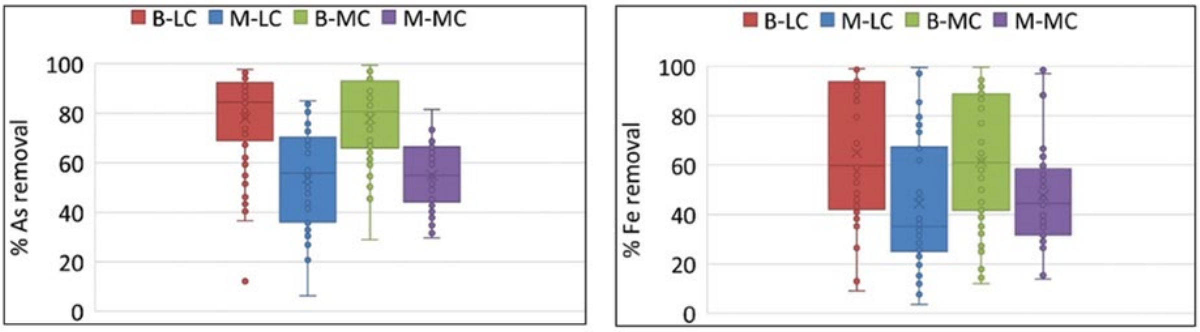


Figure 16. Globe Progress field trials

*Percentage removal for As and Fe. B-LC: Biosolids with less compost, M-LC: mussel shells with less compost, B-MC: biosolids with more compost, and M-MC: mussel shells with more compost.*

*Sources: Hayton et al. (2022).*

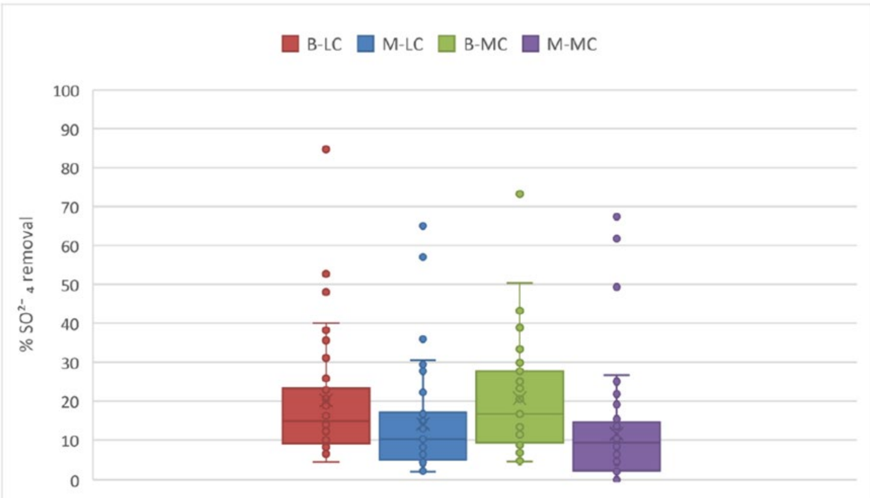


Figure 17. Globe Progress field trials

*Percentage removal for sulfate. B-LC: Biosolids with less compost, M-LC: mussel shells with less compost, B-MC: biosolids with more compost, and M-MC: mussel shells with more compost. Source: Hayton (2020).*

### *9.4.2 Enhanced Passive Treatment Systems of MIW*

Enhanced passive treatment systems (E-PTS) are bioreactors that are enhanced by the addition of nutrients to passive bioreactors to increase the rates of water treatment (Christenson et al., 2022). Nutrient addition (e.g., liquid carbon) was undertaken on laboratory bioreactors, to test contaminant removal rates with varying substrates, temperatures, HRT and nutrient addition rates, in order to optimise parameter selection for field trials.

Trial results indicated that the $SO_4$ removal rates observed in the laboratory trials were more than 25 times higher than those of standard passive bioreactors, which typically remove 0.3 mol/m$^3$/day of $SO_4$ from mine water (Figure 18). The highest $SO_4$ removal rates observed were 15 mol/m$^3$/day and the $SO_4$

removal rates consistently exceeded 7 mol/m$^3$/day (Christenson et al., 2022). It was noted that sulfide, dissolve organic carbon, and ammoniacal nitrogen could be elevated.

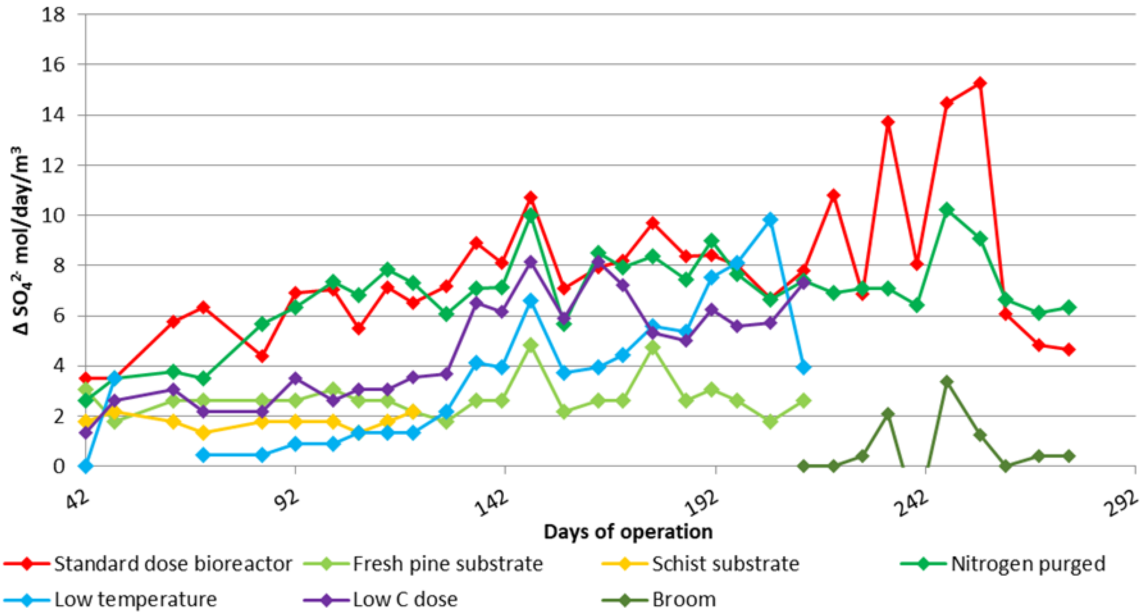


Figure 18. E-PTS bioreactor effluent sulfate concentrations.

*Source: Christenson et al. (2022).*

E-PTS have also been investigated as an option to treat nitrate-rich waters (e.g., Christenson et al., 2018) using nitrate-reducing bacteria (NRB) and water-soluble carbon compounds:

*Equation 2:* $4NO_3^- + 4H^+ + 5CH_2O \rightarrow 2N_2 + 7H_2O + 5CO_2$

NRB have been used in woodchip bioreactors to successfully reduce nitrate concentrations in agricultural and other enriched waters (Christianson et al., 2017). Similar systems could also be applied to nitrate rich MIW resulting from the use of nitrogen-based explosives. Results demonstrated a significant decrease in nitrate concentrations compared to the influent water quality (Figure 19).

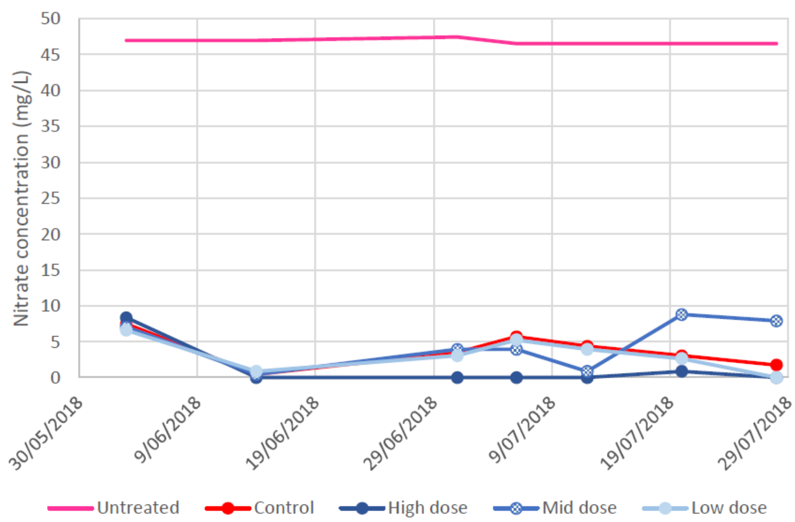


Figure 19. Nitrate treatment concentrations in the laboratory reactor effluent.

*Source: Christenson et al. (2018).*

### 9.5 Secondary Contaminants

A polishing pond is required to remove secondary contaminants generated in the anaerobic treatment stage. This is likely to include low oxygen waters elevated in secondary contaminants such as sulfide ($HS^-$) and ammoniacal nitrogen. Sulfide and ammoniacal nitrogen have been identified in passive treatment systems by odour for hydrogen sulfide and by water measurement for ammoniacal nitrogen (e.g., Crombie et al., 2011). The generation of $HS^-$ can also potentially generate health and safety issues due to $H_2S$ gas. Several options are discussed to explain how these secondary contaminants can be removed.

#### *9.5.1 Chemical Oxidation*

Chemical oxidation is often used when mechanical aeration or passive technologies are not possible or practical. Chemical oxidants include, for instance: chlorine, hydrogen peroxide ($H_2O_2$), sodium hypochlorite (NaClO: e.g., household bleach), calcium hypochlorite ($Ca(ClO)_2$), and potassium permanganate ($KMnO_4$).

#### *9.5.2 Zero Valent Iron*

Elevated sulfide can create ecotoxicity issues in waters affected by MIW. However, the sulfide readily combines with metals (often Fe) to form acid volatile sulfides, precursors to the formation of pyrite / marcasite, which can remove the sulfide from solution:

*Equation 3:* $$Fe_2O_3(s) + 4SO_4^{2-} + 8CH_2O + ½O_2 \rightarrow FeS_2(s) + 8HCO_3^- + 4H_2O$$

Iron-based compounds have been used previously for the removal of sulfide by precipitation, which can include zero valent iron (ZVI) materials such as scrap iron. Robinson et al. (2022) used sulfide scrubber (SCR) technology that involved the use of magnetite, hematite, and iron filings:

*Equation 4:* $$Fe^{2+} + S^{2-} \rightarrow FeS$$

Results (Robinson et al., 2022) indicated that the effluent from the SCR systems contained concentrations of sulfide that were lower than the other passive treatment systems using organic matter and limestone by orders of magnitude (Figure 20).

Other research has noted that the use of ZVI led to minimal levels of toxic hydrogen sulfide in the treated effluent due to its efficient precipitation of sulfide as metal sulfides, which included Fe-sulfides generated by the anoxic corrosion of ZVI (Ayala-Parra et al., 2016).

Liao et al. (2022) notes that metal sulfide precipitation is a common method to treat sulfide-containing wastewater that allows rapid precipitation of the sulfide salt and selective precipitation of heavy metals, and that zinc is commonly chosen as precipitation agent to recover sulfide due to its higher chemical stability compared to other transition metals.

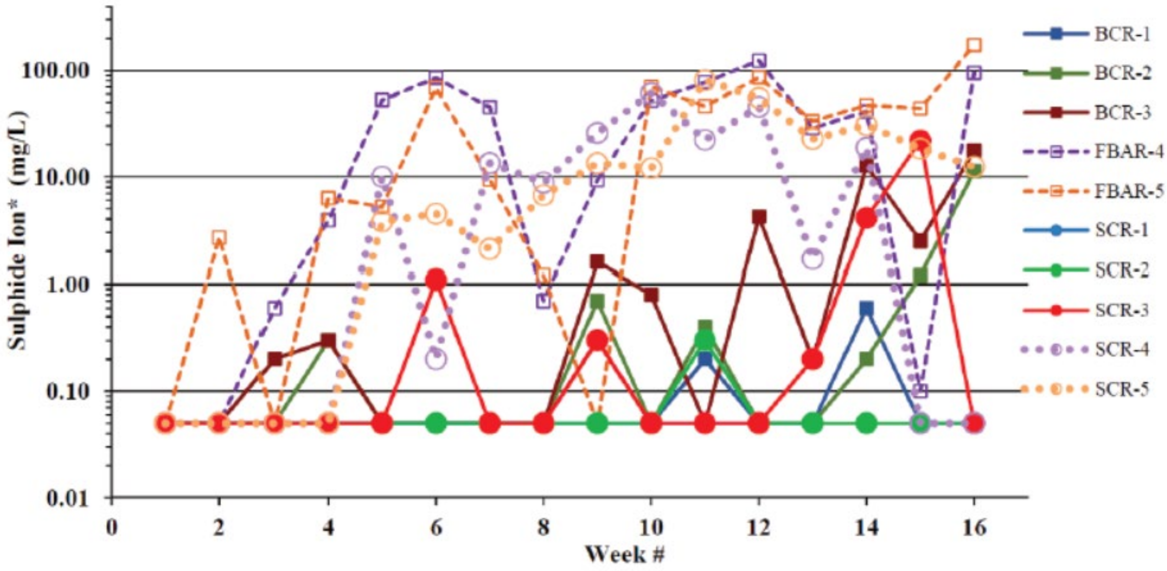


Figure 20. Sulfide concentrations following treatment.

