Passive Treatment using Mussel Shell Bioreactors –

Understanding Risks and Long-term Costs

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AusIMM NZ Branch

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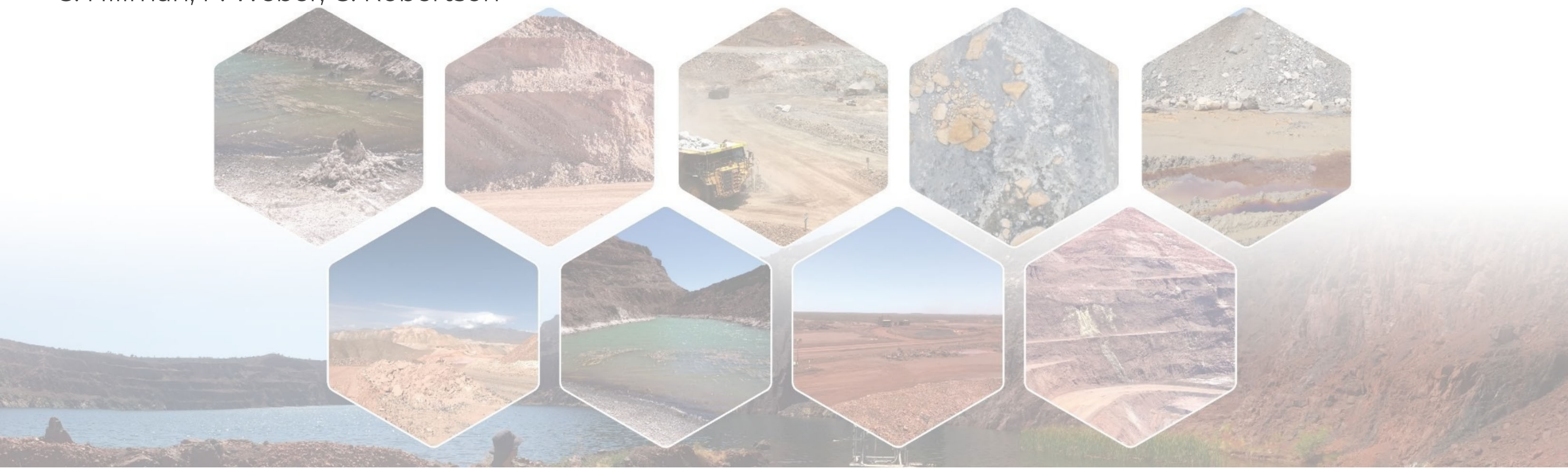

Project Introduction

Background

- The generation of acid and metalliferous drainage (AMD) from the coal bearing strata (e.g., Brunner Coal Measures and Kaiata Mudstone is well known).

$$FeS_2 + {}^{7}/_{2}H_2O + {}^{15}/_{4}O2 \rightarrow Fe(OH)_3 + 2H_2SO_4$$

- This study reviews the performance of mussel shell reactors (MSR) to treat AMD from coal mines.
- The review focuses on downflow MSR.

