Sulfate Management Options for the Coronation North Waste Rock Stack, Macraes Gold Mine

Paul Weber

O’Kane Consultants (NZ) Ltd

1 November, 2016

O'Kane Consultants

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

Introduction

- O’Kane Consultants have been engaged by OceanaGold to provide advice on methodologies to reduce the potential sulfate load from the Coronation North WRS.

- A number of options are available to reduce sulfate loads including:

  - Reducing the oxidation of sulfides in the WRS, which generates sulfate;

  - Minimising the transport of sulfate by net percolation (water); and,

  - Treatment options for sulfate-impacted drainage from the WRS.

- Such options will be used to create a Best Practicable Options (BPO) Report for the WRS to reduce sulfate loads.

- Sulfate is associated with the oxidation of sulfide minerals such as pyrite

Sulfide Oxidation Principles

Sulfate is generated by sulfide oxidation e.g., pyrite:

FeS_2 + $^7/_2O_2$ + H_2O $\Rightarrow$ Fe^{2+} + $2SO_4^{2-}$ + $2H^+$ (exothermic rx = heat)

pyrite + oxygen + water $\Rightarrow$ dissolved Fe + sulfate + acidity

wt% S x 30.6 = Maximum Potential Acidity (MPA) of a rock sample (in kg H_2SO_4/tonne)

At the MGP neutralisation of acidity is derived from calcite within the waste rock:

$CaCO_3$ + $2H^+$ $\Rightarrow$ Ca^{2+} + CO_2 + H_2O

calcite + acid $\Rightarrow$ dissolved calcium + CO_2 + water

The acid neutralisation capacity (ANC) of rock is determined by the amount of carbonate present. ANC is determined by acid digestion (expressed in kg H_2SO_4/tonne).

Sulfate remains in solution and can become elevated in WRS drainage waters.

If there is no oxygen available then pyrite cannot oxidise to sulfate.

If there is no water then the sulfate cannot be transported from the WRS.

Sulfate Management Steps

There are six general steps for sulfate management:

1. Prediction
   - Determines the potential for elevated sulfate in drainage waters (based on assessment of waste rock – Acid Base Accounting).
2. Prevention (of oxidation)
   - Involves preventing, as much as possible, the interaction of sulfides with oxygen.
3. Minimisation (of load)
   - Minimisation relates to reducing the contaminant load to the receiving environment.
   - This often involves minimising the interaction of oxidation products with net percolation of water through the WRS.
4. Control
   - Involves methods to prevent the release of sulfate impacted water to the receiving environment.
   - Often the purpose is to ensure all impacted waters are delivered to one location (for treatment).
5. Treatment
   - Includes a strategy to treat sulfate impacted waters (operationally and post closure).
6. Closure
   - Considers the final deliverable for the project – is it treatment in perpetuity or a walkaway solution

Prediction

- The net acid production potential (NAPP) of waste rock is determined from:

  NAPP = MPA – ANC

- A positive NAPP indicates that the sample is capable of generating acidity if exposed to oxygen and water.

- OceanaGold are currently analysing 700 samples from the proposed Coronation North Pit for MPA and ANC.

- Current data explain that acidity is not an issue for the site.

	ANC (0.1N)	Total S	Sulfide S	Sulfide S of total S	ANC (based on 0.1N)	MPA	NAPP	Ratio
Units	wt% $CaCO_3$ equiv.	wt%	wt%	%	kg H_2SO_4/t	kg H_2SO_4/t	kg H_2SO_4/t	Not applicable
Mean	5.36	0.17	0.12	72%	52.6	3.7	-48.8	20.1
Median	5.56	0.16	0.11	75%	54.5	3.4	-50.6	15.6

