Boliden Aitik Mine Closure Planning

WRSF Closure Planning Support Studies

25th BC MEND ML-ARD Workshop
Vancouver, BC
November 28/29, 2018
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Boliden - Aitik
Focus of Presentation: Waste Rock Storage Facilities

WRSF Footprint

Potentially Acid Forming (PAF) WRSF footprint
~ 390 ha

Non-Acid Forming (Environmental) WRSF footprint
~ 280 ha
Focus of Presentation: Waste Rock Storage Facilities

Include all Mine Site Elements (Domains):

- Waste Rock Storage Facilities (WRSFs)
- Tailings Management Facility (TMF)
- Pit Lakes
Risk Management and Opportunities:
Evaluate water quality at closure for aquatic receptors downstream to Aitik

Include all Mine Site Elements (Domains):
- Waste Rock Storage Facilities (WRSFs)
- Tailings Management Facility (TMF)
- Pit Lakes
Overarching Summary

- **WRSF Seepage Flow and Water Quality Over Time?**
- **Why…?**
  - **Input to Pit Lake Assessment and Downstream Recipient Modelling**
Overarching Summary - Methodology

Waste Rock Pore-Water Quality?

- Cover System Field Trials and Modelling

  - Model Result: Waste Rock Pore-Water Quality
    - Waste rock characteristics

- WRSF Seepage Flow and Water Quality
  - Now?: Monitoring
  - Over Time?: Modelling

- TMF Seepage Monitoring and Modelling
Risk Management and Opportunities:
Evaluate water quality at closure for aquatic receptors downstream to Aitik
Overarching Summary - Methodology

- WRSF Cover System Design Criteria:
  - Oxygen Ingress?
  - Net Percolation?
Overarching Summary - Result

- **WRSF Cover System Design:**
  - Thickness?
  - Characteristics?
  - Volume?
  - etc.
Overarching Summary - Evaluation

- **Risk Management and Opportunity Assessment:**
  - *Failure Modes and Effects Analysis*
  - *Inform on Engineering Design*
  - *An Engineering Design Tool to Manage Risk and inform (focus) research / work / studies to optimize design leading up to implementation*
Overarching Summary - Evaluation

**THE BIG PICTURE**

1. TRY
2. FAIL
3. ADDITIONAL STUDIES
4. REFINE C.M.
5. ADDITIONAL STUDIES
6. AN ENGINEERING TOOL TO INFORM ON AND DEVELOP DESIGNS USING A RISK BASED APPROACH
Overarching Summary - Evaluation

The Big Picture:
1. Try
2. Fail
3. Additional Studies
4. Refine C.M.
5. Repeat

The Natural Human Learning Process = An engineering tool to inform on and develop designs using a risk-based approach.

What is the Objective?
Derivation of flow rates for the 558 water quality monitoring location (key monitoring location below the PAF WRSFs)

CONCEPTUAL SITE FLOW MODEL
Site Topography – Pre-mining

Bog outline
Site Topography – Pre-mining

Bog outline

Fen outline
Site Topography – Pre-mining

Future pit outline

Bog outline

Fen outline
Pre-mine contours were used to analyze surface topography and infer flow direction.
Site Topography – Pre-mining

Catchments were delineated based on expected flow directions

Catchment outlines
Water Monitoring Location 558

- Majority of surface and shallow groundwater flow reports to water monitoring location 558, along T2-T4 collection channel
- Flow rate measurements and water quality data are available
- To understand Long-Term water quality, requires characterizing each flow component individually to understand current water quality
Infiltration and percolation through PAF WRSFs (T2, T3, T4) produces poor water quality.

Percolation through Environmental WRSFs (T1, T7) produces acceptable water quality.

TMF contributes a substantial flow volume.

Near surface natural ground flow contributes clean water.
Site 558 Flow Regime

- Seepage collected in T2-T4 drainage channel, which then reports to water monitoring location 558
- Majority of groundwater reports to open pit
Water Model Characteristics

- Estimation of WRSF basal seepage flow rates based on net percolation
  ~ 330 mm/yr
  - ~55% of average annual precipitation calculated based on bare waste rock conditions
- WRSF flow rates based on annual net percolation x footprint area
- PAF WRSFs ~38 L/s
  - Flow occurs as basal seepage that reports to the surficial aquifer in underlying moraine layer
  - Need: Determine Water Quality
- Env. WRSFs ~10 L/s
  - Flow occurs as basal seepage that reports to the surficial aquifer in underlying moraine layer
  - Water quality based on weighted mean from T6, representative of T1 and T7
    - pH ~ 6.9
    - Acidity ~0.2 mg/L
    - Cu ~ 0.007 mg/L
    - Al ~ 0.01 mg/L
TMF Flow and Water Quality