*Biochemical reactors (BCR); fixed-bed anaerobic bioreactors (FBAR) and Sulfide Scrubber (SCR) systems.*

*Source: Robinson et al (2022).*

This sulfide precipitation approach could be applied to the effluent of a bioreactor. Ideally this would be undertaken prior to any oxidation step to encourage Fe-sulfide precipitation under reducing conditions. This could be incorporated as multi-step treatment approach whereby a scrubber system is used after an anaerobic treatment process. Materials could include iron fillings, waste galvanised steel, and possible Fe-rich sludge mixed with gravel to provide suitable permeability.

#### *9.5.3 Adsorbents*

There are various materials that are frequently employed as adsorbents to treat waters impacted by contaminants, including zeolites, clay minerals, activated carbon, and polymers (e.g., hydrogels). Zeolite was selected for this review as a suitable adsorbent material that may be suitable for the BOGP PTS.

Zeolite is a naturally occurring hydrated aluminosilicate mineral with a negative charge. The negative charge allows for the adsorption of certain positively charged ions. In aqueous solution, the negative charge is generally neutralized by $Na^+$, however, $NH_4^+$ is preferentially adsorbed to the zeolite matrix. Zeolite has been used for decades to decrease the concentrations of ammonium in municipal effluents and, more recently, in freshwater environments (Burgess et al., 2004). Removal mechanisms include ion exchange and adsorption (Guida et al., 2020).

Zeolite materials are available in New Zealand (e.g., Blue Pacific Minerals) and are commonly used as kitty litter.

### 9.6 Passive Treatment System Efficiencies

This section reviews the treatment efficiency of passive treatment systems. The efficiencies are included in the WLBM to determine estimated water quality after PTS.

### *9.6.1 Arsenic and Iron Treatment Efficiency*

Hayton et al. (2022) reports that a vertical flow reactor removed 95% of arsenic and 99% of iron, although when the hydraulic residence time (HRT) was lower the removal efficiency decreased to 75% and 84% respectively.

Other studies (Raven et al., 1998) indicate that Adsorption maxima of approximately 0.60 (0.58) and 0.25 (0.16) $molAs.molFe^{-1}$ were achieved for arsenite and arsenate, respectively, at pH 4.6 (pH 9.2 in parentheses). For passive treatment purposes a removal efficiency of 99% is used.

Zhang et al. (2022) indicates that Fe oxyhydroxides can also be used to remove vanadium with studies indicating removal efficiencies of 84 – 92%. A nominal value of 90% has been used as the treatment efficiency within the WLBM.

### *9.6.2 Sulfate Treatment Efficiency*

It is proposed that a sulfate treatment efficiency of 30% is applied to mine-impacted waters treated by passive anaerobic treatment systems. This efficiency is in alignment with recent literature reviews of field-scale bioremediation systems. For instance, Zak et al. (2021) noted that bioremediation systems (BIOS) can achieve a variable range of sulfate removal efficiencies (Figure 21). Analysis of these data indicate that the average treatment removal efficiency is 30.7% for sulfate influent concentrations that range from 2.5 to 8,000 mg/L. Such sulfate ranges are within the bounds expected at BOGP.

The efficiency proposed will require validation through large scale field trials. The efficiency is applied to passive treatment systems in the WLBM.

*D. Zak et al.* *Earth-Science Reviews 212 (2021) 103446*

**Table 2**

Performance of field-scale bioremediation systems. CS=Composite System. CW=Constructed Wetland. SF=Surface Flow. SSF=Sub-Surface Flow. PRB=Permeable Reactive Barrier. *=refers to the cell of CS performing under anaerobic conditions. **=Water temperature reported in the studies. References: 1.Barton and Karathanasis (1999); 2. Hedin (2008); 3. Ji et al. (2008); 4. Di Luca et al. (2011); 5. Mitsch and Wise (1998); 6. Morrison and Aplin (2009); 7. Wieder (1993); 8. Woulds and Ngwenya (2004); 9. Wu et al. (2011); 10. Wu et al. (2012); 11. Benner et al. (2002); 12. Gibert et al. (2013); 13. Herbert et al. (2000); 14. Benner et al. (1999); 15. Caraballo et al. (2011); 16. Song et al. (2012); 17. Behum et al. (2011); 18. Matthies et al. (2012).

| Reference | Type | Area/Volume ($m^2/m^3$) | Duration (y) | Plants | pH | T^a (°C)/Climate | Substrate | $SO_4^{2-}$ inflow (mg $L^{-1}$) | $SO_4^{2-}$ removal (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CS/SSF* | 1,022/705 | 1.5 | Yes* | 3.4 | Temperate, USA | Limestone/ Organic* | 3034 | 53.5 |
| 2 | CS/SF* | 49,000/– | 2 | | 6.2 | Temperate, USA | | 1085 | 5.6 |
| 3 | CS | –/– | | | 2.1–7.7 | Temperate/South Korea | | 2.5–3046 | 0–62 |
| 4 | CW/SF | 2,000/900 | 1 | Yes | 9–10 | 12.8–27** | | 270–1649 | 24–66 |
| 5 | CW/SF/ SSF | 3,869/3,757 | 1 | Yes | 3 | Temperate, USA | Limestone/ Organic | 1672 | 29 |
| 6 | CW/SF | 440/132 | 3 | Yes | 5.6–6.7 | 5.9–15.8** | Organic | 355–969 | 15–25 |
| 7 | CW/SF | 180/54 | 2 | Yes | 2.9 | Temperate, USA | Limestone/Peat | 3132 | 0–14 |
| 8 | CW/SF | –/– | 0.5 | Yes | 2.6 | Temperate, Scotland | Limestone/ Organic | 900 | 17–18 |
| 9 | CW/SSF | 6/3 | 0.7 | Yes | | Temperate, Germany | Sand/Gravel | 283.1 | 7 |
| 10 | CW/SSF | 6/3 | 6 | Yes | 6.7 | Temperate, Germany | Sand/Gravel | 790–995 | 32–54 |
| 10 | CW/SSF | 6/3 | 6 | No | 6.7 | Temperate, Germany | Sand/Gravel | 790–995 | 12–0 |
| 11 | PRB | 60/216 | 4 | No | 5–6 | Continental, Canada | Gravel/Organic | 2304–2880 | 13–50 |
| 12 | PRB | 154/580 | 3 | No | 3.5–4.5 | Temperate, Spain | Calcite/Organic/ Fe | 1000 | 2–43 |
| 13 | PRB | 60/216 | 2 | No | 4.6 | Continental, Canada | Gravel/Organic | 2400–8000 | 70 |
| 14 | PRB | 60/216 | 2 | No | 4–6 | Continental, Canada | Gravel/Organic | 1000–5000 | 74 |
| 15 | Bioreactor | 120/– | 1.8 | No | 2.6 | 16,8–22,2** | Limestone/ Organic | 900 | 20–40 |
| 16 | Bioreactor | –/0.0035 | 0.5 | No | 3–4 | Temperate, South Korea | Organic | 1277 | 20–48 |
| 17 | Bioreactor | /5,887 | 3 | No | 2–3 | Temperate, USA | Limestone/ Organic | up to 4100 | 30 |
| 18 | Bioreactor | 1,511;1,124/ 1,209;899 | 6 | No | 5.8; 5.0 | Temperate, UK | Limestone/ Organic | 369/1074 | 13–40 |

Figure 21. Performance of field-scale bioremediation systems for sulfate removal.

*Source: Zak et al., 2021.*

*Note: where a range is provided, half the range is used to determine treatment efficiency*

### *9.6.3 Nitrogen Treatment Efficiency*

Nitrogenous compounds (e.g., nitrate) will be treated through the anaerobic passive treatment system. It is removed in preference to sulfate due to the higher energy yield (Figure 14) and nitrate is expected to be low after anaerobic treatment (although ammoniacal nitrogen is expected to increase and will be treated as a secondary contaminant. Christensen (2022) using enhanced PTS technologies (e.g., the addition of water soluble carbon) reports that near-complete nitrate removal occurred in all bioreactors (17 mg/L influent to <0.5 mg/L effluent $NO_3$-N) yet ammoniacal nitrogen was elevated in some trials and above proposed water quality limits for the BOGP (Table 3). These data are provided in Figure 22 and Figure 23.

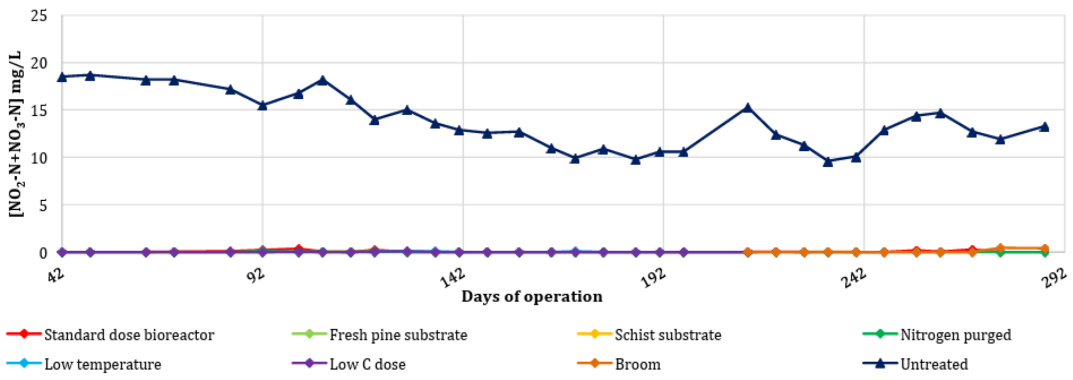


Figure 22. Nitrate + nitrite nitrogen concentration in the bioreactor effluents.

*Source: Christensen et al. (2022)*

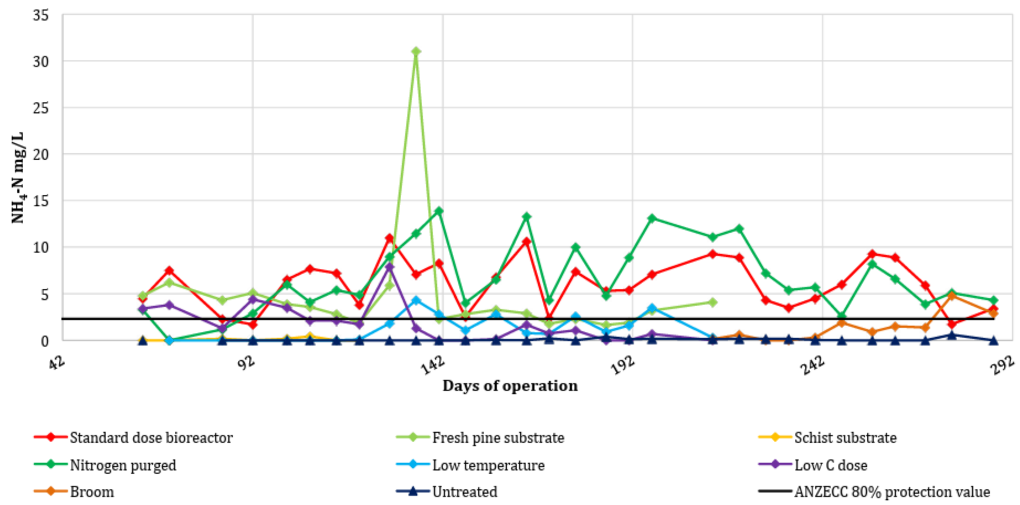


Figure 23. Ammoniacal nitrogen concentration in bioreactor effluents.

*Source: Christensen et al. (2022)*

For this review, it is assumed that nitrate nitrogen will be totally removed by passive treatment and that 50% of the influent is converted to ammoniacal nitrogen. Ammoniacal nitrogen will be treated by aeration and biological conversion to $N_2$ gas.

### *9.6.4 Metals*

Various passive treatment systems have been installed in New Zealand, some of which use waste mussel shells (e.g., Weber et al., 2015). Trumm et al. (2022) reports that the removal efficiencies of a mussel shell bioreactor (MSR) for acid rock drainage were 91.4% (Fe), 97.6% (Al), 83.3% (Zn), 85.6% (Cd), 85.2% (Co), 85.6% (Cu), and 87.0% (Ni). This is comparable to other studies for the treatment of acid rock drainage where Crombie et al. (2011) reports the removal of 96-99% of Al, Fe, Ni, and Zn with mean Ni decreasing from 0.27 mg/L to 0.0028 mg/L and mean Zn decreasing from 1.18 mg/L to 0.008 mg/L. Sinclair and Weber (2022) note that within a MSR treating circum-neutral MIW that (based on median data) 99% of the Fe; 98% of the Ni, and 99.8% of the Zn was removed. However, only 40% of the Al was removed (from 0.005 to 0.003 mg/L), but this is likely to be a function of the very low Al concentration.

Generally, these systems work well for metals that can be reprecipitated as sulfides or hydrolyse as the pH increases through the treatment system. The dataset provided by Sinclair and Weber (2002) was selected to derive metal removal efficiencies for the WLBM. This dataset was selected for the following reasons:

- Circum-neutral drainage that will be comparable to the BOGP MIW.
- Low metal loads, although iron is moderately elevated (as is expected at BOGP).
- A robust dataset provided over many months of operation.

Where the metal removal efficiencies could not be determined from Sinclair and Weber (2022) as the contaminants were below the limit of reporting (e.g., Cd, Cr, Cu, Pb) it is assumed they would be removed by similar mechanisms. As shown in Figure 11, these metals are also removed by anaerobic passive treatment systems and removal efficiency of 99% was applied. This will require validation by lab and field trials.