- ABA Data will be used to construct a waste rock block model

Prediction – Waste Rock Block Models

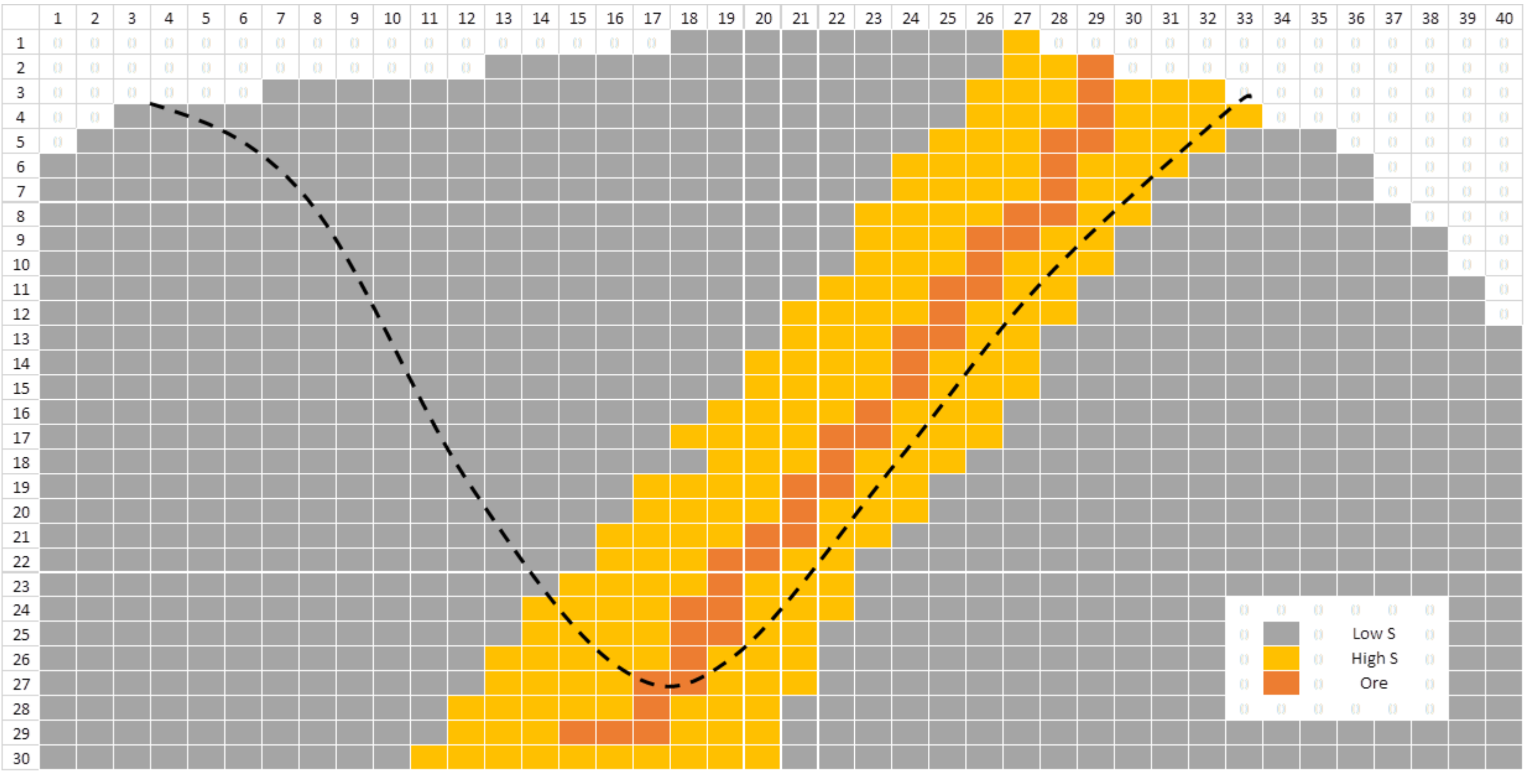
- Sulfur data can be used to determine the quantities of high and low sulfur waste rock within the proposed pit.
- For instance, the following example is provided:

Sulfur Grade (wt%)	Tonnes of waste rock per grade (t)	Total rock per grade (%)	Sulfate potential per grade (kg SO_4/t rock)	Total sulfate potential per grade (t SO_4)	Total sulfate potential per grade (%)
0.2 - 0.5	12,629,562	15.6%	10.5	132,335	2.4%
0.5 - 1.0	20,307,571	25.0%	22.5	455,971	8.3%
1.0 - 2.0	14,044,667	17.3%	44.9	630,697	11.5%
2.0 - 3.0	11,698,781	14.4%	74.8	875,586	16.0%
3.0 - 6.0	19,741,537	24.3%	134.7	2,659,572	48.5%
> 6.0	2,727,485	3.4%	269.4	734,892	13.4%
Total	**81,149,604**			**5,489,054**	

- These results indicate that if 28% of the rock is managed well then 62% of the potential sulfate load can be managed well.
- Such understandings can be incorporated into the WRS design
- OceanaGold will develop a waste rock block model for the project.

