Ettringite Formation in Mine-Impacted Waters

S. Hoodhills [1], L. Navarro-Valdivia [1], R. Brahm [1], C. Miller [1], G. Smith [2], J. Wildy [3], J. Murray [4], P. Weber [1]

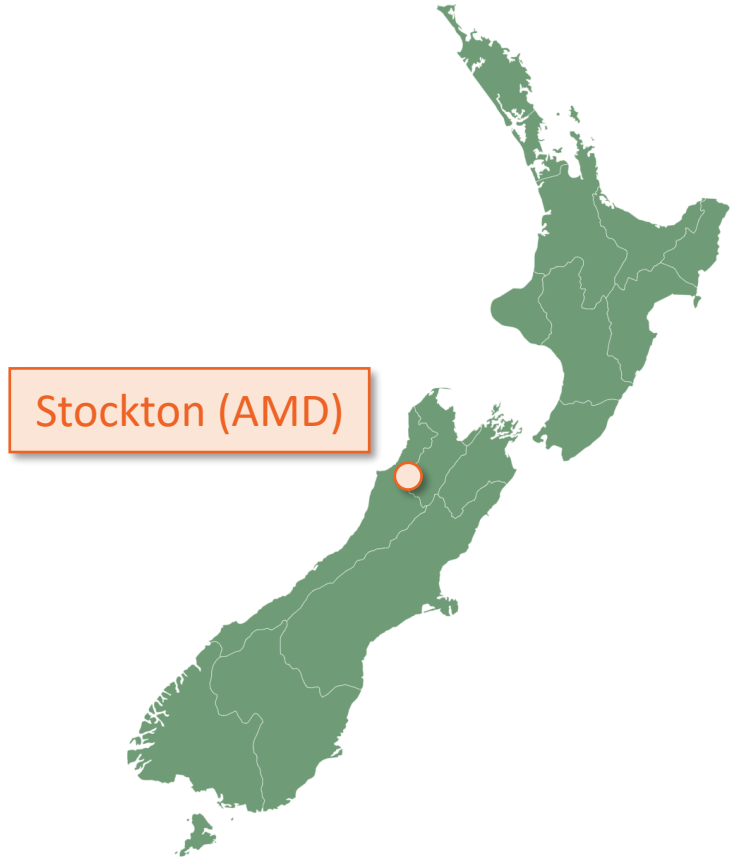
[1]Mine Waste Management; [2]Process Flow Limited; [3]JBH Environmental Engineering; [4]Bathurst Resources;



AusIMM NZ Branch Annual Conference 2026

Overview

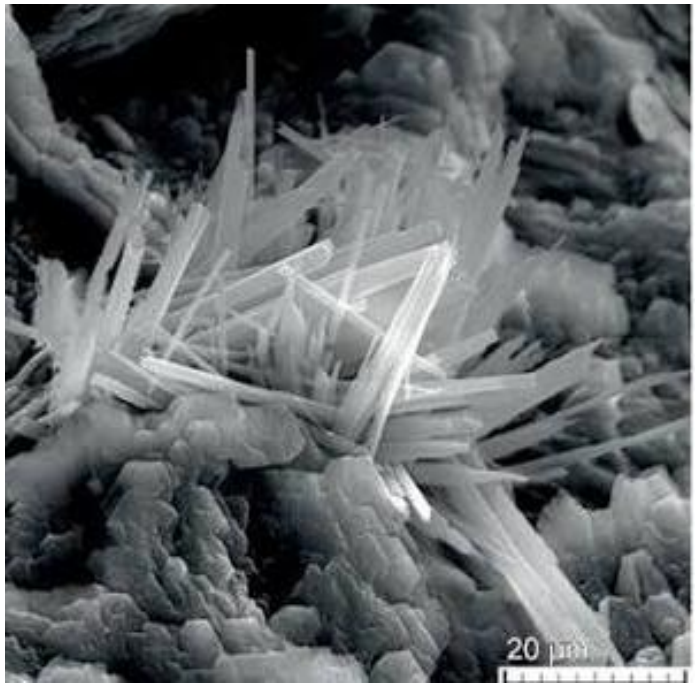
- What is ettringite?
- Background: ARD vs NMD chemistry
- *ARD Treatment → Challenge*: infrastructure scaling (often referred to as AMD to address metal content).
    - *Case Study: Stockton Coal Mine (Bathurst Resources Limited)*
- *NMD Treatment → Opportunity*: engineered SO_4 removal
    - *Bench Scale Trials*
- Practical implications



