Prediction of Groundwater Recovery and Post-Flooding Groundwater Quality

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Outline

• Site Background & Study Objectives
• Prediction of Groundwater Rebound
• Prediction of Post-flooding Water Quality
• Implications for Closure Planning
• Conclusions
Site Background

- Mine located in tropical savannah region with distinct wet season producing ~1,600 mm/year
- Mine exploited a lead-zinc deposit from 1985 – 1998
  - 100m deep open pit
  - 750m deep underground workings
- Mine produced 4.5 Mt of waste rock and 2 Mt of tailings
- Open Pit & Underground Workings located in structural zone resulting in very “wet” mine with significant dewatering during operations (up to 350 L/s)
ARD Potential & Early Decommissioning

- Tailings have a high sulphide content (~20%) and are net acid generating (NAG ~300 kg H2SO4 per tonne)
- WRD consists of a mixture of oxidized waste rock and primary waste rock with pyrite contents ranging from 3-25%
- Groundwater monitoring suggested that seepage from tailings and WRD is neutralized in local groundwater
- Zinc is the primary contaminant of concern (mobile at neutral pH)
- Between 1999-2000, high-sulphide waste rock and all tailings were backfilled into the open pit and mine allowed to reflood
Hydrogeological Study
Overview

• Hydrogeological Study initiated in 2001 in response to rapid flooding of underground workings
• Study Objectives:
  o Update prediction of groundwater recovery (time and final pit water level)
  o Predict contaminant transport (SO4 and zinc)
  o Assess closure options for WRD
  o Assist in development of closure criteria
• Study Components:
  o Field Investigation (Well Installation, hydraulic testing)
  o Groundwater Flow Model
  o Solute Transport Model
Mine dewatering has created a cone of depression which is aligned N-S along major structure;

Open pit and u/g are a major sink for groundwater

WRD seepage still draining into cone of depression
GW in pit area highly impacted (SO4, TDS, Mn, Fe, Zn etc.)

GW in tailings area shows highly variable impact

GW at downstream boundary (Creek) shows very low impact

High localised ARD load (Zn~400 mg/L) in seepage from WRD; however, no clear evidence of impact on groundwater quality
Groundwater Flow Model

Methods

• Model domain subdivided into major lithologies
• Bedrock profile subdivided into 4 model layers representing:
  ➢ Weathered bedrock (saprolite)
  ➢ Partially weathered, fractured bedrock
  ➢ Fresh, less fractured bedrock
  ➢ Deep, tight bedrock
• Major structures represented implicitly by using anisotropy
• Underground workings represented as drain nodes
Calibration of GW Flow Model

Four calibration periods:
- Pre-mining conditions
- Open Pit Dewatering
- Underground Dewatering
- Early Reflooding

⇒ Both GW levels & mine dewatering rates used for calibration
⇒ Critical that all four mining periods be modeled to predict recovery
Validation of GW Flow Model

Groundwater Rebound

Predicted Groundwater Recovery (RGC Model)

Original Prediction (Aquaterra Model)

Model Validation

Robertson GeoConsultants Inc.
Mining, Geotechnical and Environmental Engineers
Updated Validation of GW Flow Model

Groundwater Rebound

Predicted Groundwater Recovery (reccalc12_2007)

Model Validation

Model Calibration

- Geodetic Water Level (m AHD)
- Shaft
- PB-1
- PB-7
- Predicted recovery in shaft
- Calibrated recovery in shaft

Nov-99 Oct-00 Nov-01 Nov-02 Nov-03 Nov-04 Nov-05 Nov-06 Nov-07
Summary of Results

• The model predicts that the backfilled tailings will be completely reflooded by 2010-2012
• The model predicts that groundwater levels will recover to pre-mining levels (likely by 2020-2025)
• The model predicts a reversal of hydraulic gradients over time such that the entire mine site (including open pit & WRD) will drain towards the Creek after complete reflooding