O'Kane Consultants
Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology

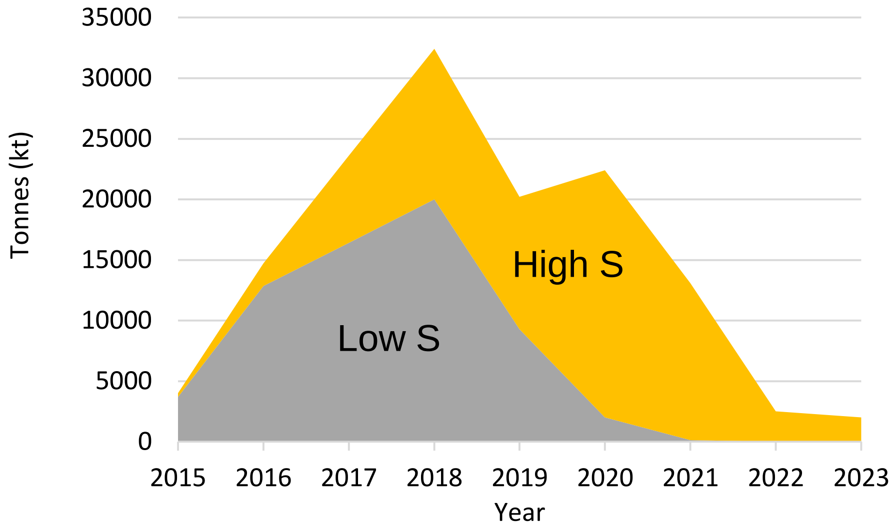
Waste Rock Block Model: Example



- With 700 sulfur data forthcoming it is proposed that a model will be built as part of the BPO Report to determine any benefits in separating waste rock into high and low sulfur materials.

Prediction: Waste Rock Scheduling

- Waste rock block models can be integrated into the mine plan to develop waste rock schedules.

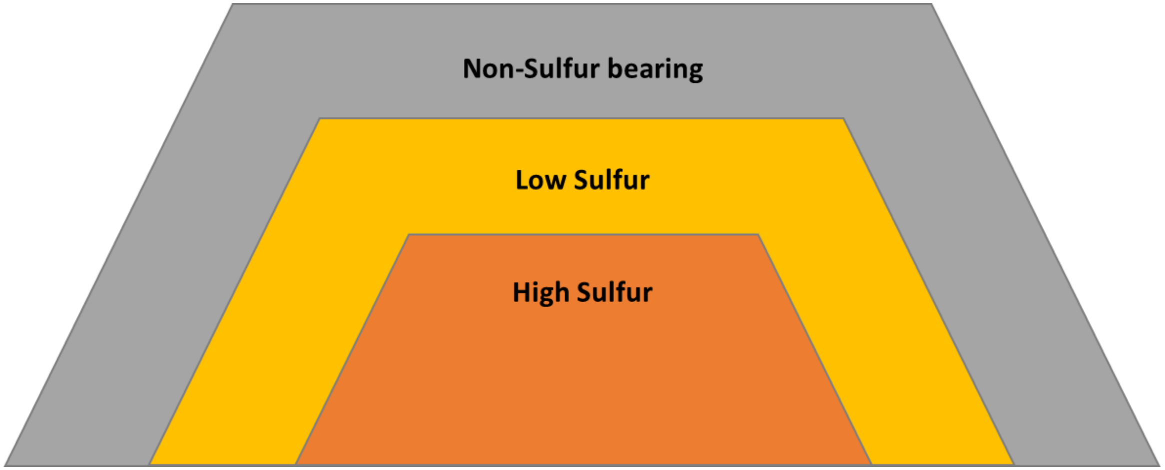


- Schedules enable better planning and WRS construction strategies including:
  - Ensuring the construction process enables all high sulfur waste rock to be buried in the core of the WRS.
  - Planning to accommodate high S rock at the end of mine life.

- A waste rock schedule will be developed by OceanaGold as part of the BPO report.

Prevention: WRS Design

- Waste rock scheduling provides the materials list for the WRS design and construction.
- This may require multiple tipheads and QA/QC procedures for truck movements.