- TMF contributes substantial flow to collection channel
- Estimated contribution ranges from 43 to 100% of flow in T2-T4 channel from previous research studies at site
- ~157 L/s (70% of flow in T2-T4 channel) based on Dupuit analysis of anticipated phreatic surface in TMF and head gradient of flow path through PAF WRSF

- Water quality from samples (mean of two representative data sources)
  - pH ~ 4.9
  - Acidity ~ 79 mg/L
  - Cu ~ 2.7 mg/L
  - Al ~ 12 mg/L
Near Surface Flow and Water Quality

- **Flow rate ~22 L/s** based on difference between measured flow at water monitoring location 558 and other flow component estimates (base flow)
- **Water Quality from** near surface water quality provided by Lorax (2015), based on water quality monitoring location 522 (close to Myllyjoki Creek)
  - pH ~ 6.8
  - Acidity ~ 2.5 mg/L
  - Cu ~ 0.002 mg/L
  - Al ~ 0.02 mg/L
Derivation of WRSF Waste Rock Characteristics
Mineralogy and Acid Base Accounting

FIELD BASED INVESTIGATIONS
Determine Current PAF WRSF Source Term (pore-water quality)

GEOCHEMICAL MODELLING
Summary of Key Parameters

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (mg/L)</th>
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<tbody>
<tr>
<td>pH</td>
<td>3.5</td>
</tr>
<tr>
<td>Acidity</td>
<td>1,490</td>
</tr>
<tr>
<td>(as CaCO₃)</td>
<td></td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>1.2</td>
</tr>
<tr>
<td>NH₄⁺</td>
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</tr>
<tr>
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<tr>
<td>NO₂⁻</td>
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<tr>
<td>Cu²⁺</td>
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</tr>
<tr>
<td>Zn²⁺</td>
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<tr>
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<td>Mg²⁺</td>
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<td>Mn²⁺</td>
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<td>SO₄²⁻</td>
<td>3,830</td>
</tr>
</tbody>
</table>

Contaminant Load = Flow Rate x Water Quality

1,490 mg/L Acidity x 37.5 L/s ~ 56,000 mg/s  
or ~1,760 tonnes acidity/year

PAF WRSF contributes dominant source of acidity to water monitoring location 558  
(558: ~2,000 tonnes/year).

Reducing load from the PAF WRSF will significantly reduce overall catchment load.
2015 Flow Measurements