Table 9. MSR Treatment Efficiencies

| PARAMETER | REMOVAL EFFICIENCIES (%) |
|---|---|
| Calcium[1] | -43.2 [1] |
| Magnesium | 8 |
| Aluminium | 83.3 [2] |
| Iron | 99.1 |
| Nickel | 97.9 |
| Zinc | 99.8 |
| Manganese | 86.4 |
| Cadmium | 85.2 [3] |
| Cobalt | 98.4 |
| Copper | 85.6 [3] |
| Uranium | 74 [3] |
| Vanadium | 90 [4] |
| Other metals | 98 [5] |

*1. - Negative numbers indicate an increase (e.g., an increase in Ca indicates minor dissolution of the shells.*

*2. - Data taken from Trumm et al. (2022). This is considered to be more reasonable due to the very low Al concentrations in the treated water assessed by Sinclair and Weber (2022).*

*3. - Data from Trumm et al. (2024).*

*4. - Zhang et al. (2022).*

*5. - Assumed to be comparable to other metals. Further laboratory and field work is required.*

# 10 FURTHER WORK

Further work is required to advance the WTP and PTS studies towards a FS level to confirm technology suitability, costs, and management requirements prior to the systems being installed. Further work should be undertaken once MIW is available from the project area as this will help with water treatability trials. The following section summarises the work that needs to be undertaken.

## 10.1 Transition to the Post Closure Phase

Modelling (MWM, 2025c) indicates that the transition from active to passive treatment in the Shepherds Creek catchment could occur within 50 years of the cessation of mining. The transition point is a function of:

- Cover system performance (e.g., NP being 20% of rainfall).
- Flow rate and quality.
- PTS treatment efficiency.
- Dilution within Shepherds Creek and Bendigo Creek catchments
- Dilution within the downgradient alluvial aquifers.

Active treatment is not required in the Rise and Shine Creek catchment with partial treatment of the SRX Pit Lake overflow being required. Modelling was based on treatment of the average flow (8 L/s).

## 10.2 Active Water Treatment Plant

Process Flow indicate that the proposed water quality objectives (Ryder, 2025) can be achieved, although further work is required to develop the OoM study to a feasibility study level. Further details are provided in Appendix B. The WTP will operate until passive treatment systems can be installed.

The WLBM (MWM, 2025c) assumes the water is treated and meets the proposed water quality objectives.

## 10.3 Passive Treatment System

Trials should be undertaken using BOGP site specific MIW, prior to the site transitioning from active to passive treatment, to assess the treatability of waters by:

- Oxidation to encourage $Fe(OH)_3$ precipitation and adsorption of metals such as As, V, and other trace metals.
- Anaerobic treatment to remove nitrate, reduce sulfate concentrations, and precipitate metals as sulfides.
- A polishing pond to remove secondary contaminants generated in the anaerobic treatment stage (e.g., hydrogen sulfide ($HS^-$), ammoniacal nitrogen, and low dissolved oxygen).

The technology development pathway should include:

- Bench-scale trials to validate OoM study assumptions.

- Site-based pilot trials (PFS[6]).
- Operational trials (FS).

For the WLBM the following efficiencies (Table 11) are proposed to understand effects to the receiving environment. These will require validation once mining commences, and MIW is available for trials. Data highlighted in Yellow have lower confidence and further work is needed to confirm the passive treatment systems will be appropriate.

Table 10. PTS Treatment Efficiencies

| PARAMETER | REMOVAL EFFICIENCIES [1] |
|---|---|
| Calcium[1] | -43.2% |
| Magnesium[1] | 8% |
| Aluminium | 83.3% |
| Arsenic | 99% [2] |
| Iron | 99.1% |
| Nickel | 97.9% |
| Zinc | 99.8% |
| Manganese | 86.4% |
| Cobalt | 98.4% |
| Uranium | 74% [3] |
| Vanadium | 90% [8] |
| Other metals | 98% [4] |
| Sulfate | 30% [5] |
| Nitrate nitrogen | 99% [6] |
| Ammoniacal nitrogen | 99% [6] |
| Cyanide | 90% [7] |

*1. – where data are taken from Table 10 for MSR and limestone of some form is assumed to be part of the treatment media.*

*2. – where data are taken from Hayton et al. (2022) = 95% removal with additional Fe to increase As removal to 99% (e.g., Raven et al., 1998).*

*3. – where data are obtained from Trumm et al. (2024).*

*4. – where data are assumed to be comparable to other metals removed by a MSR (Table 10).*

*5. – Based on 30% removal as determined from literature (Figure 21).*

*6. – Assumed to be 99% to be in alignment with nitrate removal efficiencies. Further work is required.*

*7. – Based on studies by Álvarez et al. (2004). Further work is required.*

*8. – Zhang et al. (2022).*

[6] *Prefeasibility Study*

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# 12 LIMITATIONS

Attention is drawn to the document "Limitations", which is included in Appendix C of this report. The statements presented in this document are intended to provide advice on what the realistic expectations of this report should be, and to present recommendations on how to minimise the risks associated with this project. The document is not intended to reduce the level of responsibility accepted by Mine Waste Management, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in doing so.

# APPENDIX A ABBREVIATIONS

| ABBREVIATION | DEFINITION |
|---|---|
| AMD | Acid and metalliferous drainage, which can also include low metal saline drainage |
| BIOS | Bioremediation systems |
| BOGP | Bendigo-Ophir Gold Project |
| CIT | Come in Time deposit |
| Eh | Oxidation-reduction potential |
| E-PTS | Enhanced passive treatment system |
| ELF | Engineered landform |
| FS | Feasibility study |
| HRT | Hydraulic residence time |
| MGL | Matakanui Gold Limited |
| MIW | Mine impacted water |
| MSR | Mussel shell reactor |
| MWM | Mine Waste Management Ltd |
| NAF | Non-acid forming |
| NMD | Neutral and metalliferous drainage |
| NP | Net percolation |
| NRB | Nitrate-reducing bacteria |
| OoM | Order of magnitude |
| PCOC | Potential constituents of concern |
| PTS | Passive treatment system |
| RAS | Rise and Shine deposit |
| RSSZ | Rise and Shine Shear Zone |
| SCR | Sulfide scrubber |
| SCK Fill | Shepherds Creek fill |
| SRE | Srex East deposit |
| SRX | Srex deposit |
| TSS | Total suspended solids |
| TSF | Tailings storage facility |
| TZ3 | Lower Greenschist facies Textural Zone 3 rocks of the Otago Schist |
| TZ4 | Upper Greenschist facies Textural Zone 4 rocks of the Otago Schist |
| VFR | Vertical flow reactor |
| WELM | West engineered landform |
| WLBM | Water and Load Balance Model |

| ABBREVIATION | DEFINITION |
|---|---|
| WTP | Water treatment plant |
| ZVI | Zero valent iron |

# APPENDIX B WTP OoM DESIGN REPORT

# BOGP Post Closure Active Water Treatment Plant (WTP)

# Order of Magnitude (Oom) Study

| | |
|---|---|
| Prepared For: | Matakanui Gold Limited |
| Prepared By: | Process Flow |
| Date: | 9/10/2025 |
| Document Number: | PFL-2426-PRJ-RPT-00001 |

Revision Control

| Revision | Status | Description | Author | Checked | Approved | Date |
|---|---|---|---|---|---|---|
| A | Draft | Issued for Client Comment | G Smith | E Manhart | | 12/05/2025 |
| B | Draft Client Review | Issued for Client Review | E Manhart | G Smith | | 26/05/2025 |
| 0 | Use | Issued for Use | E Manhart | G Smith | G Smith | 16/06/2025 |
| 1 | Use | Revised Flow Rates | E Manhart | G Smith | G Smith | 28/09/2025 |
| 2 | Use | Revised Tables | G Smith | G Smith | | 2/10/2025 |
| 3 | Use | Revised following client comments | E Manhart | G Smith | G Smith | 9/10/2025 |

# EXECUTIVE SUMMARY

This report provides an order of magnitude assessment of the water treatment requirements following BOGP mine closure. During the mine closure phase, water treatment will be required by an active Water Treatment Plant (WTP) for years eleven to thirty-one. There are three water management stages during the project.

- Internal water management during the operations phase
- Active water treatment post closure (Summarised in this report)
- Passive water treatment within decades of the mining cessation

This report details the recommended process requirements for an active WTP with the capacity to treat an average flow of 26.9 l/sec.

Potential constituents of concern (PCOC) have been identified for the BOGP based on baseline water quality studies, environmental geochemistry studies, and proposed water quality compliance limits: It is expected that mining of the BOGP will affect waters within the project area, and these effects will include:

- Elevated total suspended solids (TSS) in surface waters.
- Neutral metalliferous drainage (NMD) that may have elevated PCOC such as arsenic (As), Sulphate ($SO_4$), and trace metals.
- Nitrate-rich drainage due to the use of ANFO.

Following a review of predicted water quality and a literature review of available treatment processes, and the suitability of these processes to remove the PCOCs, an Ettringite precipitation process is recommended.

Known commercial chemical precipitation sulphate removal processes include the SAVMIN process, the CESR (Cost effective Sulphate removal Process) and the Outotec (now Metso) Ettringite process.

The available treatment processes for Ettringite precipitation have been developed for Sulphate concentrations above 2000mg/l, which indicate performance removal of sulphate to 200-100mg/l. (Within the proposed consent limits for surface and ground waters).

Ettringite formation can also provide a polishing effect, allowing precipitation of metals, Ni, Cd, Cu, Zn, Cr, As and Se, often below their compliance limits and laboratory detection limits. Boron, fluoride and up to 30% of chloride and nitrate-nitrite in wastewater have also been removed (Reinsel 1999)

During the operations phase of the project and prior to detailed design of the active WTP it is highly recommended that detailed testing of the actual BOGP water quality take place. This testing should simulate each of the required precipitation steps which would give real data to present and reference for final water quality. This would also give certainty about the effectiveness of the treatment process on the BOGP proposed mine water quality and assurance that the water treatment system will achieve the final water quality and cater for final flow rates.

From the water quality and literature review, the proposed sulphate and metals removal processes will have several sludge management streams with different product outputs, some which will need disposal either on site or off site and some that could be recycled or form a product for export off site.

# TABLE OF CONTENTS

# 1 INTRODUCTION

Process Flow Limited (PFL) has been engaged by Matakanui Gold Limited (MGL) to provide guidance on water treatment for Mine Impacted Water (MIW) for the proposed Bendigo-Ophir Gold Project (BOGP).

Input water quality data used in this study has been referenced from J-NZ0464-002-R-Rev1 Report on Water Treatment requirements by Mine Waste Management, dated 7 October 2025.

The MWM water and load balance model (WLBM) indicates that the BOGP needs to focus on the management and treatment of MIW that will contain potential constituents of concern (PCOC).

The following PCOC may require treatment by the WTP and PTS to achieve the proposed water quality limits for the BOGP (Ryder, 2025):

• Nitrogenous compounds (N) that include nitrate (NO3) and ammoniacal-N (Amm-N).

• Sulfate (SO4).

• Metals and metalloids that may include Aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), strontium (Sr), uranium (U), and zinc (Zn)

• Cyanide (CN) within the tailings water.

Our work specifically involves carrying out an order of magnitude (OoM) study for:

• Treatment of MIW by a WTP during the active closure phase, until the PTS can be successfully established (~ 50 years after closure).

## 1.1 Project Description

This section provides an introduction to the BOGP.

### 1.2 Introduction

MGL is proposing to establish the BOGP (Figure 1), which comprises gold mining operations, processing operations, ancillary facilities and environmental mitigation measures on Bendigo and Ardgour Stations in the Dunstan Mountains of Central Otago. The project site is located approximately 20 km north of Cromwell and will have a maximum disturbance footprint of 550 hectares.

The total Mineral Resource Estimate for the BOGP using a 0.5 g/t cut-off for open pit and 1.5 g/t for underground is 34.3 Mt at 2.1 g/t for 2.34 M oz (MGL, 2025). The Bendigo-Ophir resources occur in four deposits: Come in Time (CIT), Rise and Shine (RAS), Srex (SRX), Srex East (SRE). The majority of identified mineral resources are located within the RAS deposit. Three primary geological units are recognised at site:

- RSSZ – Rise and Shine Shear Zone
- TZ3 – Lower Greenschist facies Textural Zone 3 rocks of the Otago Schist
- TZ4 – Upper Greenschist facies Textural Zone 4 rocks of the Otago Schist

The resources will be mined by open pit methods at each deposit within the project site, with underground mining methods also proposed to be utilised at RAS to access the deeper gold deposits. The majority of the mining activities, ancillary facilities and associated infrastructure will be located in the Shepherds Valley with non-operational infrastructure located on the adjoining Ardgour Terrace. The BOGP also involves the taking of groundwater from the Bendigo Aquifer for use in mining-related activities and the realignment of Thomson Gorge Road via Ardgour Station.

The following mine facilities are proposed (Figure 2):

- Open pits targeting the RAS, SRX, SRE, and CIT deposits.
- An underground mine targeting the RAS deposit.
- Three ex-pit engineered landforms (ELFs) – Shepherds ELF, SRX ELF, and West ELF (WELF).
- Two in-pit landforms (backfill) – CIT and SRE [1].
- Plant and processing area, where CIL extraction technologies will be used as part of the ore recovery process.
- A tailings storage facility (TSF) and TSF Embankment.
- Other ancillary support services / structures (e.g., roads, water management infrastructure, water treatment plants, etc).