MINE WASTE MANAGEMENT
GREENROAD GROUP

What is Ettringite?

- Calcium-based aluminium sulfate mineral
  - $Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$
- Precipitation is pH-dependent, with an optimal range of pH 12.0–12.5, provided sufficient SO_4, Ca, Al are present in solution.
- An effective alternative to gypsum ($CaSO_4\cdot 2H_2O$) precipitation for achieving lower sulfate concentrations (< 200 mg/L vs 2,000 mg/L).
- Established uses outside mining:
  - Construction/cement — a known durability risk: sulfate attack on hardened concrete
  - Waste water treatment — an established mechanism for SO_4 removal

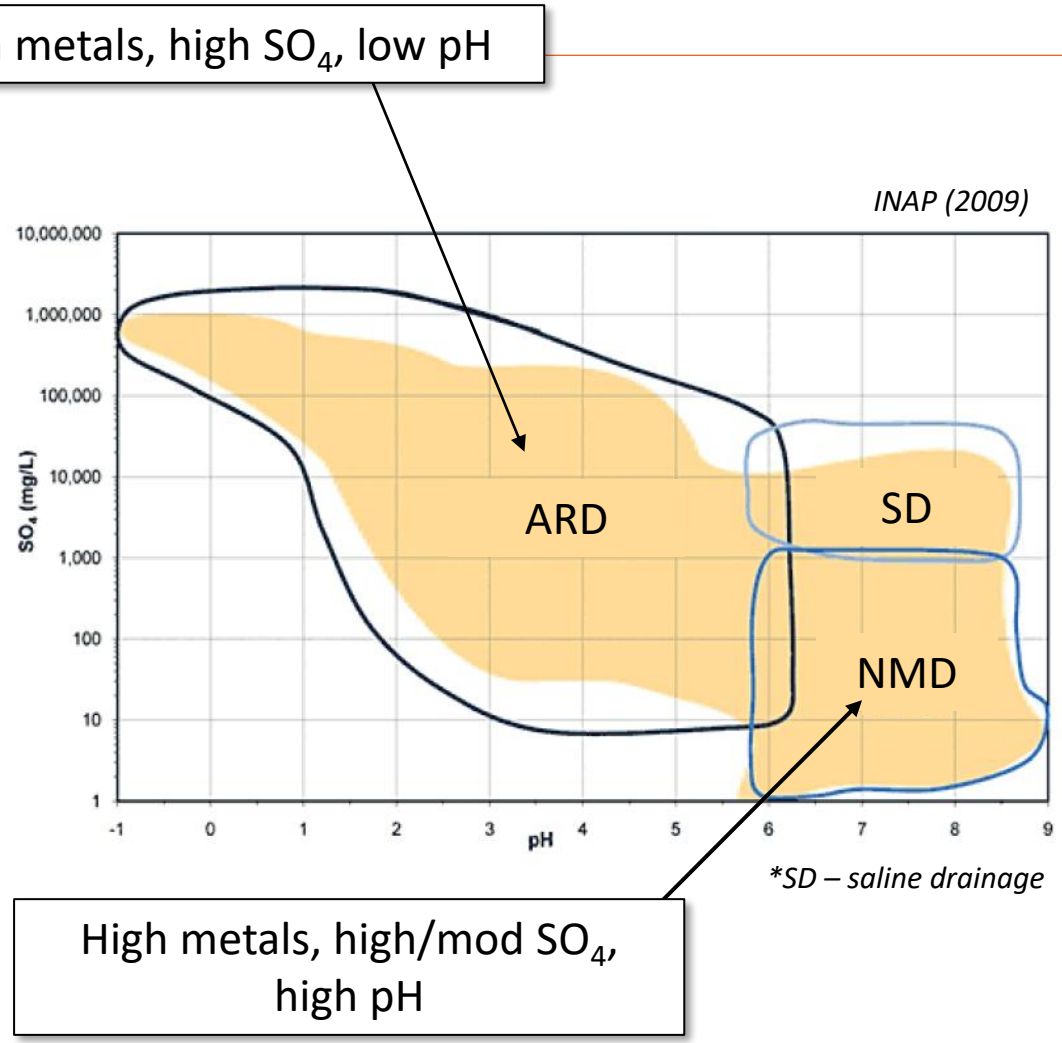


Pospíšil et al (2008)

MINE WASTE MANAGEMENT
GREENROAD GROUP

AMD: ARD vs NMD

- *Acid and Metalliferous Drainage:* forms from sulfide oxidation on exposure to air and water.
- ***Acid Rock Drainage***: sulfide oxidation outpaces available neutralisation — characterised by acidic pH, elevated metal(loid)s, and elevated SO_4
- ***Neutral Metalliferous Drainage***: occurs where sufficient neutralisation counters the acid generated — characterised by elevated metal(loid)s and SO_4 at circumneutral pH.
- Commonality and challenge: high SO_4



MINE WASTE MANAGEMENT
GREENROAD GROUP

ARD Treatment Challenge: Infrastructure Scaling

- Low pH ARD waters are high in Al and SO_4.
- Lime dosing to raise pH during treatment pushes the water chemistry into ettringite's stability field.
- Ettringite precipitates directly in pipework, decant systems, and treatment circuits during the treatment process.
- Reduces pipe capacity, causes blockages, drives unplanned maintenance.