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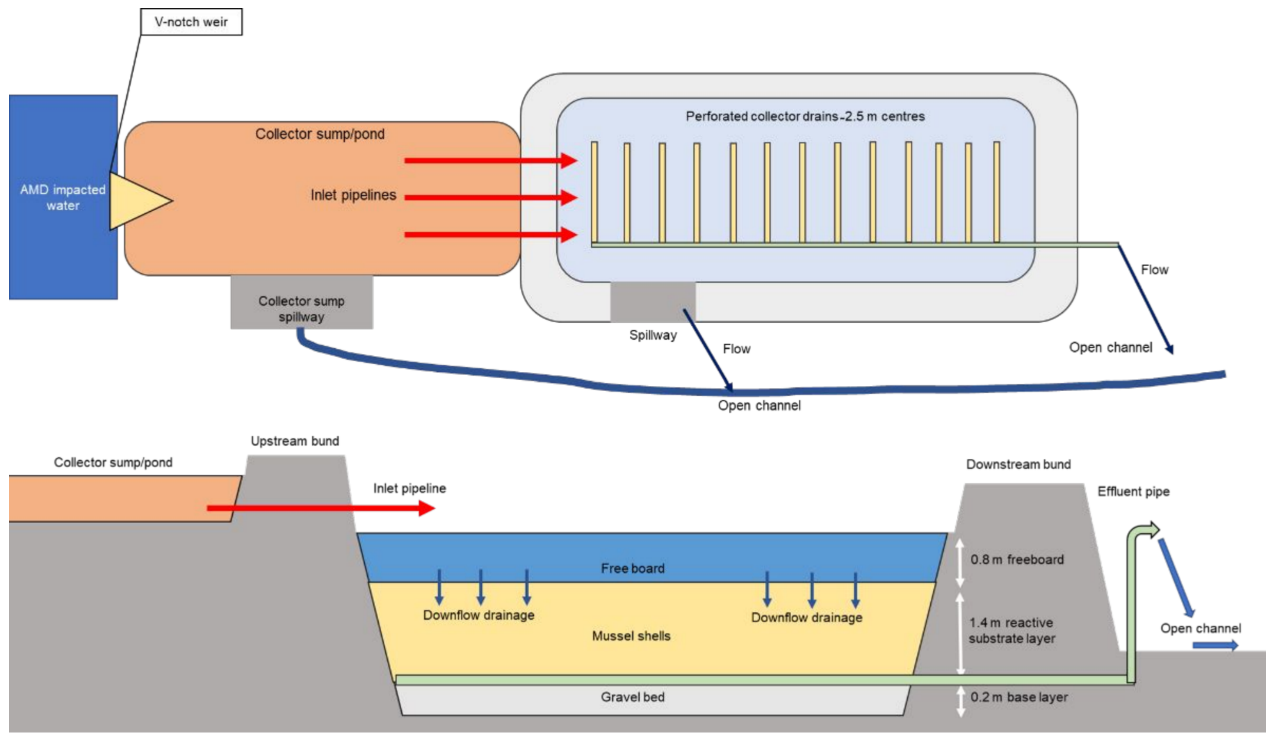
Study Sites

Three sites were assessed:

- Barren Valley Engineered Landform (ELF) MSR - Escarpment Coal Mine
- Whirlwind MSR – Stockton Coal Mine
- Tara MSR – Canterbury Coal Mine



MSR Material Properties

- Tara MSR - Fresh shells
- Whirlwind + BV-ELF MSR - weathered shells

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MSR Design Criteria

Design Specification:

- 1 L AMD/100 m^2
- Sludge removal 2-7 years
- Higher rates can be achieved (2 L/100 m^2) but requires more maintenance (annual).
- Determined from 15 years of study.

PARAMETER	WHIRLWIND MSR[1]	TARA MSR[2]	BV-MSR[3]
Average plan dimensions (m) (shell layer)	14.0 x 21.5	5 x 24	10 x 35
Average plan area (m^2) (shell layer)	302	94	350
Average shell depth (m)	1.2	1.5	1.5
Ponding depth on top of MSR (m)	0.2 – 0.6	1.0	0.2 – 0.4
Freeboard (m)	0.8 – 0.4	0.5	0.2
Volume of shells (m^3)	366.0	55.0	470.0
Flow rate (L/s)	2.80	0.06	2.50
Assumed porosity	0.52	0.52	0.52
Volume of shells (m^3/m^2)	1.23	1.29	0.99
Shells pore volume (m^3/m^2)	0.63	0.79	0.79
Total shells pore volume (m^3)	190.1	74.0	275.4
Calculated residence times (days)	0.79	5.57	1.14

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Study Design

Geochemical Reactions:

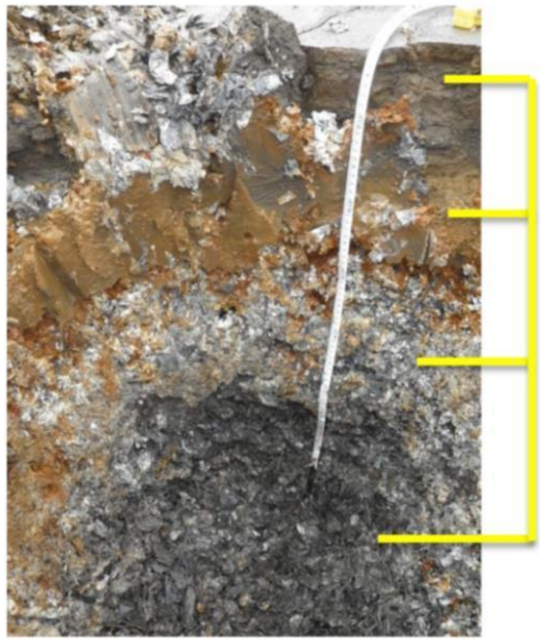
- All system utilise down flow MSR.
- Reactions include:
- Carbonate Neutralisation Phase

$$CaCO_3 + 2H^+ = Ca^{2+} + CO_2 + H_2O$$

- Sulfate Reducing Bacteria (SRB) Phase

$$SO_4^{2-} + 2CH_2O + B = 2HCO_3^- + H_2S$$

  - The process generates alkalinity



Zone 1 Sediment-sludge layer (~330 mm)

Zone 2 $Fe(OH)_3$ layer (~20 mm)

Zone 3 $Al(OH)_3$ precipitate mussel shell layer (~330 mm)

Zone 4 Black precipitate mussel shell layer (~1500 mm)

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Escarpment Coal Mine

Barren Valley ELF MSR (BV-ELF MSR)

- Construction earthworks commenced in 2015.
- Care and Maintenance period began in 2016.
- Treatment of the Barren Valley ELF underdrain by a MSR has been ongoing for ~7 years.
- Desludging was completed this year.