These facilities will be placed in the catchment of Shepherds and Bendigo creeks. Understanding baseline water quality (surface and groundwater) is important to enable the establishment of site-specific water quality compliance criteria for any resource consent that may be granted in the future.

[1] *Note: SRE Pit is backfilled by the SRX ELF.*

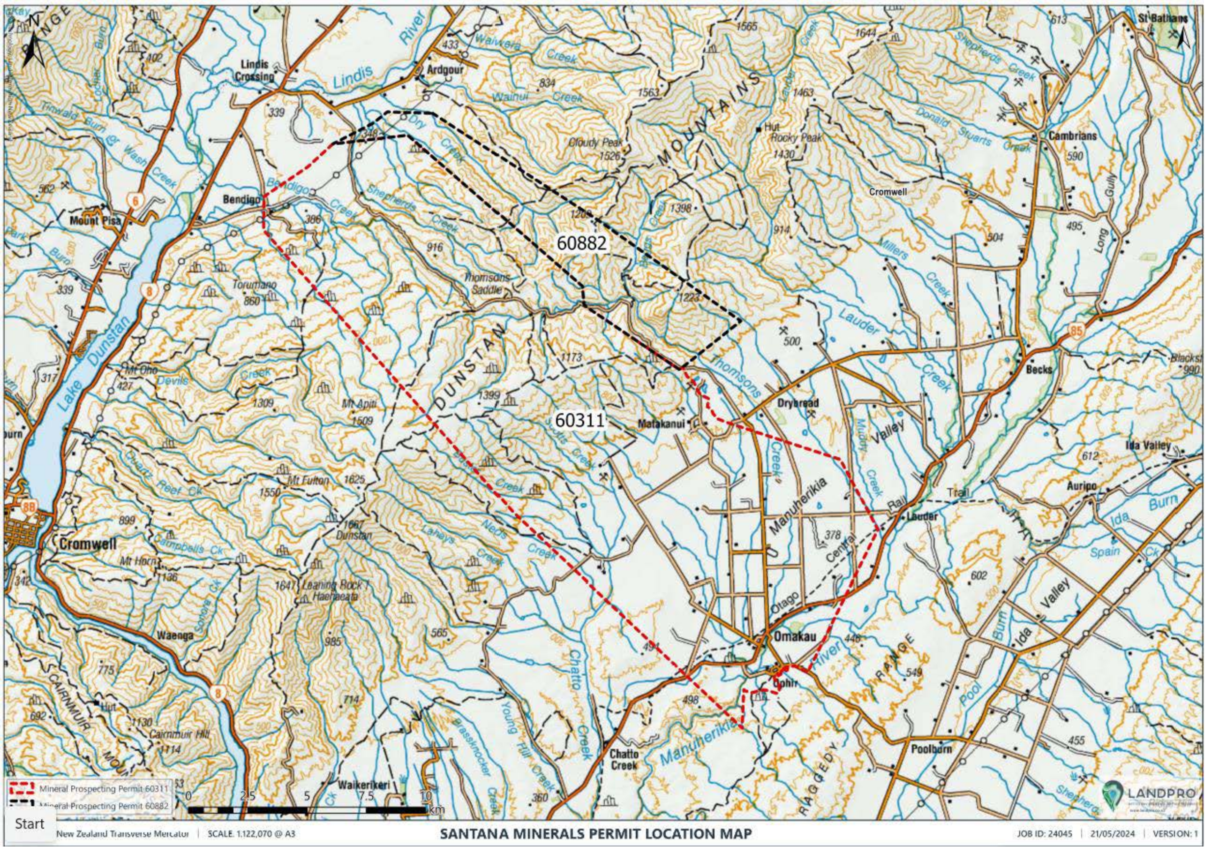


Figure 1. BOGP mineral permit boundaries showing MEP60311 and PEP60882.

### 1.3 Surface Water

The project area covers several catchments and sub-catchments (Figure 2), including:

- Shepherds Creek: This creek runs permanently through the project area and then intermittently from the Ardgour Terrace towards the Lindis River. An irrigation water-take on Shepherds Creek (RM17.301.15) downstream of SC01 monitoring site takes all available surface water in normal flow conditions, which is supplied to an irrigation dam, so the creek does not flow past this point. There is potential for groundwater to flow past this point via a thin layer of alluvial gravels along the creek bed.
- Jean Creek: This creek is an intermittent tributary to Shepherds Creek.
- Rise and Shine Creek: This creek joins Clearwater Creek south-east of the Come in Time Battery and flows into Bendigo Creek.
- Clearwater Creek: Flows into Bendigo Creek.
- Bendigo Creek: Several irrigation water-takes are in place on this creek (RM20.079.01 and RM20.079.02).

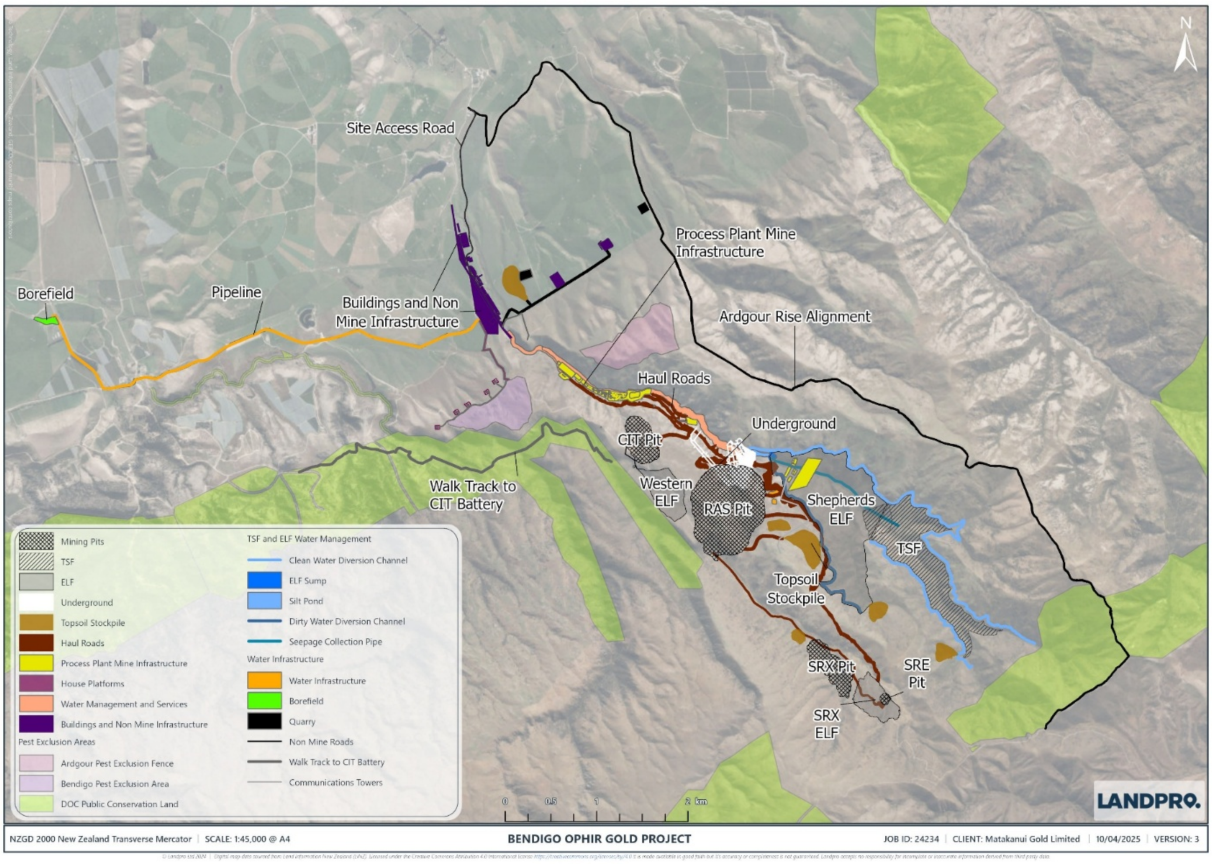


Figure 2. Bendigo-Ophir Gold Project area and water quality monitoring sites.

Baseline water quality data indicates that PCOC are elevated in the BOGP area due to historic mining activities and natural mineralisation. (MWM J-NZ0464-002-R-Rev1)

## 2 DISCLAIMER

*This report provides information that is preliminary in nature and has been prepared to provide the client with water treatment information suitable for an "Order of Magnitude" assessment for the overall project. The information provided is not suitable for detailed design or construction purposes and the information should not be used as a specification for tendering or any other construction related purpose.*

*This report has been prepared solely for the benefit of Matakanui Gold Limited. No liability is accepted by this company or any employee or sub-consultant of this company with respect to its use by any other person/parties.*

*This disclaimer shall apply notwithstanding that the memo may be made available to other persons for an application for permission or approval or to fulfil a legal requirement.*

*This report has been prepared for the particular purpose outlined in the Process Flow Proposal and no responsibility is accepted for the use of this Document, in whole or in part, in other contexts or for any other purpose.*

*Any assessments made in this report are based on the conditions indicated from published sources and the investigation described. No warranty is included, either express or implied, that the actual conditions will conform exactly to the assessments contained in this memo.*

*Where data supplied by the client or other external sources, including previous site investigation data, have been used, it has been assumed that the information is correct unless otherwise stated. No responsibility is accepted by Process Flow Limited for incomplete or inaccurate data supplied by others.*

*Process Flow acknowledges that this report will be relied on by a Panel appointed under the Fast Track Approvals Act 2024 and these disclaimers do not prevent that reliance.*

*The information presented in this report is based on a literature review of known water treatment process technologies for primarily sulphate and metals removal. The information presented is preliminary, and test-work should be carried during the mining phase of the project (prior to active closure) to confirm design assumptions and prove final water qualities can be achieved for the flows required.*

# 3 PROCESS OBJECTIVES AND ASSUMPTIONS

## 3.1 Reference Information

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### 3.2 Process Objectives

During the Active Closure Phase, water treatment is required by a water treatment plant (WTP) once the project switches from a process of internal water management for MIW (during operations) to discharge of MIW from site after closure of the mine. Model results indicate that the WTP can be replaced by a passive treatment system (PTS) within decades of mining cessation, which then defines the commencement of the Post Closure Phase.

### 3.3 Definition of Plant Flow Rates

This section summarises the long-term average flow rates for each mine domain that may require treatment during the Active Closure and Post Closure phases of the BOGP.

#### 3.3.1 Average Flow Rates

Average flow rates are estimated from the Water and Load Balance Model. It is assumed that the use of average flow rates is suitable for the WTP OoM Study and the PTS Concept Study. Peak flows may require either a larger capacity plant or a surge pond prior to any treatment. Further work is required to advance the designs to a feasibility Study (FS) level including understanding the treatment requirements for peak flow rates.

Table 1 provides a summary of flow rates for the various mine domains that require treatment. These flow rates are preliminary and are intended to provide guidance for the OoM study on the WTP design. For the OoM WTP Study it is recommended that the design include suitable contingency for variable flow rates. Active treatment is not required for SRX Pit - It is expected that the water quality from this mine domain will be acceptable for release to the receiving environment (e.g., Rise and Shine Creek / Bendigo Creek) with passive treatment.

Table 1: Estimated average water quantity per mine domain.

| MINE DOMAIN | WTP DESIGN CRITERIA (L/s) | PTS (L/s) | COMMENTS |
|---|---|---|---|
| Shepherds ELF | 4 | 4 | • 20% Net percolation |
| SRX ELF [1, 2] | - | 1 | • 20% Net percolation |
| West ELF [2] | 1 | 1 | • 20% Net percolation |
| Shepherds TSF | 13.4 | 3 | • Flow is expected to be ~13.4 L/s decreasing to 3 L/s after 5 years |
| RAS Underground Portal | 6 | 6 | • Flow from the RAS Underground is not expected for 20-30 years after closure |
| CIT Pit Backfill | 1.5 | 1.5 | • Further details are available in MWM J-NZ0464-002-R-Rev1 |
| SRX Pit | - | 8 | • Further details are available in MWM J-NZ0464-002-R-Rev1. It is assumed this water will not require active |

| MINE DOMAIN | WTP DESIGN CRITERIA (L/s) | PTS (L/s) | COMMENTS |
|---|---|---|---|
| | | | treatment. Passive treatment is required. |
| SCK Fill [2] | 1 | 1 | • 20% Net percolation |
| Non-AMD impacted water | - | - | • Managed for TSS separate to the active WTP. At closure rehabilitated surfaces are assumed to be suitable for discharge with TSS management. |

*1. Active treatment for SRX ELF and SRX Pit are not anticipated.*
*2. Flow rates rounded up to 1 L/s*
*Table sourced from MWM J-NZ0464-002-R-Rev1*

This results in an active water treatment plant with the capacity to treat an average flow of 26.9 l/sec.

## 3.4 Definition of Mine Water Quality (Plant Feed Envelope)

This section summarises the water quality from the various mine domains that require treatment at closure of the BOGP by the active water treatment plant. Peak concentrations are provided for the following streams

- Shepherds ELF
- West ELF
- Shepherds TSF
- RAS Underground Portal
- CIT Pit Backfill
- SCK Fill

### 3.4.1 Shepherds TSF Water Quality

*TSF seepage water quality at mine closure (Year 11) is presented in Table 2. Further details on how the water quality was derived are provided in MWM J-NZ0464-002-R-Rev1*

Constant concentration is assumed.