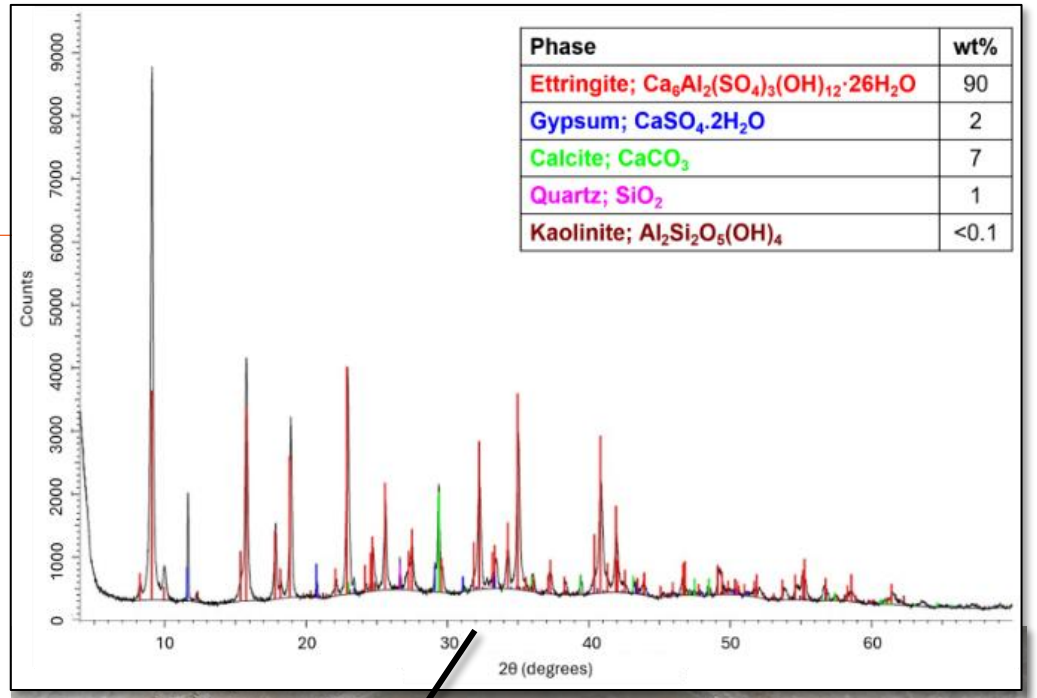


Pipe scaling at Stockton

MINE WASTE MANAGEMENT
GREENROAD GROUP

Case Study: Stockton Mine

- Active lime treatment system observed formation of ettringite scaling in outlet pipes from the Lime Dosing Plant 2 (LDP2) but not LPD1.
- XRD analysis of a scale: 90 wt% ettringite, with minor calcite and gypsum.
- PHREEQC modelling was completed to understand the conditions that allowed for the formation of ettringite scale at LDP2.