Prevention: WRS Construction Techniques

- Significant grainsize segregation during the dumping of waste rock can cause the development of basal rubble layers and angle-of-repose chimneys.
- This can occur on every lift.
- This allows significant advective oxygen ingress along these layers into the WRS.

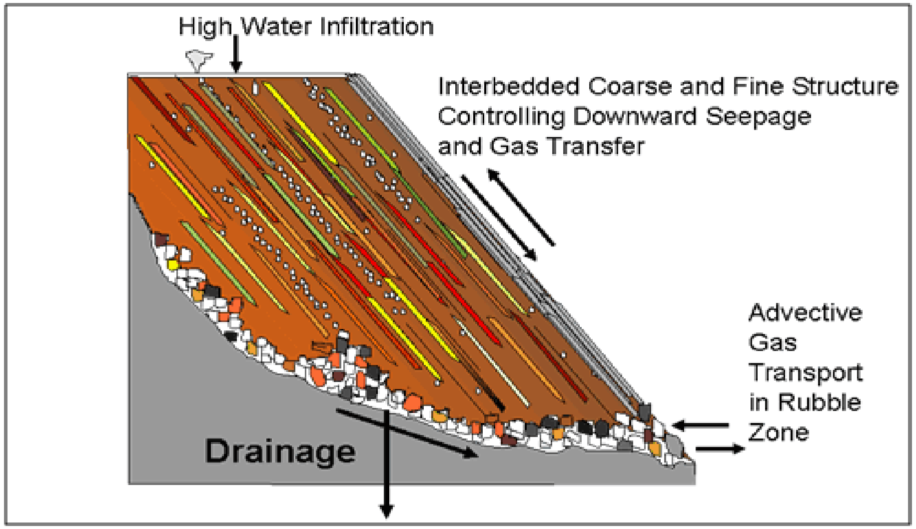
Macraes Gold Mine. Source: Plate 8; EGL 2016.

Prevention: WRS Construction Techniques

- These coarser layers are zones of oxygen ingress
- Moisture travels down the finer layers

Advective ingress of oxygen = 90% of oxygen flux. (Brown et al. 2014)

Eliminate this and sulfide oxidation can be reduced by ~one order of magnitude.

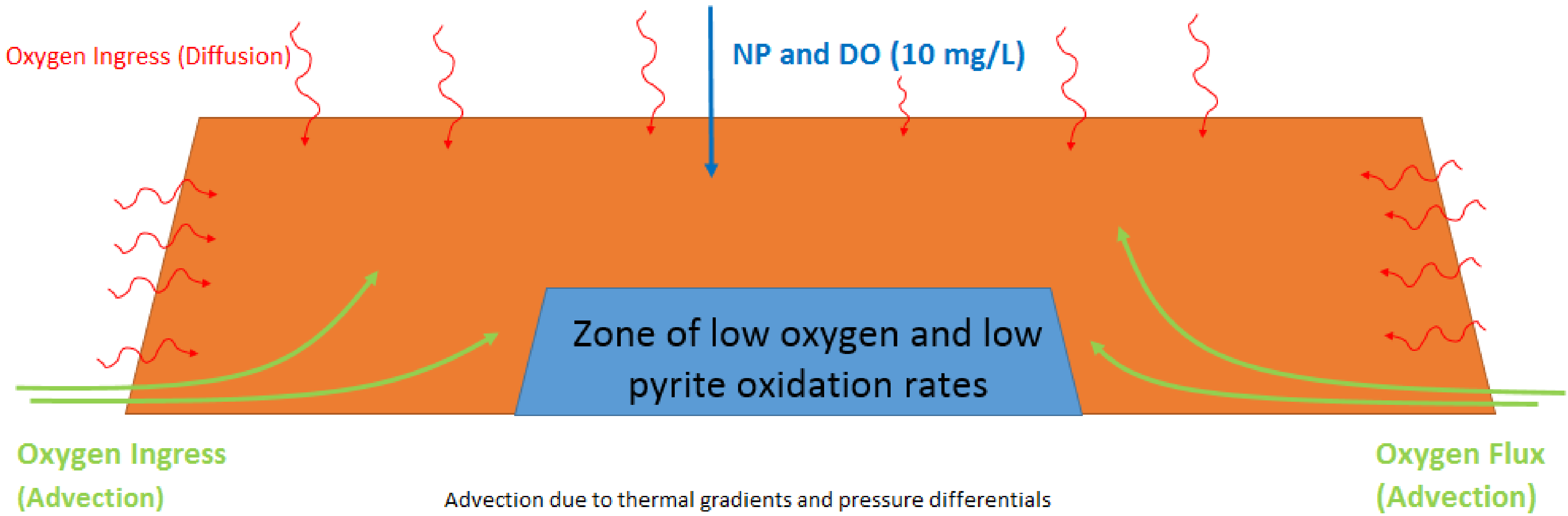


Source: Wilson 2008 (Aussie AMD conference Tasmania)