Table 2: TSF seepage water quality (Closure).

| PARAMETER | CLOSURE TSF SEEPAGE WATER QUALITY |
|---|---|
| Alkalinity (mg $CaCO_3$/L) | 73.21 |
| pH (pH units) | 6.41 |
| EC (µS/cm) | 4,121 |
| Ca | 297 |
| Cl | 804 |
| F | 1.93 |
| Mg | 99 |
| Na | 847 |
| K | 50.8 |
| TOC | - |

| PARAMETER | CLOSURE TSF SEEPAGE WATER QUALITY |
|---|---|
| Al | 0.01 |
| Ag | 0.0068 |
| As | 2.05 |
| B | 0.825 |
| Cd | 0.0002 |
| Co | 0.053 |
| Cr | 0.0055 |
| Cu | 0.001 |
| Fe | 15.3 |
| Mn | 0.59 |
| Mo | 0.14 |
| Ni | 0.678 |
| Pb | 0.0275 |
| Sb | 0.18 |
| Se | 0.003 |
| Sr | 4.4 |
| Tl | 0.001 |
| U | 0.028 |
| V | 0.004 |
| Zn | 0.0296 |
| Cyanide - WAD | 0.35 |
| Sulfate | 954 |
| Ammoniacal-N | 2 |
| Nitrate-N | 0.005 |

*Note: All units in mg/L unless otherwise stated. Green data are LOR and are included in the source term as '0' WAD – Weakly Acid Dissociable cyanide; If no data are provided these are identified by ' - '.*

### 3.4.2 ELF and CIT Backfill Water Quality

Water quality for the ELFs is provided in Table 3, (Table sourced from MWM J-NZ0464-002-R-Rev1) which shows the water quality for Year 27, when maximum loads are being derived from the Shepherds ELF to provide peak concentration data for the design of the WTP.

Constant concentrations are assumed for As (0.2 mg/L) and Fe (7.6 mg/L) based on empirical data for sub-oxic conditions (e.g., Globe Progress Waste Rock Stack, Hayton et al., 2022). These concentrations are above the proposed water quality reference limit (Ryder, 2025) and will require management. The SCK Fill assumes full oxidation, which results in low Fe concentrations.

Table 3. Water Quality Data (Year 27) for WTP design – 20 m Oxygen Exclusion Model

| STATION | TSF SEEPAGE | SHEPHERDS ELF SEEPAGE | WELF SEEPAGE | CIT PIT BACKFILL | SCK FILL SEEPAGE | MIW COMBINED* |
|---|---|---|---|---|---|---|
| Acidity | 0.01 | 0 | 0 | 0 | 0 | 0.03 |
| Al | 0.011 | 0.003 | 0.003 | 0.005 | 0.003 | 0.013 |
| Alkalinity | 73 | 189 | 183 | 190 | 158 | 160 |
| As | 2.06 | 0.20 | 0.20 | 0.08 | 0.20 | 0.61 |

| STATION | TSF SEEPAGE | SHEPHERDS ELF SEEPAGE | WELF SEEPAGE | CIT PIT BACKFILL | SCK FILL SEEPAGE | MIW COMBINED* |
|---|---|---|---|---|---|---|
| B | 0.83 | 0.87 | 0.10 | 0.09 | 0.01 | 0.59 |
| Ca | 297 | 51 | 51 | 39 | 36 | 107 |
| Cd | 0.0002 | 0 | 0 | 0.0001 | 0 | 0.0001 |
| Cl | 806 | 63 | 37 | 12 | 8 | 223 |
| Co | 0.053 | 0.109 | 0.023 | 0.004 | 0.003 | 0.061 |
| Cr | 0.00636 | 0.00020 | 0.00019 | 0.00040 | 0.00007 | 0.00170 |
| Cu | 0.00100 | 0 | 0 | 0.00021 | 0 | 0.00049 |
| DOC | 0 | 0 | 0 | 0.206 | 0 | 0.038 |
| F | 1.94 | 6.30 | 6.12 | 1.39 | 2.37 | 3.90 |
| Fe | 15.3 | 7.6 | 7.6 | 2.4 | 7.6 | 8.7 |
| Hg | 0 | 0 | 0 | 0.00014 | 0.00000 | 0.00003 |
| K | 51 | 683 | 672 | 84 | 159 | 372 |
| Mg | 100 | 38 | 37 | 20 | 24 | 49 |
| Mn | 0.594 | 0.819 | 0.774 | 0.103 | 0.182 | 0.567 |
| Mo | 0.140 | 1.005 | 0.672 | 0.119 | 0.157 | 0.535 |
| NO3-N | 2.01 | 49.64 | 9.54 | 0.73 | 1.33 | 22.89 |
| Na | 848 | 922 | 734 | 127 | 170 | 673 |
| Ni | 0.6784 | 0.0121 | 0.0010 | 0.0013 | 0.0001 | 0.1652 |
| Pb | 0.0276 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0068 |
| Sb | 0.1802 | 2.9986 | 3.2208 | 0.3622 | 0.7601 | 1.6317 |
| Se | 0.0030 | 0.1544 | 0.1649 | 0.0196 | 0.0388 | 0.0826 |
| SO4 | 954 | 957 | 888 | 110 | 208 | 730 |
| Sr | 4.40 | 16.15 | 15.91 | 3.77 | 10.89 | 10.12 |
| Tl | 0 | 0 | 0 | 0.00021 | 0.00000 | 0.00005 |
| CN | 0.35 | 0 | 0 | 0 | 0 | 0.08238724 |
| U | 0.0280 | 0.2751 | 0.2225 | 0.0299 | 0.0515 | 0.1468 |
| V | 0.0040 | 0.1200 | 0.1155 | 0.0135 | 0.0269 | 0.0633 |
| Zn | 0.0296 | 0.0098 | 0.0021 | 0.0014 | 0.0003 | 0.0117 |
| pH (pH unit) | 6.41 | 7.93 | 7.92 | 8.03 | 7.92 | 6.72 |
| Hardness | 1,151 | 285 | 280 | 179 | 190 | 469 |

*Units in mg/L *MIW Combined - This is a weighted average*

### 3.4.3 RAS Underground Water Quality

As discussed in MWM J-NZ0464-002-R-Rev1 seepage from the RAS Underground will be comparable to the RAS Pit Lake. The RAS Underground is not expected to commence discharge until Year 26. Water Quality for Year 26 is provided in Table 4.

Table 4 RAS Underground water quality (Year 27)

| PARAMETER | RAS UNDERGROUND |
|---|---|
| Acidity | 0.44 |
| Al | 0.100 |
| Alkalinity | 182 |
| As | 0.09 |
| B | 0.05 |
| Ca | 59 |
| Cd | 0.0001 |
| Cl | 14 |
| Co | 0.000 |
| Cr | 0.00058 |
| Cu | 0.00302 |
| DOC | 0.090 |
| F | 0.23 |
| Fe | 7.9 |
| Hg | 0.00006 |
| K | 34 |
| Mg | 37 |
| Mn | 0.014 |
| Mo | 0.020 |
| NO3-N | 4.35 |
| Na | 42 |
| Ni | 0.0009 |
| Pb | 0.0035 |
| Sb | 0.0234 |
| Se | 0.0008 |
| SO4 | 141 |
| Sr | 0.79 |
| Tl | 0.00031 |
| CN | 0 |
| U | 0.0094 |
| V | 0.0006 |
| Zn | 0.0022 |
| pH (pH unit) | 5.91 |
| Hardness | 299 |

*Units in mg/L*

### 3.5 Discharge Water Requirements

PCOC that have been identified for the BOGP based on baseline water quality studies, environmental geochemistry studies, and proposed water quality compliance limits are shown in Table 3. Limits are based on:

- Ecotoxicity assessments developed by Ryder (2025) for the proposed surface water compliance sites
- Groundwater limits are based on New Zealand Drinking Water Standards (MoH, 2022).

The proposed compliance monitoring locations are shown in Figure 2 for surface waters and groundwaters.

For conceptual desk-top studies, it is proposed that the WTP and PTS design should be based on the more stringent water quality criteria (i.e., the lower compliance value) for surface and groundwaters to ensure that treated waters comply with both criteria.

These proposed water quality criteria for the BOGP (Ryder, 2025) are summarised in Table 5.

Table 5. Proposed Water Quality Compliance Limits for the BOGP

| PARAMETER (UNITS ARE mg/L UNLESS STATED OTHERWISE) | SURFACE WATER RECOMMENDED COMPLIANCE LIMIT(S) | GROUNDWATER RECOMMENDED COMPLIANCE LIMIT(S) |
|---|---|---|
| pH (unitless) | 6.5 - 9.0 | - |
| Turbidity (NTU) | 5 (over a 5-year rolling period, 80% of samples, when flows are at or below median flow, are to meet the limit) | - |
| Ammoniacal-nitrogen ($NH_3$-N) | ≤0.24 (annual median)<br><0.4 (annual $95^{th}$ %)[1] | - |
| Nitrate-nitrogen ($NO_3$-N) | <2.4 (annual median)<br><3.5 (annual 95th %) | 11.3 (MAV)[2] |
| Cyanide ($CN^-$) | 0.011 (un-ionised HCN, measured as [CN], ANZG 2018)[1] | 0.6 (MAV) |
| Sulfate ($SO_4^{2-}$) | • If hardness is <100 mg/L ($CaCO_3$), the sulfate compliance limit = 500 mg/L.<br>• If chloride is <5 mg/L, the sulfate compliance limit = 500 mg/L.<br>• If the hardness is 100–500 mg/L AND if chloride is 5–<25 mg/L, the sulfate compliance limit is (in mg/L):<br>[-57.478 + 5.79*(hardness mg/L $CaCO_3$) + 54.163*(chloride mg/L)] * 0.65<br>• If hardness is between 100 and 500 mg/L AND if chloride is between ≥25 and ≤500 mg/L, the sulfate limit is (in mg/L):<br>[1276.7+5.508*(hardness mg/L $CaCO_3$) + 1.457*(chloride mg/L)] * 0.65<br>A minimum of 12 samples must be collected over any rolling 12-month period. | ≤250 (taste threshold) |

| PARAMETER (UNITS ARE mg/L UNLESS STATED OTHERWISE) | SURFACE WATER RECOMMENDED COMPLIANCE LIMIT(S) | GROUNDWATER RECOMMENDED COMPLIANCE LIMIT(S) |
|---|---|---|
| | For compliance limits in the points above, no more than 20% of samples collected over a rolling 12-month period may exceed the relevant compliance limit.<br>• An acute compliance limit = 1,000 mg/L averaged over 4 days and not to be exceeded more than once in a one-year period, OR in more than 10% of samples over a one-year period. | |
| Aluminium (Al) | ≤0.08 | 1 (MAV) |
| Antimony (Sb) (total) | 0.074 (chronic)<br>0.250 (acute) | 0.02 (MAV) |
| Arsenic (As(V)) | ≤0.042 | 0.01 (MAV) |
| Cadmium (Cd) | ≤0.0004[3] | 0.004 (MAV) |
| Chromium (Cr) | ≤0.0033 (Cr(III))[4]<br>≤0.006 (Cr(VI))[4] | ≤0.05(MAV, Total Cr) |
| Cobalt (Co) | 0.001 (chronic)[5]<br>0.11 (acute, not to exceed)[5] | <1 (livestock drinking water) |
| Copper (Cu) | ≤0.0018 | ≤0.5 |
| Iron (Fe) (total) | - | ≤0.3 |
| Lead (Pb) | - | 0.01 (MAV) |
| Manganese (Mn) | - | 0.4 (MAV) |
| Molybdenum (Mo) | ≤0.034 | <0.01 |
| Selenium (Se) | - | 0.02 |
| Strontium (Sr) (total) | - | 4 |
| Uranium (U) | - | 0.03 (MAV) |
| Zinc (Zn) | ≤0.015[6] | ≤1.5 |

*All limits are dissolved unless noted as total*

*"-" = no limit recommended.*

*[1] = refer to Ryder (2025), for concentration adjustments.*

*[2] MAV = Maximum acceptable value – From the NZ drinking water standards.*

*[3] Cd (dissolved) is adjusted by the following algorithm: HMTV = TV*(H/30)*0.89, where hardness-modified trigger value (HMTV) = (µg/L), trigger value (TV) (µg/L) at a hardness of 30 mg/L as CaCO3; H, measured hardness (mg/L as CaCO3) of a fresh surface water.*

*[4] = Cr (dissolved) is adjusted by the following algorithm: Chromium (mg/L) = Toxicity value (mg/L)*(H (mg/L)/30)$^{0.82}$*

*[5] = Co (dissolved) is adjusted by the following algorithm: Cobalt (µg/L)= exp {(0.414[ln(hardness $CaCO_3$ mg/L)] – 1.887}*

*[6] = Zn (dissolved) is adjusted by the following algorithm: Zinc (mg/L) = Toxicity value (mg/L)*(H (mg/L)/30)$^{0.85}$*