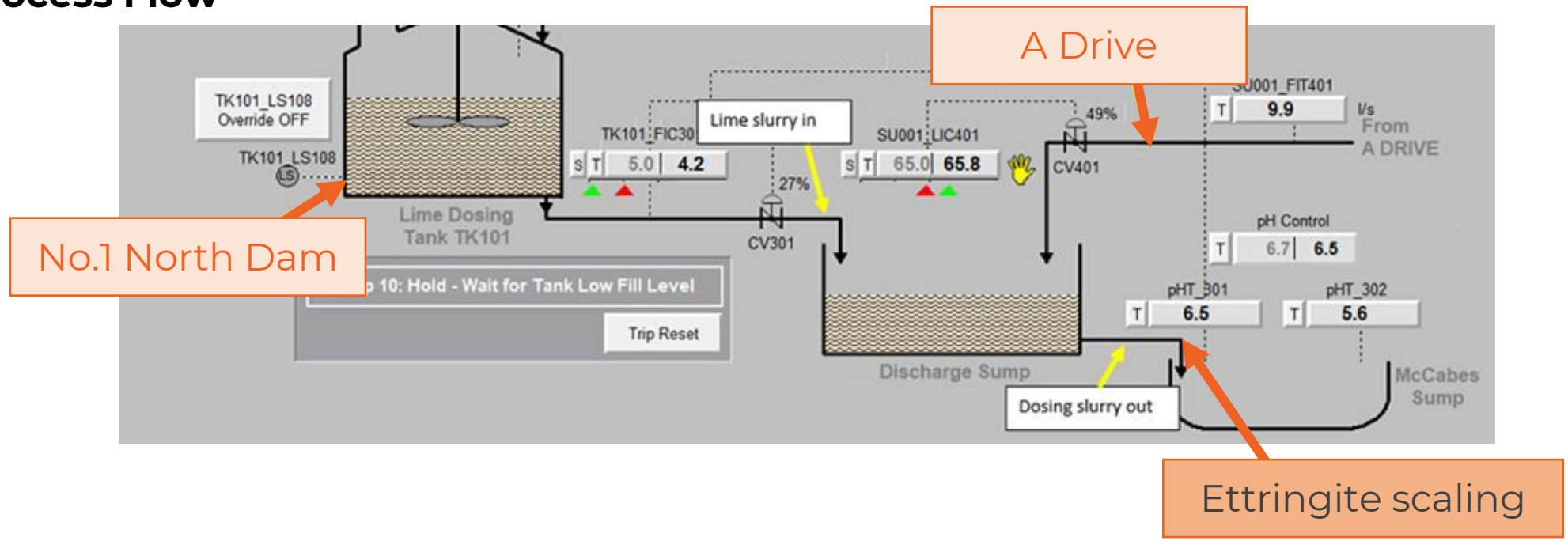




Pipe scaling at Stockton

MINE WASTE MANAGEMENT
GREENROAD GROUP

LDP2 Process Flow



Modelling Approach

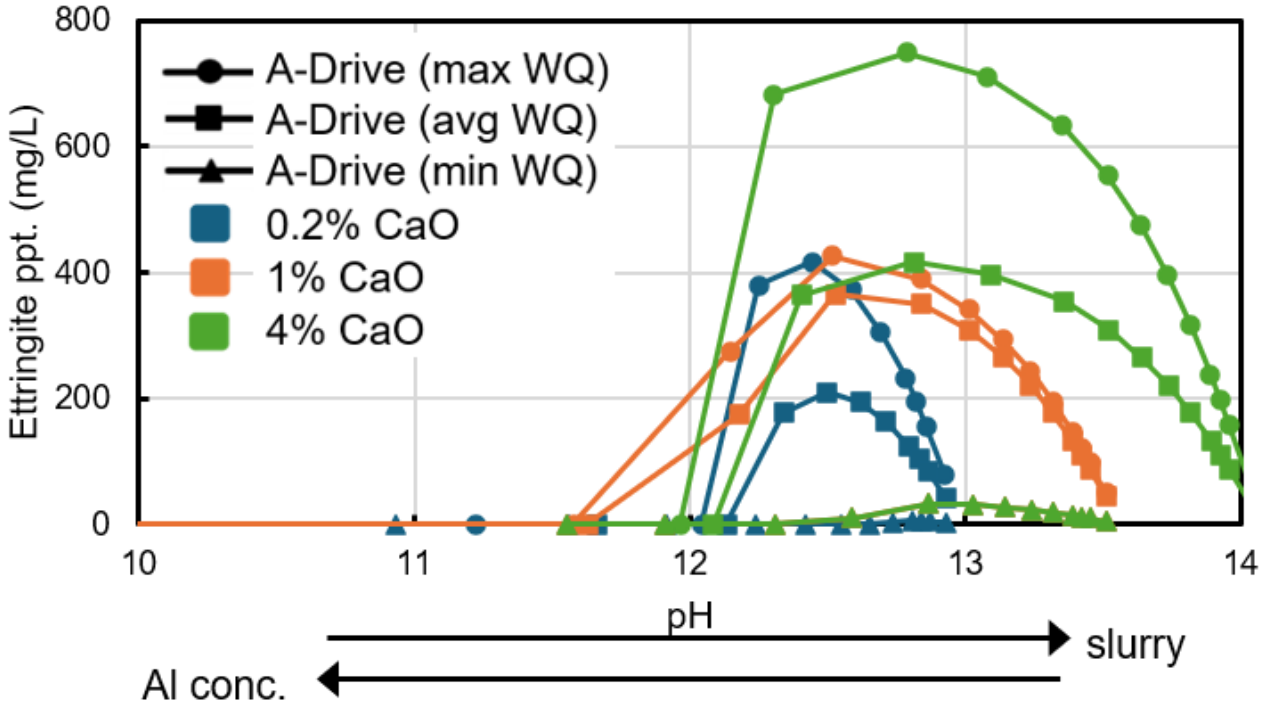
No. 1 North Dam → Lime (CaO 65 wt%) → A Drive

(ave. [X]) (0.2 – 4%) (min, ave. max [X])

MINE WASTE MANAGEMENT
GREENROAD GROUP

Case Study: Stockton Mine

- pH controls *when* ettringite starts forming — consistent formation from pH 12 – 13.5
- Aluminium in solution controls *how much* forms — higher Al (A-Drive maximum case) produces more ettringite.
- Dosing plant objective is to neutralise the ARD, constraining dosage to avoid pH > 12 solves LDP2 scaling issues.