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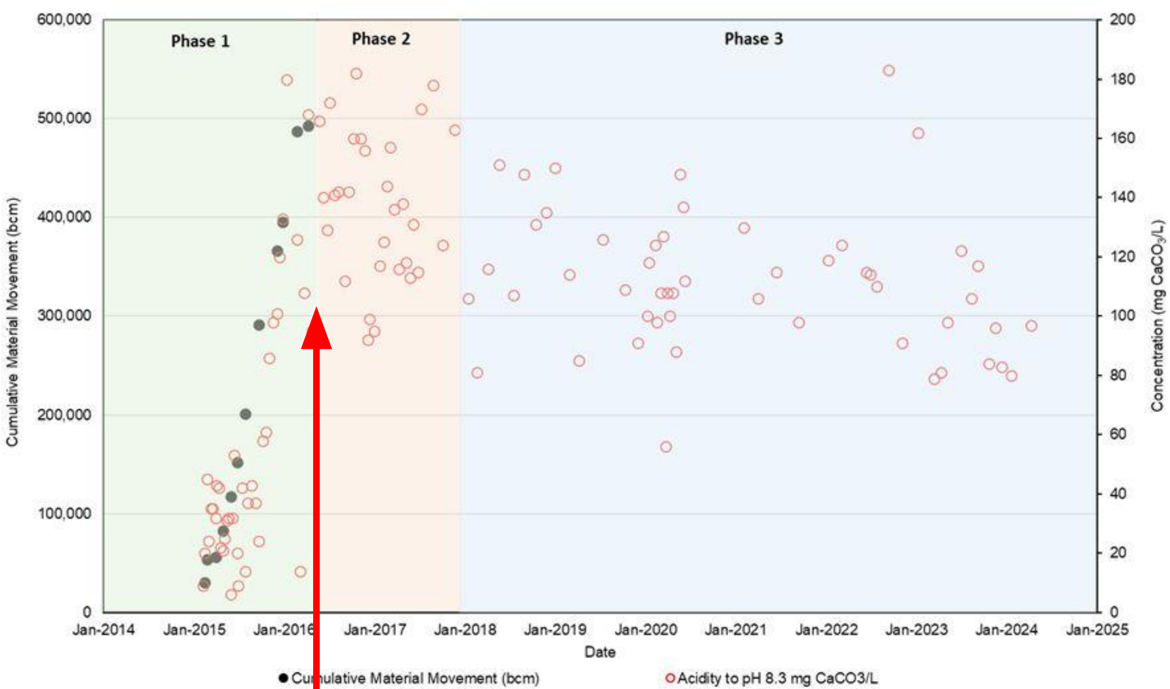
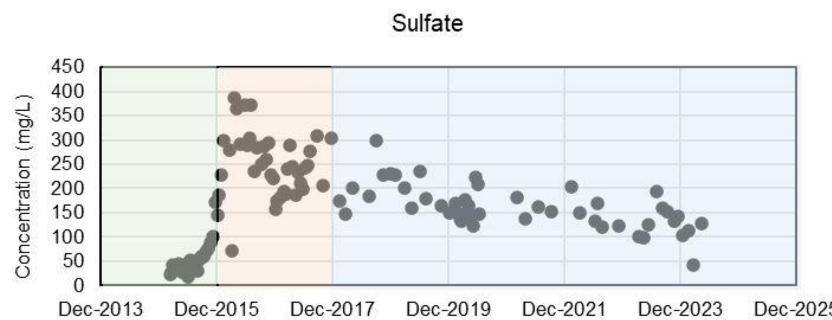
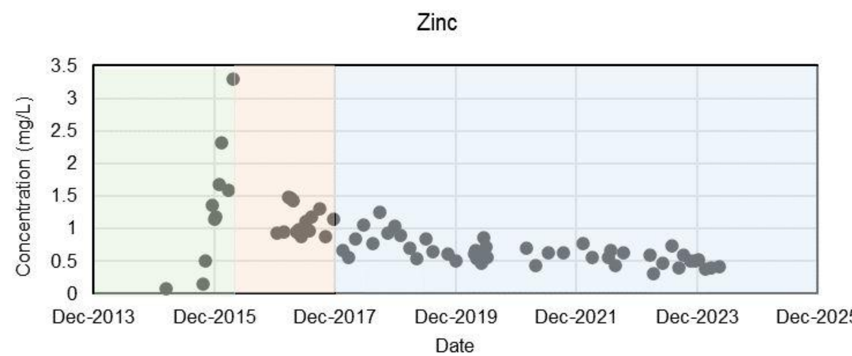
BV ELF Seepage Water Quality







BV ELF Underdrain flooded in ~ April 2016.

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BV-ELF MSR Water Quality

Treatment Efficiencies

Study focused on

- Acidity Removal (Al, Fe, pH).
- Ni and Zn removal – lower removal efficiencies.
- Red = elevated compared to the water quality reference values (site specific).

PARAMETER	BV-MSR (OCTOBER 2016 – MAY 2023)		
	AVERAGE INFLUENT	AVERAGE EFFLUENT	REMOVAL EFFICIENCIES (%)[1]
pH (pH units)	3.36	7.86	-
Al	11.5	0.06	99.6
Fe	5.97	0.02	99.7
SO_4	177.8	158.2	10.3
Ni	0.14	0.07	41.7
Zn	0.83	0.28	60.1
Flow rate (L/s)	2.50		
Calculated HRT (days)	1.14		