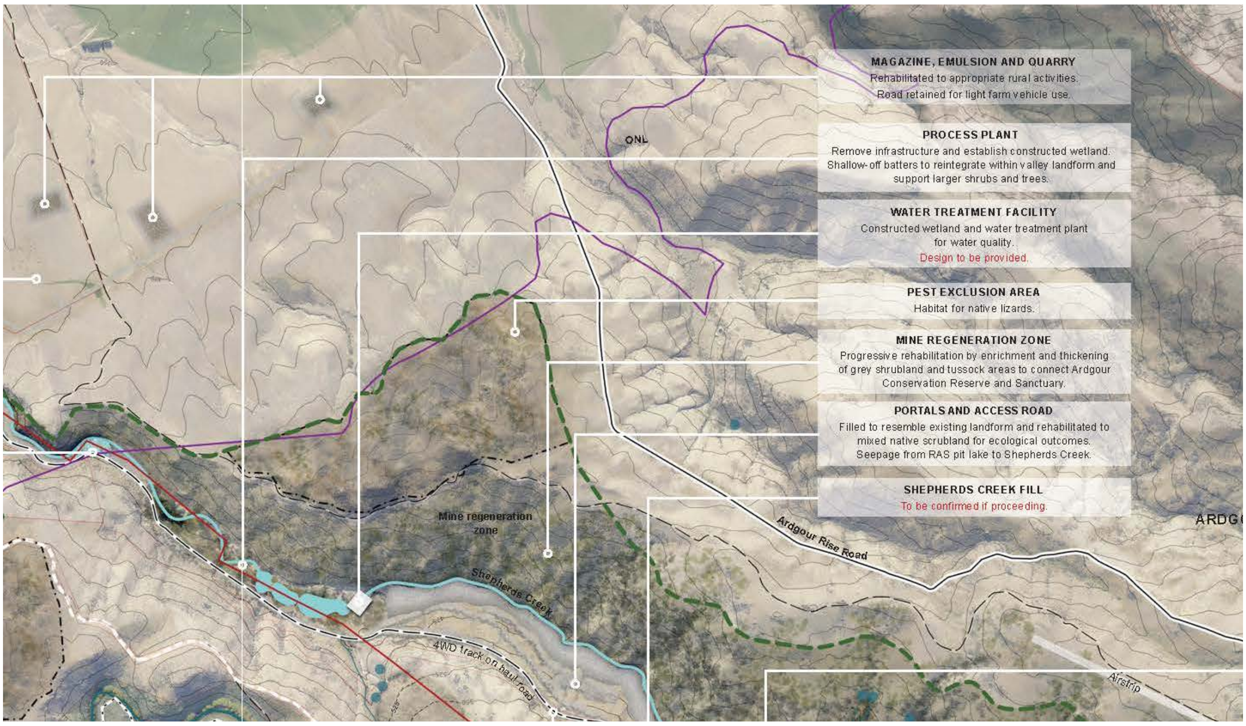
The PCOC presented in section 3.4 were identified from the baseline studies, source hazard assessment, geochemical modelling, and the water and load balance modelling to understand potential effects of the BOGP.

### 3.6 Plant Location and Footprint

The proposed location for the Active WTP is located on Shepherds creek near the mine regeneration zone (area labelled "Water Treatment Plant" on the image shown below).

The size and footprint requirements for the WTP and Surge and Treated water ponds is as follows.

- WTP Footprint – An area approximately 100 m x 60 m TBA is recommended to be located near the surge and treated water ponds.
- WTP Surge Pond – 14,000 $m^3$ (see section 4.4 for detail and sizing philosophy)
- WTP Treated Water Pond – 2,000 $m^3$ (see section 4.6 for detail and sizing philosophy)



# 4 PRELIMINARY PROCESS DESIGN

The following is a description of the preliminary level process design which has been developed for the purpose of selecting plant options. This description should be read in conjunction with the preliminary design process flow diagrams PFL-2426-PRO-PFD-00001 to 00003 (Sheets 1 to 3) included in Appendix A of this report.

The selected process is based on known water treatment process technologies for primarily sulphate and metals removal as described in the following sections. It should be noted that the design selection is preliminary, and test-work should be carried during the mining phase of the project (prior to active closure) to confirm design assumptions and prove final water qualities can be achieved.

The process selected involves the following unit processes.

- Surge Sump
- Pontoon mounted pumps for plant feed
- Metal hydroxide precipitation and settling
- Gypsum precipitation and settling
- Ettringite precipitation and settling
- Carbonation and pH trimming
- Treated Water Sump
- Sludge Management

Other processes that will likely be needed in addition to the active WTP are:

- Cyanide Destruct on the Shepherds TSF influent stream
- Potential additional nitrate removal after the WTP via biological processes

## 4.1 Treatment Literature Review

A range of Active Treatment technologies for sulphate and metals removal exist, including Ettringite Precipitation, Biological Sulphate Removal, Ion Exchange, Reverse Osmosis, Electrocoagulation, Treatment and Extraction of Rare Earth Metals. This section is a review of the processes currently available at bench and pilot trial and full plant scale for sulphate and metals removal.

### 4.1.1 Active Treatment Processes reviewed

The following active treatment processes were reviewed for suitability for sulphate and metals removal:

- Biological processes
- Membrane treatment including Reverse Osmosis
- Ion exchange
- Electrocoagulation
- Treatment and extraction of rare earth elements
- Chemical Treatment and Mineral Precipitation (Lime addition, Barium Salts addition, CESR, Savmin, Outotec/Metso, (GARD, 2021; Lorax, 2023))

The processes that are still only under bench scale and research and development stage are:

- Electrocoagulation (developed to bench scale)
- Treatment and extraction of rare earth elements (This is under research and development only (GARD, 2021)

With the passage of time, these treatment options may become viable however at this stage they are not considered a proven technology suitable for full scale plant application for this BOGP project.

Reverse Osmosis, Ion exchange and Biological Processes have been discounted for this project as active treatment options.

Reverse Osmosis may be appropriate if sulphate concentration was lower than the sum of all metals and chloride (if operational and capital consideration allowed).

Reverse Osmosis and membrane processes generally produce large quantities of membrane reject waters (brine) which requires reprocessing and disposal. Capital and operating costs for membranes are high, with RO operating pressures high, and chemical use for fouling removal has potential to be high (Lorax, 2023). Operational issues associated with RO and Membranes include high fouling and cleaning rates with membrane longevity is shown to be reduced in these applications (Lorax, 2023).

Ion exchange processes do not have long track record for this application at full plant size, although information about trials at pilot scale are available (Lorax, 2023). Ion exchange processes produce quantities of gypsum sludges, and high amounts of brine which need further processing. They are not widespread in use for this application (Bratty et al,2014). One ion exchange technology, the GYP-CIX process is suitable for treated mine waters with high levels of TDS, sulphate and calcium (up to 2000mg/l). It uses calcium hydroxide and sulphuric acid to regenerate the ion exchange resins. Costing of resins would have to be done to compare lime and other chemical costs to see if this process would be viable. For this BOGP project it has been discounted due to insufficient information on its long-term use at full scale for this application.

Biological Processes can be limited by sufficient organic carbon and nutrients in mine influence waters and the presence of heavy metals limiting growth. (Lorax 2023, Bratty et al, 2014)

*Biological treatment with sulphate-reducing bacteria is suitable to low or moderate sulphate loadings (Qian et al., 2015; Silva et al., 2012), but its application is usually hindered by the shortage of organics, the inhibition of high salinity and metal ions in the wastewater (Mothe et al., 2017), and the generation of hydrogen sulphide (Runtti et al., 2016).* (Dou. W, 2017)

There has been limited application of Biological Treatment in Active Water Treatment systems and is more successful used in Passive Treatment systems. (Bratty et al, 2014)

Sulphate removal using chemical precipitation include processes of lime addition, barium salts addition and proprietary processes such as the CESR (Cost Effective Sulphate Removal process), Savmin, Oututec/(Metso) processes (GARD, 2021; Lorax, 2023).

(It is noted in literature that Barium Sulphate is highly insoluble and as an alternative to Calcium Hydroxide, the addition of Barium Hydroxide is extremely effective at removing sulphate. Barium Hydroxide is however, an expensive, corrosive and toxic treatment chemical and this rarely represents a cost-effective treatment option to use this as a hydroxide for this stage of the process. (Gard, 2021).)

For mine water that is net acidic, where low residual metal and sulphate concentrations are needed in the treated discharge water, and the sulphate concentration is higher than the sum of metals and chloride, where carbon sources (crude or refined) are not available or are expensive, then the Savmin process is recommended as an appropriate technology (Younger et al 2002).

Ettringite Precipitation (addition of Lime and $Al(OH)_3$ can be used to remove sulphate and heavy metals. Ettringite ($3CaO.2CaSO_4.Al_2O_3.31H_2O$) has very low solubility and therefore sulphate concentrations are low in treated water after precipitation and settling.

The Main unit operations for known processes for sulphate removal with Ettringite precipitation involve:

1. Metals Precipitation - pH lift with Lime to the range of 11.5 to 12 (Calcium Hydroxide, rather that barium), this enables Al dissolution
2. Gypsum Precipitation
3. Ettringite Precipitation - $Al^{3+}$ addition to remove sulphate as precipitated ettringite
4. pH reduction of the treated water with CO2 to meet effluent discharge criteria and precipitate CaCO3

Ettringite sludge must be separated by gravitation separation and or filtration (Reinsel 1999, Lorax Environmental 2003, Outotec 2014).

Known commercial chemical precipitation sulphate removal processes include the SAVMIN process, the CESR (Cost effective Sulphate removal Process) and the Outotec (now Metso) Ettringite process. All commercial processes follow similar principles:

SAVMIN uses aluminium oxide (aluminiumtryhydroxide in amorphous or gibbsite form) to create ettringite, with recovery. CESR uses a proprietor Al containing chemical from cement production, without recovery of aluminium source. The Outotec process does not contain a separate lime addition step. (Lorax Environmental 2003, Outotec 2014).

The processes have been developed for Sulphate concentrations above 2000mg/l, with performance levels providing removal of sulphate to 200-100mg/l. Ettringite formation can also provide a polishing effect, allowing precipitation of metals, Ni, Cd, Cu, Zn, Cr, As, Se, Cd, Boron, fluoride and chlorite and nitrate, in waste up to 30% have been removed (Reinsel 1999, Outotec 2014)

### 4.1.2 Design Considerations

Operating costs for the SAVMIN process depend on reagent use which depends on levels of sulphate and univalent cations (Na, K, NH4 etc present in the feed water (Smit, 1999)).

Typically, there are low settling rates for the liquid/solid separation phases (Smit 1999). For this reason, conventional high-flow thickeners are preferred for the solid-liquid separation phases in the treatment process (Lorax, 2023). Mixing times for each phase varies from 30-60 minutes but will depend on site specific water quality.

Magnesium ions can interfere with sulphate removal by inhibiting the formation of ettringite (Zahedi et al, 2022).

*It is reported that $Mg^{2+}$ has adverse effects on the formation of ettringite in cement paste (De Weerdt et al., 2014), and prevents sulphate removal as gypsum (Tolonen et al., 2015). However, the effects of $Mg^{2+}$ on ettringite, precipitation are scarcely reported, and it should be essential for process design and very useful for understanding the precipitation behaviour in real wastewater rich in $Mg^{2+}$ and sulphate.* (Dou. W, 2017), also

The study by Dou. W, et al shows that $Mg^{2+}$ has a significant inhibitory effect on sulphate removal by ettringite precipitation and that an additional precipitation step prior to ettringite precipitation is needed to remove magnesium hydroxide as a settled precipitate (as well as metal hydroxides).
Dou.W, 2017 et al found in their study that High Caustic alkalinity (using Sodium Hydroxide) and low Mg are the most suitable conditions to precipitate ettringite.

Others have found that using calcium hydroxide as the initial step is effective in reducing magnesium concentration by conversion to insoluble magnesium hydroxide precipitate at pH 12. (Zahedi et al, 2022, Smit, 1999 and Lorax, 2023)

The operating parameters such as molar ratios of $SO_4^{2-}$/ $Ca^{2+}$ and $SO_4^{2-}$/$Al^{3+}$, and pH value have a significant effect on the sulphate removal process efficiency (Aygun et al. 2018, as cited in Zahedi 2022).

### 4.1.3 Treatment Process Site Specific Testing

The sulphate removal process is not commonly used in New Zealand and elsewhere there are limited full size treatment plant sites with available design data to reference.

The ability to test the on-site mine influenced water, or a laboratory formed mimic water, similar to the BOGP proposed water quality and then simulate each of these precipitation steps would give real data to present and reference for final water quality. This would also give more certainty about the effectiveness of the treatment process on the BOGP proposed mine water quality and assurance that the water treatment system will achieve the final water quality. It is proposed that during the detailed design phase that this level of bench scale and pilot scale testing be performed.

## 4.2 Treatment Plant Process

Of the chemical precipitation processes, a process like the SAVMIN process is proposed for this project.

### 4.2.1 Savmin Process Summary

The Savmin process uses precipitation reactions to remove sulphates from minewater. This process also removes heavy metals and calcium. The first stage is addition of lime to raise pH and precipitate out metals and magnesium as hydroxides.
After separating out the hydroxides, the resulting supersaturated calcium sulphate solution is contacted with gypsum crystals, which catalyse the precipitation of calcium sulphate (gypsum). Due to the slow settling rate of the precipitates, the most cost-effective equipment for the solid-liquid separation stages of the process are parallel-plate cone clarifiers.

In the third stage of the process, aluminium hydroxide is added to the solution which causes formation of the insoluble salt ettringite, which removes calcium and sulphate from solution.
The solution is then treated with carbon dioxide to lower the pH (process pH values in the first and third stages of the process need to be maintained at 11.6 to 12). The lower pH causes the precipitation of pure calcium carbonate which is separated from the water by filtration.

The final stage of the process is the recycling of ettringite, in which the ettringite slurry is which is treated with sulphuric acid to regenerate aluminium hydroxide.
Reported removal rates are: Heavy metals removed to below drinking water levels; 99% of calcium; 100% of magnesium and 98% of Sulphate. Sodium, chloride, potassium and fluoride are not removed. (Brown. et al, 2002)

### 4.2.2 Metal Hydroxide precipitation and settling

The metal hydroxide precipitation step is part of both the Savmin and CESR (Cost Effective Sulphate removal process) and generally consists of addition of Hydrated lime (Calcium Hydroxide) to a pH of 10.5-11, mixing from 30- 60 minutes (Reinsel.M,1999). Levels of pH of up to 12-12.5 have been documented and mixing time up to 3 hours.