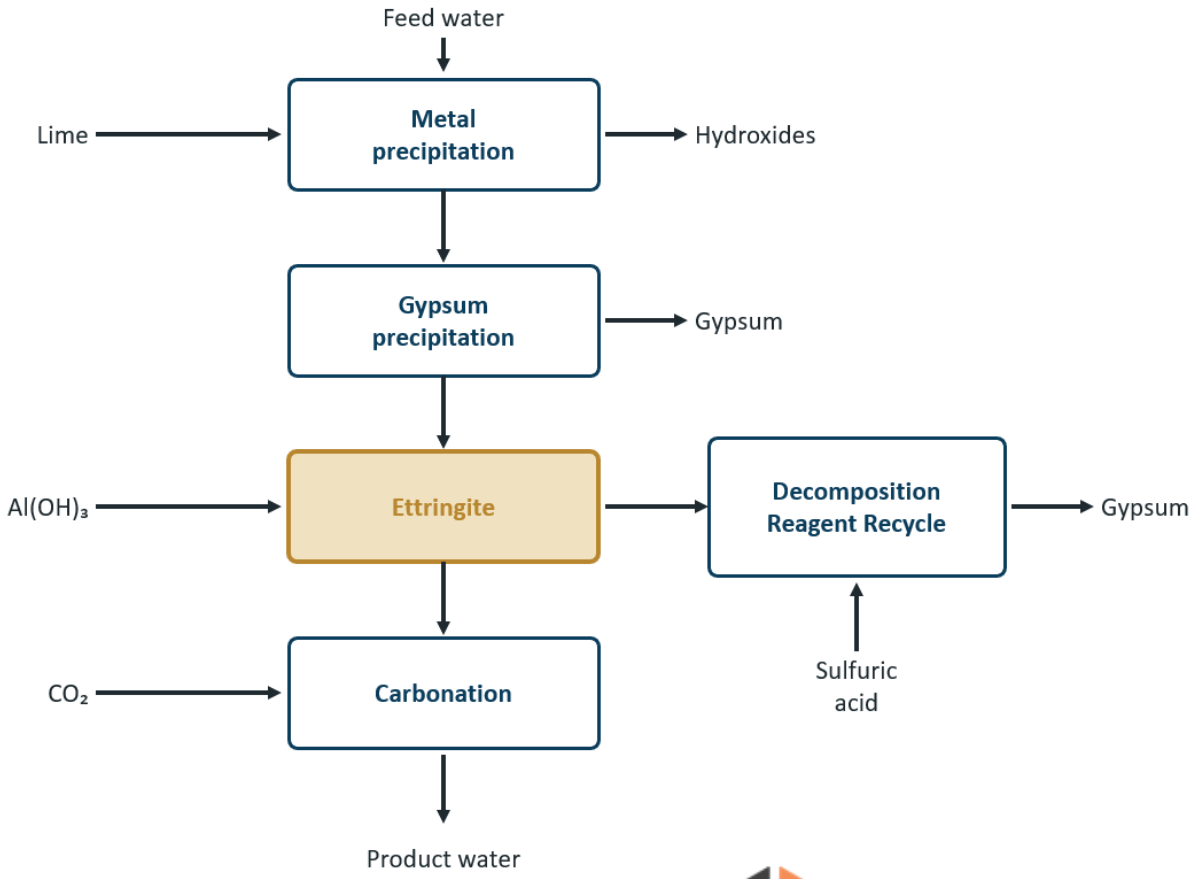
MINE WASTE MANAGEMENT
GREENROAD GROUP

NMD Treatment: Bench Scale Testing

Bench Scale Testing:

- NMD near-neutral, Ca-rich chemistry can be deliberately modified to pH 12.0–12.5.
- Standard SO_4 removal (gypsum via lime dosing) is capped by gypsum's own solubility (1,500–2,000 mg/L SO_4 remaining in solution).
- Ettringite incorporates SO_4 directly into its structure, at lower solubility than gypsum (<200 mg/L remaining in solution).
- Its structure also supports substitution and sorption of trace metal(loid)s — removal beyond sulfate alone (e.g., arsenic, boron, selenium).