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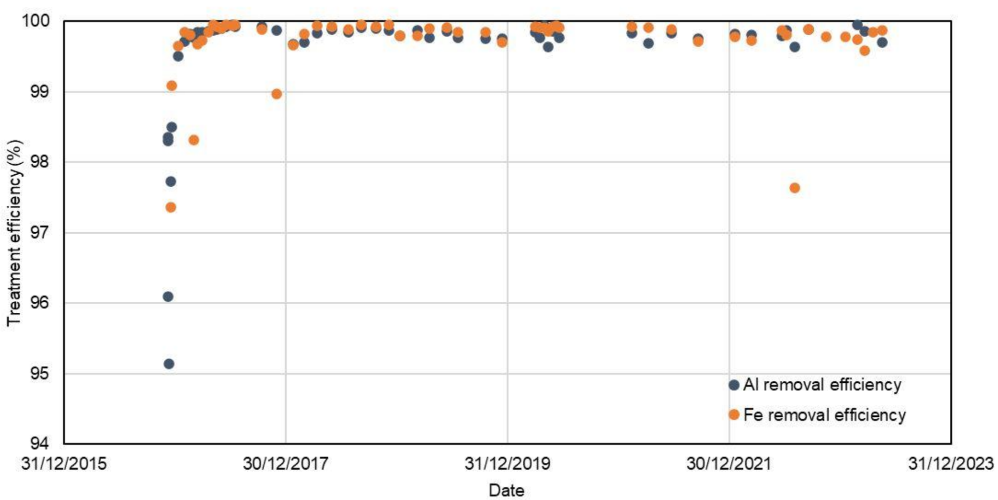
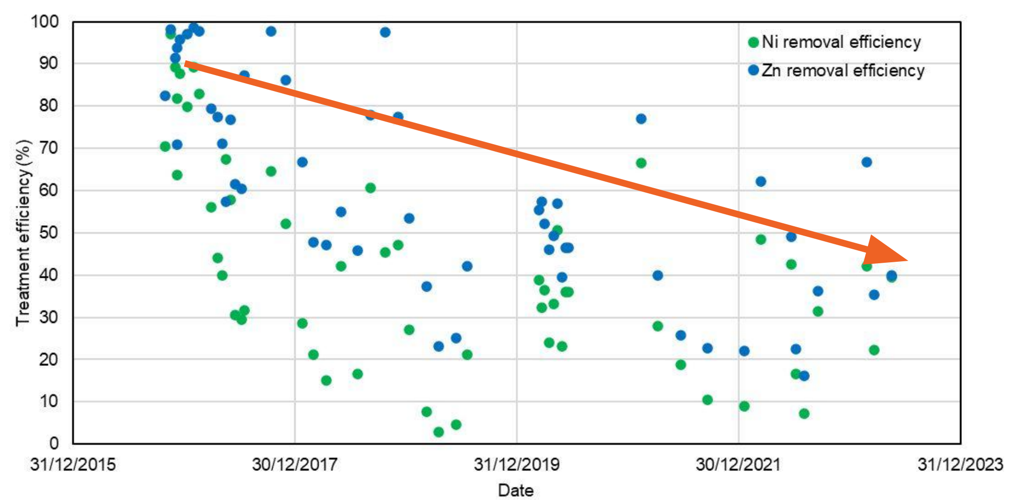
[1] Removal efficiencies shown for each parameter were derived from influent and effluent water quality samples taken concurrently (i.e., on the same day).

BV-ELF MSR Water Quality





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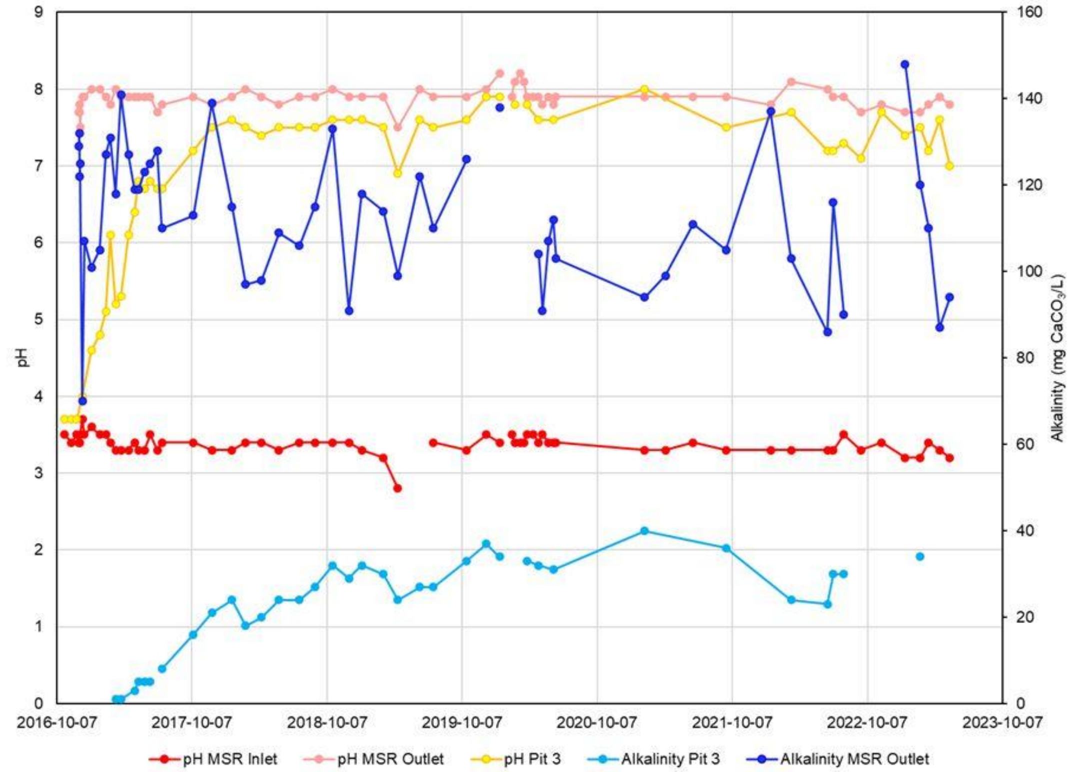
BV-ELF MSR – Downstream Water Quality

Effluent Alkalinity and Pit 3

- MSR export alkalinity
- MSR started in 2016
- MSR alkalinity boosted the pit pH
- Reflected by Pit 3 alkalinity increasing



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Stockton Coal Mine

Whirlwind MSR:

- Construction Earthworks in 2012.

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Whirlwind MSR Water Quality

Treatment Efficiencies

PARAMETER	WHIRLWIND MSR (SEPTEMBER 2012 – JUNE 2023)		
	AVERAGE INFLUENT	AVERAGE EFFLUENT	REMOVAL EFFICIENCIES (%)[1]
pH (pH units)	3.43	5.90	-
Al	14.3	0.03	99.8
Fe	1.60	0.10	97.7
SO_4	183.4	160.5	12.7
Ni	0.07	0.02	71.2
Zn	0.25	0.04	82.8
Flow rate (L/s)	2.80		
Calculated HRT (days)	0.79		

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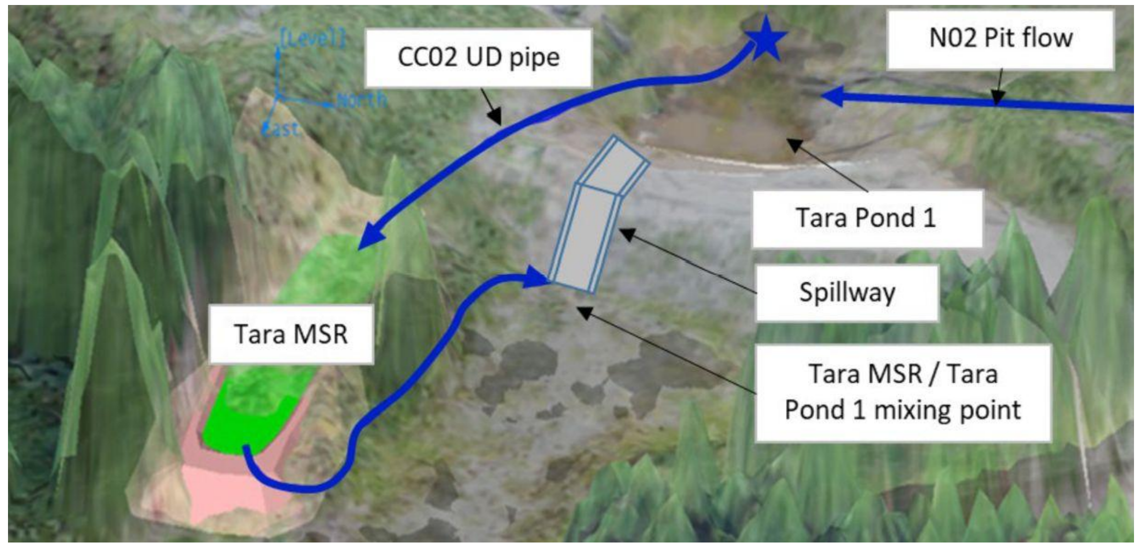
[1] Removal efficiencies shown for each parameter were derived from influent and effluent water quality samples taken concurrently (i.e., on the same day).