Settling of the precipitated metals and magnesium as hydroxides occurs and this sludge will need further processing via thickening, dewatering and disposal.

With respect to the BOGP project, during the closure phase in the 50 years when the active treatment system will be used, if Chemical precipitation processes are chosen, large volumes of sludge will be produced (as a byproduct of water treatment) will be created.

Further studies need to be completed to determine the quantity and quality of the water treatment residues (including sludge) for both active and passive treatment systems and identify appropriate disposal options and locations. The sludge should be disposed of at a suitable facility or studies should be undertaken to confirm onsite management options.

### 4.2.3 Gypsum precipitation and settling

Following removal of the settled metal hydroxides, the liquid is contacted with gypsum to provide active surfaces and catalyse the precipitation of the supersaturated gypsum (Smit, 1999). This precipitated gypsum is then thickened and filtered with some leaving the process and some recycled to the mixing tank as the seed gypsum. It is noted that the sulphate content of the water leaving this stage is dependent on the pH. Higher pH will result in lower sulphate concentrations. The pH in this stage is determined by the settling of the metal hydroxides from the previous stage (at high pH, poor settling occurs).

As gypsum interferes with the precipitation reaction of ettringite, it is important that all gypsum is removed from the feed water before the ettringite formation process steps. (Lorax, 2023).

### 4.2.4 Ettringite precipitation and settling

Following the precipitation and removal of gypsum, Aluminium Hydroxide is added to the liquid phase. This allows the insoluble salt ettringite to precipitate which results in the removal of both sulphate and calcium from the solution (Smit, 1999).

The stoichiometry of the formation of ettringite with the addition of aluminium is:

$6Ca^{2+} + 3SO_4^{2-} + 2Al(OH)_3 + 38H_2O \leftrightarrow Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O + 6H_3O^+$

The optimal pH range for the formation of ettringite is 11.6-12.0. The pH is maintained in this range by the addition of lime. Literature suggests that for efficient sulphate removal, a multistage reactor is required to produce an ettringite product with good liquid solid separation characteristics (Smit 1999). The ettringite is removed from the process using thickening, filtration.

Long mixing phases for the aluminium hydroxide/ettringite formation were reported in some instances, up to 61h mixing (Zahedi et al, 2022).

### 4.2.5 Carbonation and pH trimming

At this stage the waste water stream, with a pH 11-12 and dissolved SO4 <200mg/L is treated with carbon dioxide gas to lower the pH and to prevent scaling. The reduction of pH is prior to discharge to the receiving environment such as surface water or to the nitrate removal system. Relatively pure $CaCO_3$ is precipitated and removed by filtration or settling. Alternatively, pH can be adjusted to precipitate $Ca(HCO_3)_2$. (Lorax, 2023)

If treated water will be used again in the process, as service water, (for mixing, dosing chemical makeup water and washing), then reduction of pH and stabilisation to prevent deposition of hard carbonate scale on filters and distribution piping is required.

### 4.2.6 Recycling of Aluminium Hydroxide

Aluminium hydroxide is recovered by thickening and filtration and reused in the third stage as the ettringite formation catalyst (Lorax, 2023).
This recovery is achieved by taking the ettringite slurry from the Ettringite Precipitation phase, adding sulphuric acid to lower the pH and decompose the ettringite. This decomposition takes place in gypsum saturated water at a liquid to solid ratio that allows the calcium and sulphate ions to remain in solution as supersaturated calcium sulphate (Smit 1999). The stoichiometry is the reverse of the ettringite formation reaction.

Instead of sulphuric acid, CO2 can be used, however it converts half of the calcium from the ettringite forms solid calcium carbonate. Some of the regenerated aluminium hydroxide then has to be removed from the circuit as a bleed to control the buildup of calcium carbonate (Smit 1999).

## 4.3 Treatment Process Equipment

The SAVMIN process contains precipitation reactions in conventional stirred reactors at ambient pressure and temperature. The reactors will be mixing tanks, with mechanical agitators, and settling/clarification vessels in the most part and associated slurry and sludge pumps.

During settling phases of this treatment, settling rates potentially will be lower than conventional thickeners, but sludge volumes may be high, so allowance should be made on site for tall deep cone settlers. The Wren Parallel Cone clarifiers are mentioned in literature. These either have no moving parts for the settling phase or have rotating flocculator in the centre cylinder. Parallel settlers are also mentioned in literature, as an option for a smaller site footprint, but scale removal provisions for maintenance in design would have to be paramount and a less restricted settling vessel may be preferable if site space allows.

Most of the vessels will contain water to pH 12 or thereabouts. There will also be chemical dosing of strong acids such as sulphuric acid and acid coagulants (Aluminium Sulphate and Aluminium Hydroxide). Durability of vessels, piping and pumps will be paramount in design, as will chemical safety during maintenance.

Most of the pipelines and pumping and vessels will involve materials in liquid, slurry or sludge form with the propensity for scale formation from calcium carbonate, gypsum and ettringite, so allowance should be made for scale removal maintenance and redundancy for all equipment in case of blockage and scale removal maintenance downtime.

| EQUIPMENT DESCRIPTION | PROCESSES USED |
|---|---|
| Mixing Vessels | Stage 1, 2 and 3 plus lime saturation and Ettringite decomposition |
| Settling Clarifiers | Stage 1, 2 and 3 |
| Chemical Dosing systems | Lime, Aluminium Hydroxide, Aluminium Sulphate, Carbon Dioxide<br>Sulphuric Acid |
| Sludge Handling, Dewatering and disposal systems | Metal Hydroxide, Gypsum, Ettringite, Calcium Carbonate |

## 4.4 Surge Sump

A surge sump located adjacent to plant has been included in the design. Primarily this is to allow a pumped (fixed speed) feed to the plant. Recommended sump/pond sizing is based seven days storage at average flow.

| PLANT FEED RATE | DURATION/RETENTION | RECOMMENDED SUMP VOLUME |
|---|---|---|
| Average Flow Rate (26.9 l/sec) 96.84 m3/hr | 7 Days | 16,269 $m^3$ |

## 4.5 Pontoon Mounted Pumps

A pontoon mounted pump system with duty/standby pumps is recommended to reclaim MIW from the surge sump for plant feed. Therefore, two centrifugal pumps are recommended (each capable of feeding the plant at full flow. The required pump specification is as follows.

| PUMP DETAILS | TECHNICAL DATA |
|---|---|
| Actual Calculated Flow | (30 l/sec) 108 $m^3$/hr each (VSD Driven) |

### 4.6 Treated Water Sump

A treated water surge sump located adjacent to plant has been included in the design. Primarily this is to allow retention time on treated water prior to discharge. Additional residence time post treatment is recommended as a polishing pond to allow for any carry over of final impurities to settle before discharge. Recommended sump/pond sizing is based on 24 hours storage at maximum flow.

| PLANT FEED RATE | DURATION/RETENTION | RECOMMENDED SUMP VOLUME |
|---|---|---|
| Average Flow Rate (26.9 l/sec) 96.84 m3/hr | 24 Hours | 2,324 $m^3$ |

### 4.7 Sludge Management

From the water quality and literature review, the proposed sulphate and metals removal processes will have several sludge management streams with different product outputs, some which will need disposal either on site or off site and some that could be recycled or form a product for export off site.

1. Metal hydroxide sludge will need to be thickened and dewatered prior to transport to disposal in an appropriate landfill off site. There may be potential to process this further to recover certain metal if this was desired.
2. Gypsum sludge will be collected, processed and mainly be recycled on site, but there may be the need to export some gypsum product off site or to on-site disposal.
3. Ettringite sludge will partially be recycled and again disposal will be required in an appropriate landfill off site.
4. Calcium Carbonate Sludge, which may contain impurities will also have to be thickened, dewatered and disposed in an appropriate landfill off site.

Theoretical maximum TSS and metals quantities predicted will give a total precipitated solids amount of in g/m3 (% solids w/v) of influent to the WTP. Preliminary theoretical design suggests that a range of 5-10% of the total flows from the various processes will be required to report to the settlement column underflow. Further design will require test work on mimic waters to confirm proposed sludge volumes and dry weight percentages expected.

Preliminary theoretical sludge volumes based on 5-10% range of total underflows, with dry weight percentage of 0.5-1% would give the following sludge qualities. Note that not all the total underflows need disposal as some will be recycled, but this represents the total sludge processing capacity needed, not total disposal.

#### 4.7.1 Total Sludge Processing Capacity – Theoretical

| DESCRIPTION | DATA |
|---|---|
| Total Underflow 5-15% Plant flow | 4.8 -15 $m^3$/hr |
| Solids in Total Underflow (assume 0.5-1%) | 5-10 kg/$m^3$ |
| Dry Weight Solids (kg/Hr at average flow rate) | 24-150 kg/hr |

| DESCRIPTION | DATA |
|---|---|
| Dry Weight Solids (T/Year at average flow rate) | 210.2-1,314.0 kg/year<br>( Assuming 24 WTP hour continuous operation) |
| Wet solids at spadable consistency 20% solids T/year | 1051.2 T/yr – 6570.0 T/yr |

There are number of methods/technologies for available for dewatering of the settler underflow sludge, these include.

- Mechanical dewatering – centrifuge, belt press filters etc
- Wet/dry stacking of tailings (tailings dam)
- Bag dewatering technologies – vertical bag, geo bags etc

## 4.8 Other Treatment Processes

Other processes that will likely be needed in addition to the active WTP are:

- Cyanide Destruct on the Shepherds TSF influent stream
- Potential additional nitrate removal after WTP via biological processes

### 4.8.1 Cyanide Destruct – Shepherds TSF Influent Stream

As part of baseline water quality studies and environmental geochemistry studies, (MWM, 2025). It is reported that the influent stream from Shepherds TSF will have low concentrations of Cyanide present. Modelling indicates that this could be approximately 0.35mg/L. Compliance limits allow 0.6 mg/L in ground water and 0.011 mg/L in surface water (Ryder, 2025). Therefore, treatment may be required for this influent stream. Cyanide is highly toxic even in very low concentrations.

Cyanide removal is required for the waste flows coming from the Shepherds TSF area. This is estimated to contain Cyanide at around 0.35 mg/L. The recommended compliance limits for Cyanide are: 0.011mg/L (Surface Water) and 0.6mg/l (MAV Groundwater).

To provide more efficient treatment, it is anticipated the cyanide treatment would be carried out on the Shepherds TSF Stream only, prior to combining this with flows from other areas of the mine. Information from BOGP PFS document for the Bendigo Mine states that an Air/SO2 circuit has been chosen as the preferred form of Cyanide treatment for the process due to the amenability of the ore to this type of process and this is expected “to reduce the weakly acid dissociable cyanide to less than 30ppm at discharge” (30ppm=30mg/L).

Various forms of Cyanide treatment have been used in gold mines worldwide, including Alkaline Chlorination, Hydrogen Peroxide, SO2/Air, Ferrous Sulphate Complexation, Ozonation, Caro’s Acid, Biological Treatment, Thermal destruction (SGS 2005, Palmer et al 1987) and UV Oxidation. Copper is used as a catalyst in some of these processes.

Of the cyanide removal processes, there are various advantages and disadvantages for each. A brief comment on some of the technologies is offered below.

Alkaline Chlorination is a very common process for cyanide removal and is reported to be inexpensive and effective. However, it has the potential to generate hazardous by-products and more recently is

considered to be undesirable due the potential for negative environmental effects including high discharge of chloride and hypochlorite anions (Young and Jordan, 1995). It is also unable to remove some cyanide metal complexes known as SADs (Strong Acid Dissociable Complexes).
In terms of performance, it was shown that the Ozonation process at a San Diego plating plant reduced cyanide from 1.02mg/L in the Influent to 0.08mg/L in the effluent (Palmer et al, 1987). Ozonation was reported to have high operating costs.

More recently, UV oxidation has also been shown to be effective.

Wet Air Oxidation was reported to remove 99% of cyanide at a waste treatment facility in California from influent concentrations of 110mg/L to 0.035mg/L in the effluent (Palmer et al, 1987). This technology is more commonly used in domestic wastewater applications but is also used in industrial waste treatment to lesser extent.

The SO2/Air processes include a range of technologies. One such process called the INCO Process used at a Gold Mill site has been shown to reduce cyanide concentrations from around 40mg/L to 0.07mg/L in industrial applications (Palmer et al, 1987) however we have not established if this technology can achieve concentrations lower than this.

During the mining phase of the project, it is recommended that detailed testing of the BOGP water quality from Shepherds TSF take place to determine actual levels of Cyanide present prior to detailed design of a cyanide destruct process.

### 4.8.2 Nitrate Removal

Nitrate removal may be required but again this will need to be confirmed by test work.

Ettringite formation can also provide a polishing effect, allowing precipitation of metals, Ni, Cd, Cu, Zn, Cr, As and Se, often below their compliance and laboratory detection limits. Boron, fluoride and up to 30% of chloride and nitrate-nitrite in wastewater have also been removed (Reinsel 1999).

If required following test work, additional nitrate treatment systems can be added as a bolt on to the back end of the plant, depending on the amount of removal required. Options include the following.