=> Impact to local Creek??
Prediction of Post-Flooding Groundwater Quality

- Predict contaminant transport using solute transport model (MT3D) and calibrated groundwater flow model

- Phase 1: Predict future migration of SO4 plume for initial cover design
- Phase 2: Predict future loading of zinc to Creek for detailed cover design (incl. ecological risk assessment)
Phase 1: Closure Alternatives
Sulphate Transport

- Alternative 1: Tailings backfilled in pit & no cover on WRD (2001 conditions)
- Alternative 2: Tailings backfilled in pit & “high quality” cover on WRD

<table>
<thead>
<tr>
<th>Alternative</th>
<th>WRD Seepage Rate</th>
<th>WRD Seepage Quality (mg/L)</th>
<th>Initial SO4</th>
<th>Future SO4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33% of MAP</td>
<td></td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>2</td>
<td>1% of MAP</td>
<td></td>
<td>4,000</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Note: SO₄ in backfilled tailings assumed to remain constant (1,500 mg/L)
Predicted SO4 Transport

No Cover on WRD

High Quality Cover on WRD

⇒ ~30 years required to flush existing $SO_4^{2-}$ plume

⇒ High Quality Cover reduces long-term $SO_4^{2-}$ concentrations more than 10 times
Predicted SO4 Transport

Base Case: No WRD Cover

High Quality WRD Cover

T=30 yrs

Local Creek

Local Creek (Left Branch)
### Phase 2: Cover Scenarios

**Zinc Transport**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>WRD Seepage Rate</th>
<th>WRD Seepage Quality (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No cover (WRD removed)</td>
<td>0% of MAP</td>
<td>Initial Zn: 10, Future Zn: 0</td>
</tr>
<tr>
<td>2</td>
<td>High Quality Cover</td>
<td>1% of MAP</td>
<td>Initial Zn: 10, Future Zn: 10</td>
</tr>
<tr>
<td>3</td>
<td>Lower Quality Cover</td>
<td>10% of MAP</td>
<td>Initial Zn: 10, Future Zn: 50</td>
</tr>
<tr>
<td>4</td>
<td>Low Quality Cover</td>
<td>20% of MAP</td>
<td>Initial Zn: 10, Future Zn: 100</td>
</tr>
</tbody>
</table>

**Notes:**

Assume Zn in backfilled tailings remains constant (13 mg/L)
Assume retardation of zinc in aquifer (Rf = 2 to 6)
Predicted Zinc Transport

- Significant increase in zinc loading to Creek predicted over next 100-200 years for “low quality” cover on WRD (Scenario 4)
- No significant increase in Zn loading to Creek predicted for “high quality” cover on WRD (Scenario 2)
Predicted Zinc Transport
after 300 years

Scenario 2:
Backfilled Pit & High Quality Cover

Scenario 4:
Backfilled Pit & Low Quality Cover
No significant increase in SO4 and Zn has yet been observed in monitoring wells downstream of the WRD and backfilled pit. At least 10-15 years of monitoring will be required before the transport model can be validated with any degree of confidence.
Implications for Closure

• Modeling exercise created awareness of potential long-term deterioration in groundwater quality and contaminant loading to local Creek
• Model predictions assisted in setting more realistic expectations of time horizon for lease relinquishment
• High quality cover was selected for WRD to minimize future ARD seepage and potential long-term metal loading to creek (constructed in 2003/04)
• Groundwater model assisted in communication with local stakeholders & development of closure criteria
Lessons Learned

• Prediction of groundwater rebound very sensitive to aquifer parameters (T, S); successful prediction requires very good calibration data (incl. pre-mining water levels, dewatering rates, early recovery)

• Solute transport models are much more difficult to calibrate and validate due to the very slow rates of contaminant transport in groundwater systems

• Despite these limitations groundwater modeling provides a powerful tool for closure planning and may assist in developing closure performance criteria

• Groundwater flow and transport models should be updated as new monitoring data become available
Thank You!