Canterbury Coal Mine

Tara MSR:

- The mine was purchased by BRL in 2013.
- A legacy AMD issue was identified.
- Mine closure commenced in 2021.
- One aspect of managing this AMD legacy was the installation of a MSR.
- The Tara MSR treats seepage from the Green ELF (CC02 underdrain).



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TARA MSR Water Quality

Treatment Efficiencies

- Significant Ni and Zn removal.
- A higher HRT
- Fresh Shells (>DOC).

PARAMETER	TARA MSR (JANUARY 2022 – JANUARY 2024)		
	AVERAGE INFLUENT	AVERAGE EFFLUENT	REMOVAL EFFICIENCIES (%)[1]
pH (pH units)	6.55	7.21	-
Al	0.029	0.003	60.9
Fe	18.5	0.69	96.5
SO_4	629.2	486.6	22.4
Ni	0.03	0.002	91.0
Zn	1.28	0.007	96.7
Flow rate (L/s)		0.06	
Calculated HRT (days)		5.57	

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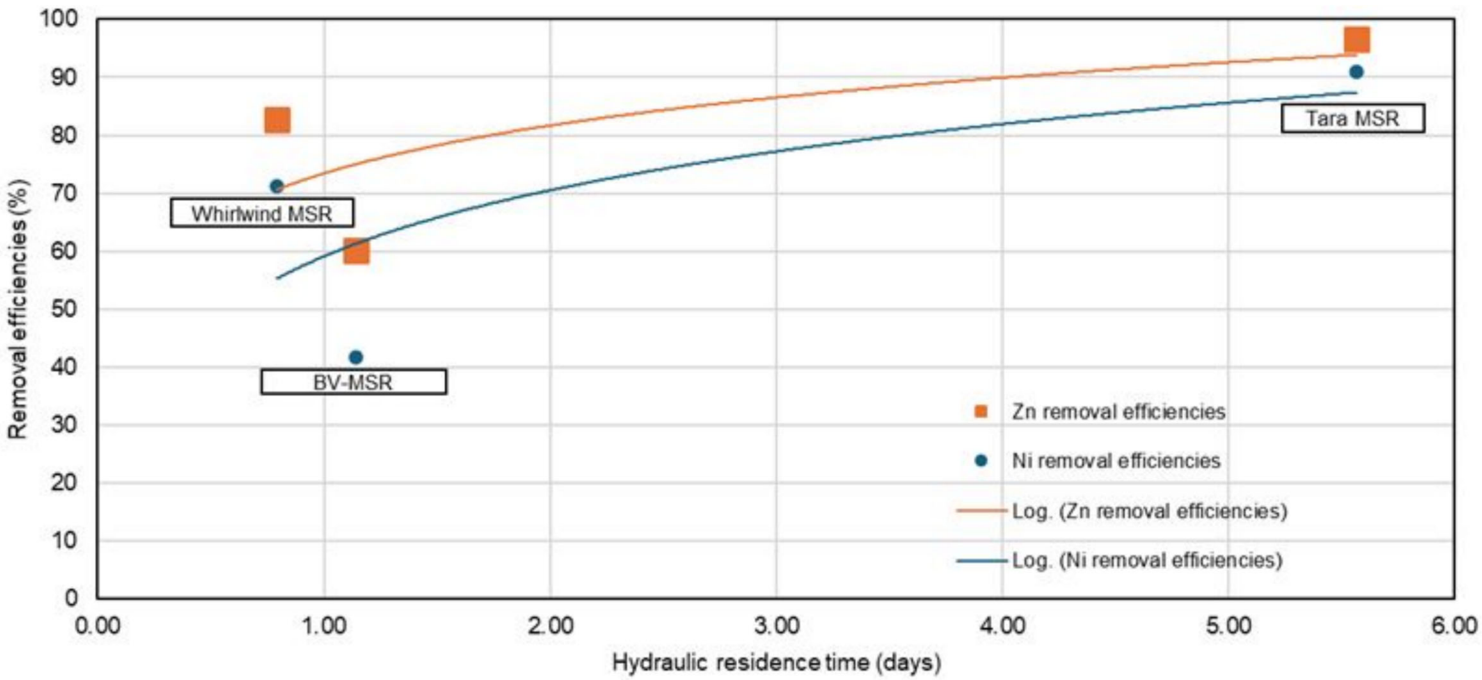
[1] Removal efficiencies shown for each parameter were derived from influent and effluent water quality samples taken concurrently (i.e., on the same day).

MSR Treatment Efficiencies

HRT versus Treatment Efficiency



MSR - Secondary Products

Secondary products can be generated from anaerobic treatment of AMD

- Sulfide (HS^-)
- Ammoniacal nitrogen (Amm-N)
- Low dissolved oxygen (DO)
- High biological oxygen demand (BOD)
- Dissolved organic carbon (DOC)

HS- can form sulfide minerals (FeS_2, (Zn,Fe)S etc

- DOC and HS^- important for anaerobic treatment: $SO_4^{2-} + 2CH_2O + B = 2HCO_3^- + H_2S$
- But HS^- is also a contaminant (ANZECC guidelines are 0.001 mg/L – un-ionised H_2S. LOR = 0.05 mg/L
- Secondary treatment may be required for these contaminants.

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Performance Data

Amm-N, DOC and HS^-

PARAMETER	TARA MSR (JANUARY 2022 - JANUARY 2024)[1]			BV MSR (MARCH 2024 - JULY 2024)[2]		
	MIN	AVE	MAX	MIN	AVE	MAX
Total Amm-N	0.68	6.69	144	0.01	0.02	0.03
Nitrate-N	0.002	0.08	2.40	0.03	0.32	0.58
Nitrite-N	0.002	0.005	0.01	0.01	0.01	0.01
Nitrate-N + Nitrite-N	0.002	0.025	0.36	0.04	0.33	0.59
Total Nitrogen	4.47	8.57	11.6	0.229	0.33	0.51
DOC	4.90	7.59	10.0	0.10	0.29	0.7
BOD	1.00	2.66	8.00	-	-	-
Total sulfide screen	0.002	4.86	31.0	0.002	0.002	0.002
H_2S	0.002	0.69	5.70	0.05	0.05	0.05

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Secondary Treatment

- Polishing ponds with aeration can be constructed where necessary for secondary treatment of MSR effluent.
- Other options include:
  - Zero-valent iron (e.g., scrap iron) to remove sulfide in the polishing step.
  - Zinc is another option to remove HS^- (better due to higher chemical stability compared to transition metals such as Fe (waste galvanised steel?).

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Summary – Design Criteria: Downflow MSR

- MSR are very efficient at treating acidity (pH, Al, Fe)
  - Design criteria for acidity – 1L/100 m^2 (but up to 2L/100m^2 with annual maintenance)
  - Maintenance (sludge removal) is a function of TSS + Fe + Al load (ranges from 2-7 years)
- Removal efficiencies of trace metals such as Ni and Zn can be improved by::
  - A longer HRT (5 days)
  - Fresh mussel shells to increase DOC or other forms of carbon (e.g., ETPS)
- Secondary products may require treatment / additional management (this is site specific)

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