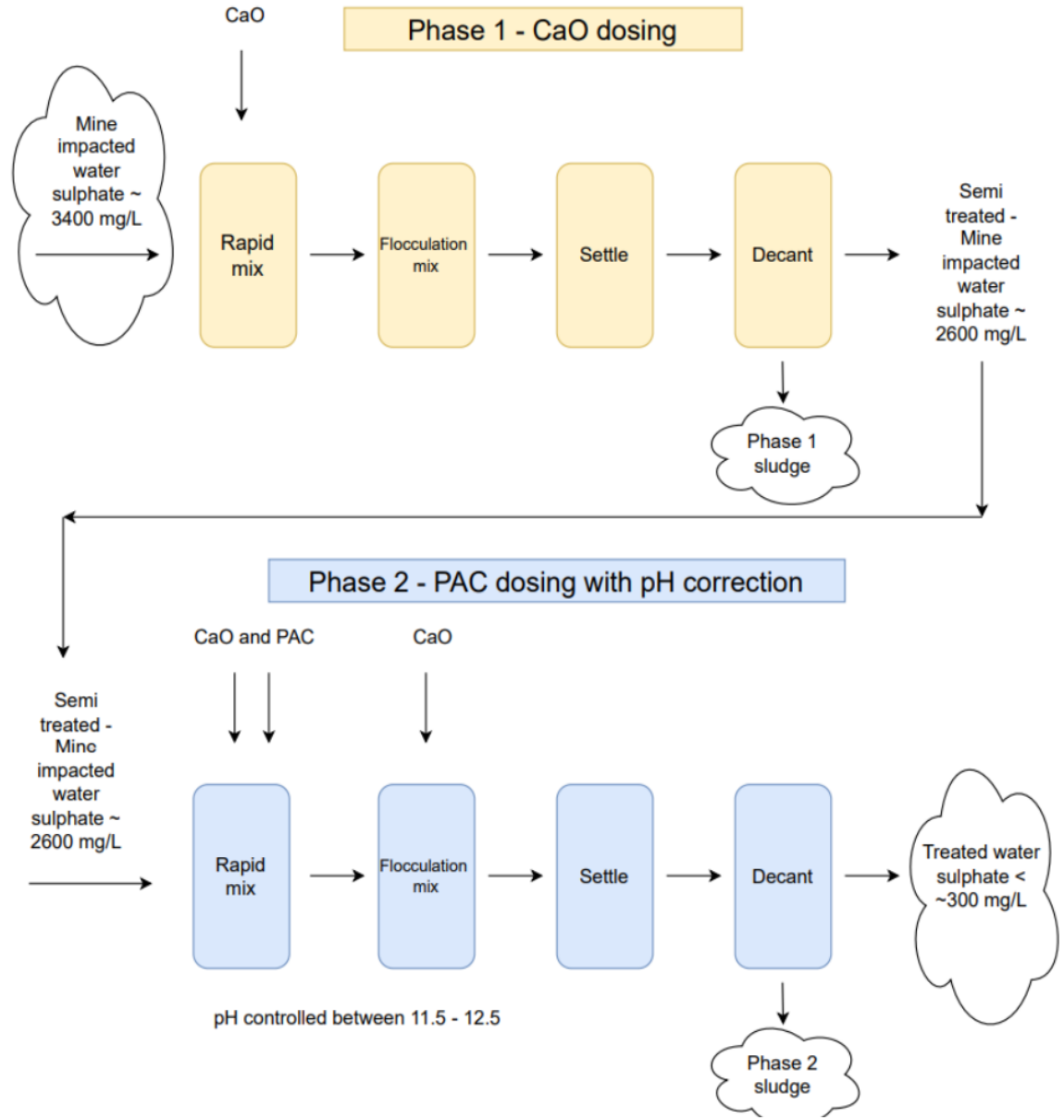
SAVMIN process flowsheet (Bowell, 2004)



MINE WASTE MANAGEMENT
GREENROAD GROUP

Bench Scale Testing

- **Concept Study**: Active treatment options for NMD (target: 200 – 500 mg/L SO_4 , metal(loid) reduction).
- Two phases:
  - Phase 1: CaO dosing to find optimal dosage for pH increase and SO_4 removal through gypsum precipitation.
  - Phase 2: PAC* and CaO dosing to find optimal dosage for additional sulfate removal through ettringite precipitation.