- Fluidised bed reactors (FBR)
- Ion exchange
- Wetland (if polishing required)

Note that biological processes can be limited by sufficient organic carbon and nutrients in mine influence waters and the presence of heavy metals limiting growth. (Lorax 2023, Bratty et al, 2014)

#### 4.8.2.1 Fluidised Bed Reactor

Fluidised bed reactors can be effective in removing nitrates from mine wastewater. They use a biological process where the wastewater flows upwards through a bed of granular materials, such as sand or activated carbon. This allows the growth of biofilm within the FBR using the denitrification process, converting nitrate to nitrogen gas in anoxic conditions. (Metcalf and Eddy, 2003).

Design would include the sizing appropriately of the following:

- Upflow velocities
- Bed depth
- Specific surface area
- Hydraulic retention times

A pilot size trial with similar water would provide more accurate sizing for a full-size plant.

#### 4.8.2.2 Ion Exchange

As mentioned earlier in this document, any ion exchange processes will generate a brine waste stream which will have to be disposed of off-site.

#### 4.8.2.3 Wetlands

There are three types of wetlands that differ in form, function and applicability:

- Aerobic wetlands (reed beds)
- Compost wetlands
- Reducing and Alkalinity Producing Systems (RAPS)

Aerobic wetlands can legitimately be regarded as proven technology when applied to ferruginous net alkaline waters. (Brown Barley and Wood, (2007)).

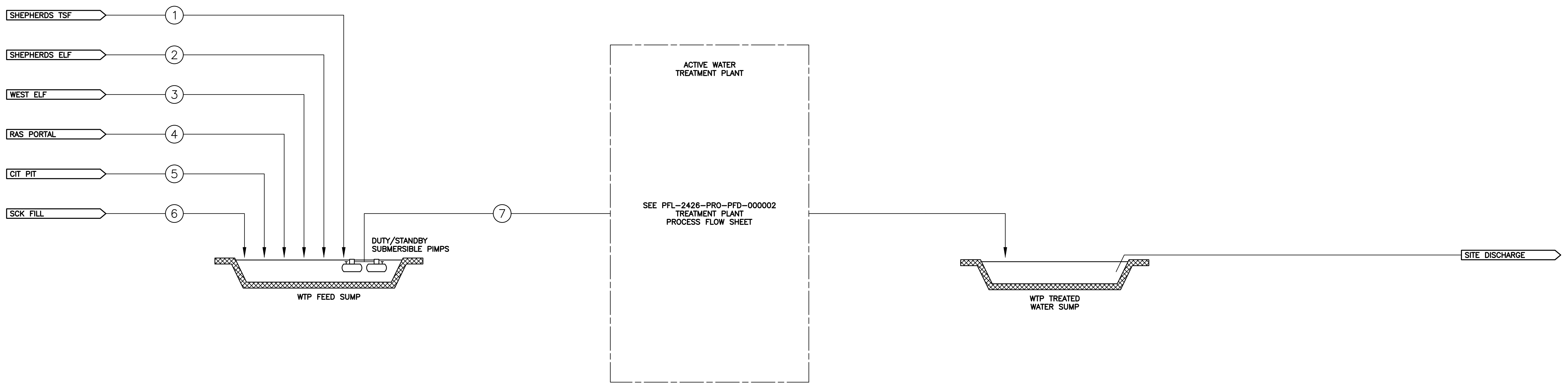
The two principle aims of mine water treatment in wetlands are.
1. To neutralise acidity and
2. To precipitate out metals.

Constructed wetlands need to comprise the following five components:

1. Substrates (which may have widely varying rates of hydraulic conductivity
2. Plants adapt to water saturated anaerobic conditions
3. Wate column (water flowing in or above the substrate)
4. Vertebrates and invertebrates
5. Aerobic and microorganisms

Natural wetlands are biologically complex and cover large land areas. When designing constructed wetlands, care must be taken when reducing them to minimal components and treatment areas for minewater processing purposes. Such loss of biological complexity may prevent the achievement of a balanced self-sustaining ecosystem which is the aim of passive treatment. (Brown Barley and Wood, (2007))
At this stage it is not possible to quantify the amount of nitrate that would be removed by a wetland system prior to detailed design.

# APPENDIX A - PROCESS FLOW SHEETS




| Parameter | Units | Stream 1 TSF Seepage | Stream 2 Shepherds ELF Seepage | Stream 3 WELF Seepage | Stream 4 RAS Portal | Stream 5 CIT Pit Backfill | Stream 6 SCK Fill Seepage | Stream 7 MIW combined |
|---|---|---|---|---|---|---|---|---|
| **Flow Rate** | l/sec | 13.4 | 4 | 1 | 6 | 1.5 | 1 | 26.9 |
| **Acidity** | mg/L | 0.01 | 0 | 0 | 0.44 | 0 | 0 | 0.03 |
| **Al** | mg/L | 0.011 | 0.003 | 0.003 | 0.1 | 0.005 | 0.003 | 0.013 |
| **Alkalinity** | mg/L | 73 | 189 | 183 | 182 | 190 | 158 | 160 |
| **As** | mg/L | 2.06 | 0.2 | 0.2 | 0.09 | 0.08 | 0.2 | 0.61 |
| **B** | mg/L | 0.83 | 0.87 | 0.1 | 0.05 | 0.09 | 0.01 | 0.59 |
| **Ca** | mg/L | 297 | 51 | 51 | 59 | 39 | 36 | 107 |
| **Cd** | mg/L | 0.0002 | 0 | 0 | 0.0001 | 0.0001 | 0 | 0.0001 |
| **Cl** | mg/L | 806 | 63 | 37 | 14 | 12 | 8 | 223 |
| **Co** | mg/L | 0.053 | 0.109 | 0.023 | 0 | 0.004 | 0.003 | 0.061 |
| **Cr** | mg/L | 0.00636 | 0.0002 | 0.00019 | 0.00058 | 0.0004 | 0.00007 | 0.0017 |
| **Cu** | mg/L | 0.001 | 0 | 0 | 0.00302 | 0.00021 | 0 | 0.00049 |
| **DOC** | mg/L | 0 | 0 | 0 | 0.09 | 0.206 | 0 | 0.038 |
| **F** | mg/L | 1.94 | 6.3 | 6.12 | 0.23 | 1.39 | 2.37 | 3.9 |
| **Fe** | mg/L | 15.3 | 7.6 | 7.6 | 7.9 | 2.4 | 7.6 | 8.7 |
| **Hg** | mg/L | 0 | 0 | 0 | 0.00006 | 0.00014 | 0 | 0.00003 |
| **K** | mg/L | 51 | 683 | 672 | 34 | 84 | 159 | 372 |
| **Mg** | mg/L | 100 | 38 | 37 | 37 | 20 | 24 | 49 |
| **Mn** | mg/L | 0.594 | 0.819 | 0.774 | 0.014 | 0.103 | 0.182 | 0.567 |
| **Mo** | mg/L | 0.14 | 1.005 | 0.672 | 0.02 | 0.119 | 0.157 | 0.535 |
| **NO3-N** | mg/L | 2.01 | 49.64 | 9.54 | 4.35 | 0.73 | 1.33 | 22.89 |
| **Na** | mg/L | 848 | 922 | 734 | 42 | 127 | 170 | 673 |
| **Ni** | mg/L | 0.6784 | 0.0121 | 0.001 | 0.0009 | 0.0013 | 0.0001 | 0.1652 |
| **Pb** | mg/L | 0.0276 | 0.0001 | 0.0001 | 0.0035 | 0.0002 | 0 | 0.0068 |
| **Sb** | mg/L | 0.1802 | 2.9986 | 3.2208 | 0.0234 | 0.3622 | 0.7601 | 1.6317 |
| **Se** | mg/L | 0.003 | 0.1544 | 0.1649 | 0.0008 | 0.0196 | 0.0388 | 0.0826 |
| **SO4** | mg/L | 954 | 957 | 888 | 141 | 110 | 208 | 730 |
| **Sr** | mg/L | 4.4 | 16.15 | 15.91 | 0.79 | 3.77 | 10.89 | 10.12 |
| **Tl** | mg/L | 0 | 0 | 0 | 0.00031 | 0.00021 | 0 | 0.00005 |
| **CN** | mg/L | 0.35 | 0 | 0 | 0 | 0 | 0 | 0.082 |
| **U** | mg/L | 0.028 | 0.2751 | 0.2225 | 0.0094 | 0.0299 | 0.0515 | 0.1468 |
| **V** | mg/L | 0.004 | 0.12 | 0.1155 | 0.0006 | 0.0135 | 0.0269 | 0.0633 |
| **Zn** | mg/L | 0.0296 | 0.0098 | 0.0021 | 0.0022 | 0.0014 | 0.0003 | 0.0117 |
| **pH** | mg/L | 6.41 | 7.93 | 7.92 | 5.91 | 8.03 | 7.92 | 6.72 |
| **Hardness** | mg/L | 1151 | 285 | 280 | 299 | 179 | 190 | 469 |



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WATER INFRASTRUCTURE
PROCESS FLOW LIMITED
4/38 ESTUARY PLACE,
RICHMOND 7020
T +64 3 540 2625
www.processflow.com


| | | |
|---|---|---|
| DESIGNED | GS | 11/03/25 |
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BOGP
ACTIVE WATER TREATMENT PLANT
PLANT FEED ENVELOPE
PROCESS FLOW DIAGRAM SHEET 1 OF 1

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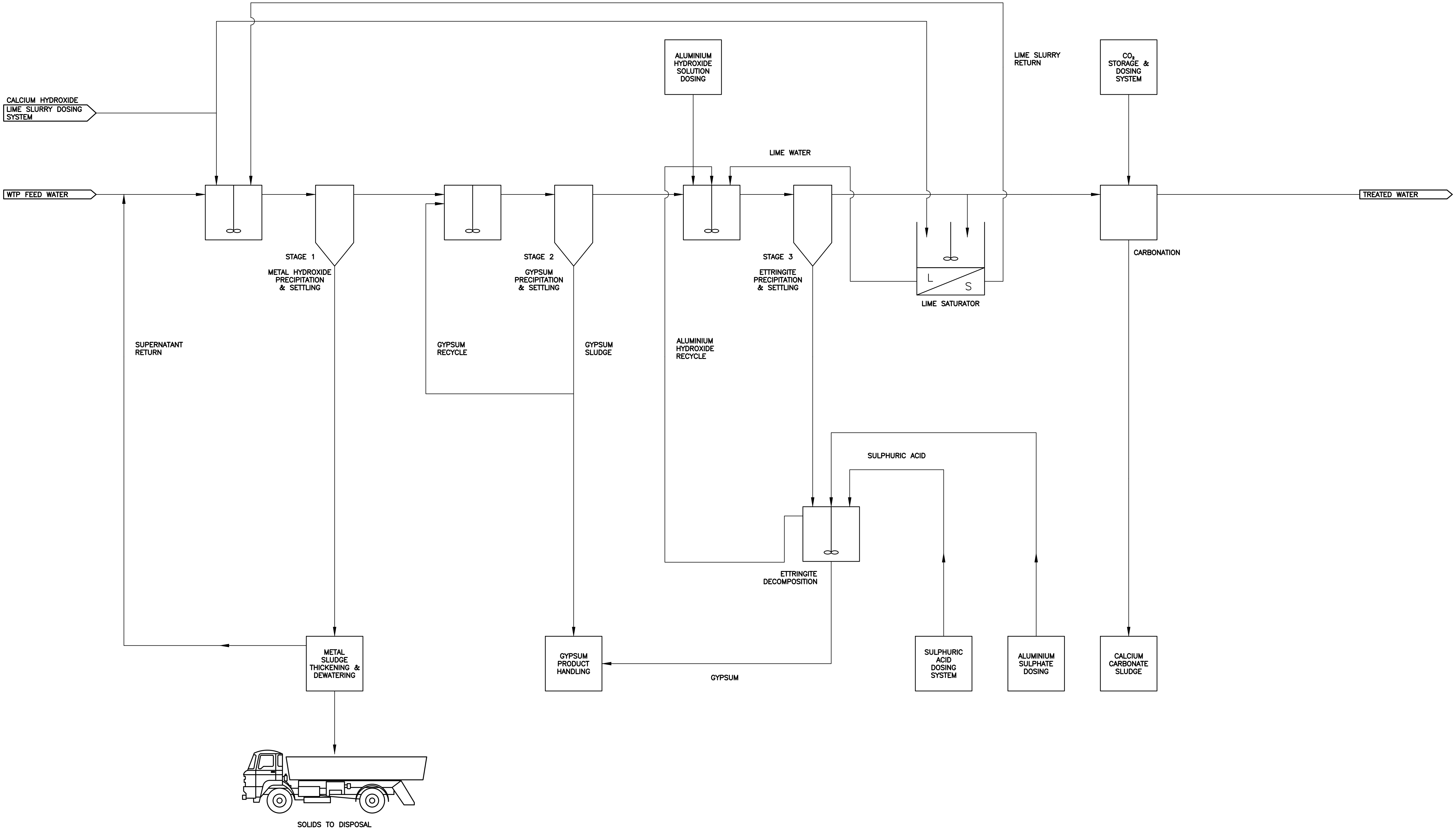




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WATER INFRASTRUCTURE
PROCESS FLOW LIMITED
4/38 ESTUARY PLACE,
RICHMOND 7020
T +64 3 540 2625
www.processflow.com

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| DRAWN | DAB | 11/03/25 |
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BOGP
ACTIVE WATER TREATMENT PLANT
PROCESS SCHEMATIC
SHEET 1 OF 1

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