Segregation is materials specific – OceanaGold will undertake trials to understand such segregation effects and optimal tiphead height as part of the BPO report

WRS Conceptual Design

- High end tips

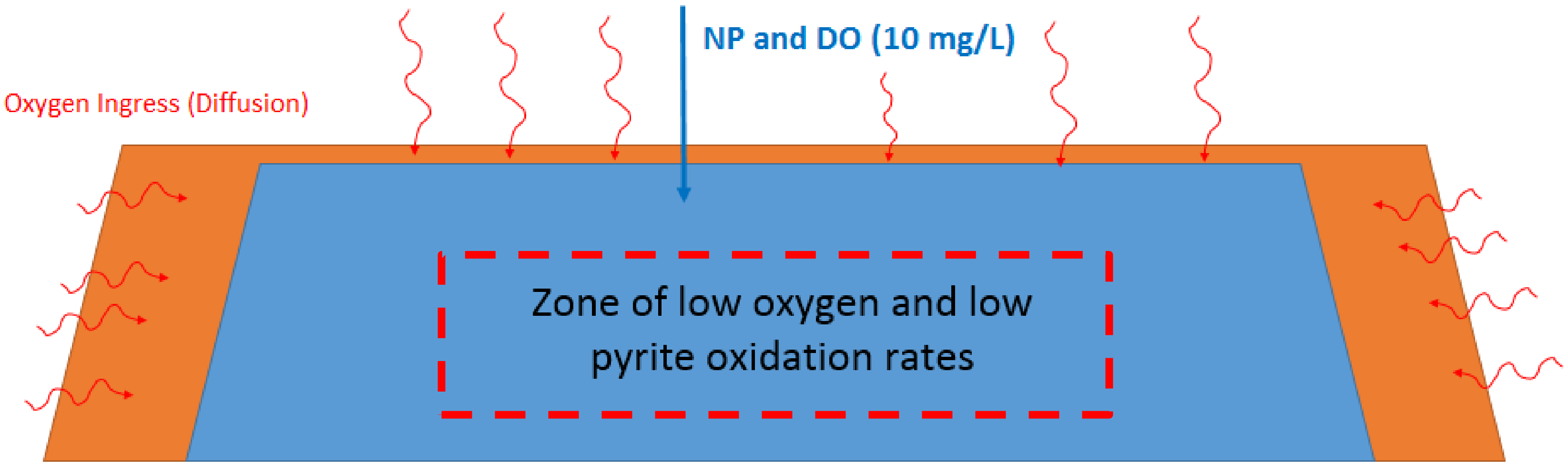


WRS constructed by larger endtips have grainsize segregation and rubble zones for advection ingress of oxygen

WRS Conceptual Design

- Low end tips

High S waste rock to be placed in the core of WRS away from significant oxygen ingress



WRS batter slopes are higher permeability = greater ingress by diffusion

WRS constructed to minimise grainsize segregation and formation of rubble layers

Less sulfide oxidation means less stored sulfate oxidation products that can then be mobilised by net percolation.