*Poly-aluminium chloride

MINE WASTE MANAGEMENT
GREENROAD GROUP

Bench Scale Testing

Phase 1

- SO_4 reduction of 18.75% (limited removal likely due to residence time and ionic strength of solution)
- Effective removal of other metal(loid)s (As, Sb, Co, Mg, Ni, Zn (note: no B removal).

Phase 2

- Final SO_4 concentrations <10 mg/L — a 99.8% removal efficiency.
- Ettringite precipitation also removed boron, chromium, cobalt, and selenium.

Table 3. Removal efficiencies of Phase 1 and Phase 2.

PARAMETER	PHASE 1 REMOVAL%	PHASE 2 REMOVAL%	TOTAL REMOVAL%
	CaO/SO_4 = 1.75	$Al(OH)_3/SO_4$ = 0.75	
SO_4 (mg/L)	18.75%	99.77%	99.81%
Sb (mg/L)	90.00%	--	> 90.0%
As (mg/L)	98.83%	-82.14%	97.88%
As tot. (mg/L)	99.52%	-26.19%	99.39%
B (mg/L)	9.09%	> 75.0%	> 77.3%
Cr (mg/L)	--	60.00%	--
Co (mg/L)	99.12%	70.00%	99.74%
Fe tot. (mg/L)	> 99.2%	--	> 99.2%
Mg (mg/L)	~100.0%	--	~100.0%
Mn (mg/L)	~100.0%	--	~100.0%
Ni (mg/L)	99.29%	--	99.29%
Se (mg/L)	-3.51%	93.22%	92.98%
Zn (mg/L)	> 90.1%	--	90.10%
	Gypsum	Ettringite	

MINE WASTE MANAGEMENT
GREENROAD GROUP

Bench Scale Testing

Results

- Significant decrease in sulfate.
- Decrease in trace metal(loid)s (e.g., arsenic)
- Decrease in boron and selenium
- Harness increased.
- pH has not been adjusted, remains elevated.
- Al is low given the Al dose rate and elevated pH.

PARAMETER (mg/L UNLESS INDICATED)	INITIAL AMD	AFTER PHASE 1	PHASE 2 SUPERNATANT RESULTS			
$Al(OH)_3$ equiv. / SO_4 (mg/mg)	-	--	0.6	0.75	0.9	1.2
SO_4	**3,200**	2,600	470	6	11	3
pH (pH units)	**7.2**	12.5	11.9	12.0	12.0	12.4
Tot. Alk. (mg/L $CaCO_3$)	**370**	1,940	460	1,340	1,820	1,790
Tot. Hard. (mg/L $CaCO_3$)	**3,100**	4,000	1,880	2,400	3,200	3,400
Al (total)	**0.023**	<0.0032	0.10	1.05	0.66	1.2
As (total)	**0.87**	0.0028	0.0054	0.0051	0.0048	0.0045
B	**0.22**	0.2	<0.05	<0.05	<0.05	<0.05
Se	**0.0171**	0.0177	0.0123	0.0012	0.0014	<0.0010

MINE WASTE MANAGEMENT
GREENROAD GROUP

Practical Implications

Treating ARD

- Management of ettringite formation may be required within water treatment plants in high sulfate waters if lime treatment used.
- If Lime slurry pH > 12 with elevated sulfate, then consider risks for carry water that is elevated in Al.
- Pre-treatment to remove Al may be required.

Treating NMD

- Ettringite formation offers benefits for the treatment of high sulfate mine impacted waters.
- Bench scale testing demonstrates applicability of the process to NMD waters.
- Expect co-benefits beyond sulfate: e.g., trace metals and B, Se.

MINE WASTE MANAGEMENT
GREENROAD GROUP

GREENROAD

MINE WASTE MANAGEMENT

HYDRO GEOCHEM GROUP

MINE CLOSURE MANAGEMENT

GEOCONTAM RISK MANAGEMENT

RESOURCESTACK

GR PROJECTS