• Additional flow modelling conducted in 2015.
  ➢ Total average flow measurement at location 558 between February and May 2015 was **318 L/s**, higher than **225 L/s** used in model
  ➢ 2015 flow rate influenced by spring freshet; Therefore Ave. Flow Rate Likely Lower

```
<table>
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<tr>
<th>Flow (Model)</th>
<th>Flow (2015 Data)</th>
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</thead>
<tbody>
<tr>
<td>~225 L/s</td>
<td>~318 L/s</td>
</tr>
</tbody>
</table>
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2015 Flow Measurements

- Additional flow modelling conducted in 2015.
  - Total average flow measurement at location 558 between February and May 2015 was 318 L/s, higher than 225 L/s used in model
  - 2015 flow rate influenced by spring freshet; Therefore Ave. Flow Rate Likely Lower

- However, **Load** is a critical parameter in understanding effects

- Total acidity used in model ~2,000 tonnes/year

- Total acidity associated with 2015 measurements is ~10% higher

*Confirms model is reasonable*
EVALUATION OF POST CLOSURE WRSF SEEPAGE WATER QUALITY

Three key components of long-term water quality model:
1. Current water quality of the PAF WRSF
2. Long term water quality (geochemical maturity)
3. Transition water quality (during flushing of stored oxidation products)
Long-Term WRSF Seepage Water Quality Methodology

High

Total Acidity Load
(e.g. tonnes/year in WRSF seepage)

Low

Time
(e.g. year after closure cover system construction)

pH

~3

~7
Long-Term WRSF Seepage Water Quality Methodology

WRSF “Draindown” Phase

Total Acidity Load (e.g. tonnes/year in WRSF seepage)

High

Low

Time

(e.g. year after closure cover system construction)

pH

~3

~7
Long-Term WRSF Seepage Water Quality Methodology

WRSF “Draindown” Phase
- Stored sulfide-oxidation products (acidity/metals)
- Potential sulfide acidity/metals (cover system oxygen flux)
- Mobilized by net percolation and draindown

Time
(e.g. year after closure cover system construction)
Long-Term WRSF Seepage Water Quality Methodology

- Stored sulfide-oxidation products (acidity/metals)
- Potential sulfide acidity/metals (cover system oxygen flux)
- Mobilized by net percolation and draindown

Total Acidity Load (e.g. tonnes/year in WRSF seepage)

“Draindown”

WRSF “Transition” Phase

Time
(e.g. year after closure cover system construction)

~3

~7

pH

Integrated Mine Waste Management and Closure Services
Specialists in Geochemistry and Unsaturated Zone Hydrology
Long-Term WRSF Seepage Water Quality Methodology

“Dra indown”

“Transition”

WRSF “Long-Term” Phase

High

Low

Total Acidity Load
(e.g. tonnes/year in WRSF seepage)

➢ Stored sulfide-oxidation products (acidity/metals)
➢ Potential sulfide acidity/metals (cover system oxygen flux)
➢ Mobilized by net percolation and draindown

➢ Leaching of stored acidity/metals
➢ Decreasing acidity/metals
➢ Increasing pH

Time
(e.g. year after closure cover system construction)

~7

~3

pH

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Long-Term WRSF Seepage Water Quality Methodology

High Total Acidity Load (e.g. tonnes/year in WRSF seepage)

"Draindown"

➢ Stored sulfide-oxidation products (acidity/metals)
➢ Potential sulfide acidity/metals (cover system oxygen flux)
➢ Mobilized by net percolation and draindown

"Transition"

➢ Leaching of stored acidity/metals
➢ Decreasing acidity/metals
➢ Increasing pH

WRSF “Long-Term” Phase

➢ Geochemical maturity
➢ Low oxidation rates due to presence of cover system

~3 to ~7 pH

Low Total Acidity Load (e.g. tonnes/year in WRSF seepage)

Time (e.g. year after closure cover system construction)
Initially, waste rock, when placed, has a low water content (degree of saturation ($S\%$))

Then, due to surface infiltration, the waste rock “wets up”

But the waste rock does not “wet up” to the point where $S = 100\%$

“Draindown”

“Transition”

“Long-Term”

Degree of Saturation (of Waste Rock Material)

Time
(e.g. year after closure cover system construction)
Long-Term WRSF Seepage Water Quality Methodology

“Draindown”

➢ When the cover system is placed, the waste rock “drains down”
➢ Due to the net percolation rate being lower than initial surface infiltration rate

“Transition”

“Long-Term”

Degree of Saturation (of Waste Rock Material)

High

Low

Time

(e.g. year after closure cover system construction)
“Draindown”

- When the cover system is placed, the waste rock “drains down”
- Due to the net percolation rate being lower than initial surface infiltration rate

“Transition”

- And, the system reaches a new quasi steady-state (lower S%) where WRSF seepage flow is a function of the cover system

“Long-Term”

(e.g. year after closure cover system construction)
Long-Term WRSF Seepage Water Quality Results

Seepage water quality influenced by:

➢ Current pore-water quality;
➢ Draindown time frame of WRSF

Seepage water quality influenced by transition from:

➢ Current pore-water quality; and
➢ Net percolation rate from cover system
➢ Eventually resulting in “new water” reporting as basal seepage

Seepage water quality influenced by:

➢ Long-term $O_2$ ingress rate from cover system (low oxidation rates)
➢ Long-term net percolation rate from cover system (dissolution of alkalinity and sparingly soluble acidity)

“Draindown” Phase

“Transition” Phase

“Long-Term” Water Quality Phase
Long-Term WRSF Seepage Water Quality Results

- **Base Case**
  - ~2/3 of soluble acidity removed
  - Circum-neutral seepage water quality
  - Remaining soluble and sparingly soluble acidity removed
  - Dissolution of alumina-silicate minerals

- **“Draindown” Phase**
  - Acidity Load

- **“Transition” Phase**
  - pH

- **“Long-Term” Water Quality Phase**
Long-Term WRSF Seepage Water Quality Results

**Base Case:**

- Long-term WRSF seepage meets requirements for Pit Lake performance and Recipient water quality

**Risk Management / Opportunities:**

- Prior to Implementation
- FMEA informs on managing risk and assessing opportunities to optimize design through additional study, work, and research
Thank You!

O'Kane Consultants Inc.
Habitat for Humanity Initiative – El Salvador