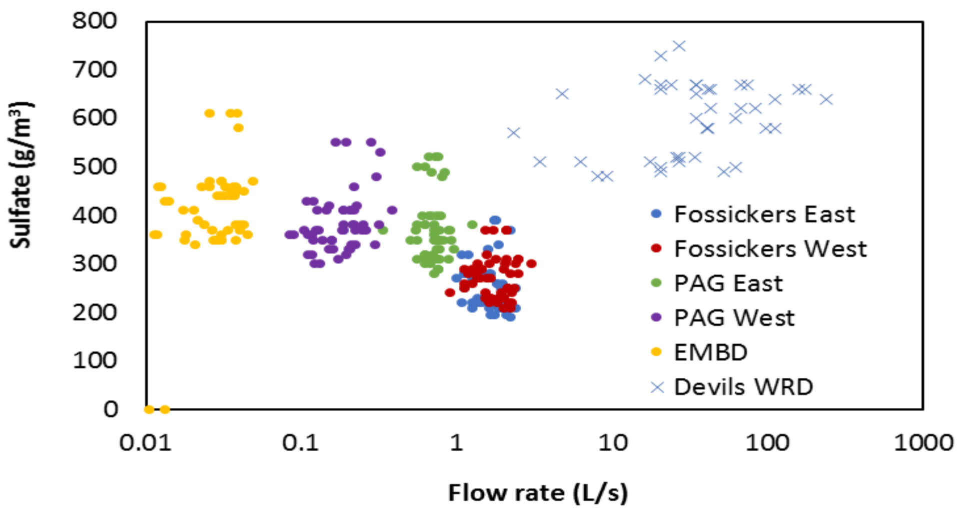
Minimisation: Net Percolation

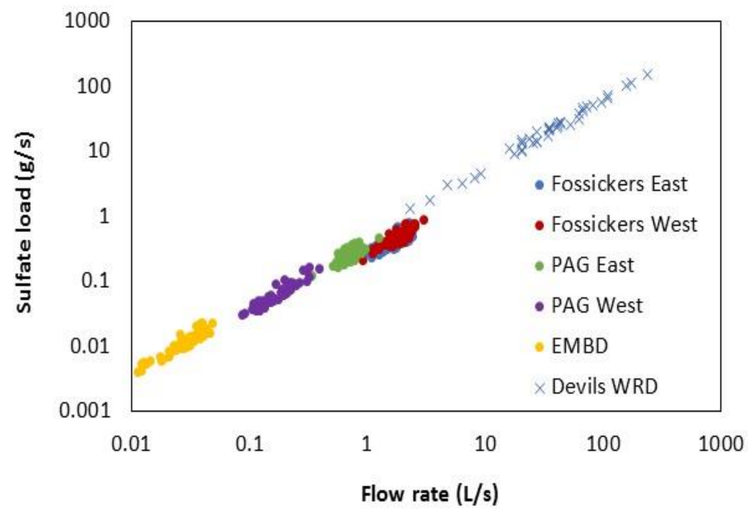
- Reducing water ingress into the WRS will reduce the opportunity to transport sulfate from the WRS and thus the contaminant load to the receiving environment.
- Opportunities include:
  - Maximising the diversion of upslope water away from the WRS.
  - Shedding of rainfall as runoff from the WRS as quickly as possible to minimise infiltration.
  - Progressive rehabilitation and the installation of the low permeability oxide cover systems.
  - Compaction of lifts and the outer slopes of the final rehabilitated WRS.
  - Cover technologies to minimise net percolation.
- OceanaGold will be investigating such options as part of the BPO Report

Example: Sulfate Load

- It is expected that minimisation of flow through the Coronation North WRS will reduce sulfate load to the receiving environment.

- Such trends are observed at other sites:





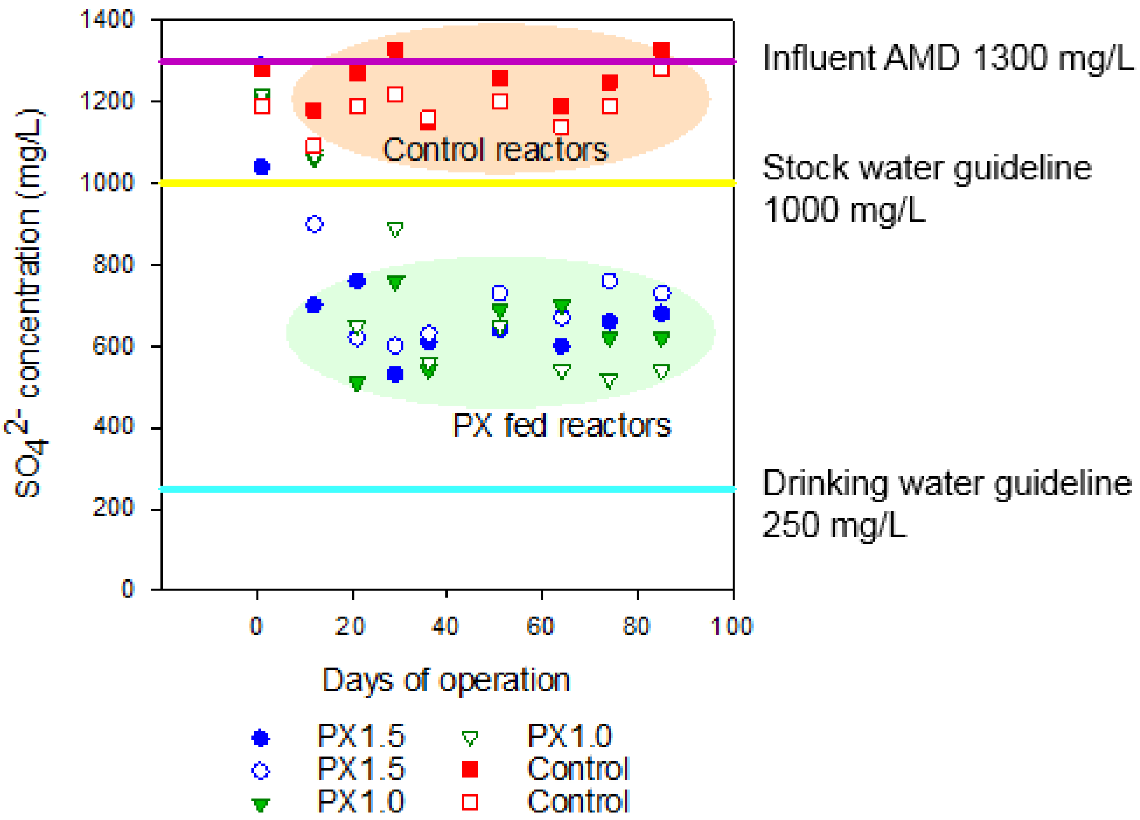
Globe-Progress Mine

Underdrainage systems

Treatment

- Basal seepage from the WRS can be treated to improve water quality and reduce sulfate load.
- If treatment is required it is likely to be treatment in perpetuity.
- One approach would be the use of passive treatment technologies to reduce sulfate load.
- Active treatment technologies can also be considered and would be part of the adaptive management plan, although the approach is not favoured.
- OKC is part of a research project looking at passive treatment systems to remove sulfate using a novel technology.

Passive Treatment



- Trials are required to confirm such technologies are suitable for basal seeps at the MGP.
- Flow rates expected are < 5 L/sec, which is within the capacity of passive treatment technologies.

Example Whirlwind Mussel Shell Reactor

Parameter	Approx. size
Average Plan Dimensions (m) (Shell layer)	14.0 x 21.5
Average Plan Area (m^2) (Shell layer)	302
Average Shell depth (m)	1.2
Ponding depth (m)	0.2 - 0.6
Freeboard (m)	0.8 - 0.4
Volume of shells (m^3)	366
Mass of Shells* (T)	362
Pore volume (m^3)	192
Residence time (days) (@ 1 - 6 L/s)	2.2 - 0.44

Sulfate Reduction Alkalinity Phase

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

5 L/sec

Conclusions

- Further work is required to confirm these opportunities to:
  - Reduce oxygen ingress and thus the formation of sulfate;
  - Reduce flow rates through the WRS and thus sulfate loads; and,
  - Treat any basal drainage from the WRS to reduce sulfate concentrations.
- This will be part of the Best Practicable Options Report and consider from a cost : benefit perspective the suitability of each option.
- It is reasonable to consider an adaptive management process that might include one or more of the following options:
  - Waste Rock Management (e.g., segregation of high and low sulfur waste rock);
  - Engineered Landform Design (ELF) to minimise oxygen ingress and net percolation;
  - Cover technologies;
  - Passive treatment;
  - Active treatment (least preferred); and,
  - Engineered dilution using the Coal Creek Freshwater Dam.

Thank You

O'Kane Consultants

Supporting:

- Rainbow of Hope for Children,
- Habitat for Humanity Initiative – El Salvador

Habitat for Humanity®

Rainbow of HOPE for Children

Supporting:

- **Mine Overlay Site Testing Facility – University of Saskatchewan (Canada)**
- **Centre for Minerals Environmental Research (New Zealand):**

The University of Saskatchewan Global Institute for Water Security

Mine Overlay Site Testing Facility (MOST)

University of Saskatchewan

CMER

Centre for Minerals Environmental Research

New Zealand

O'Kane Consultants

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology