Approach for Estimating a Probable Range of Pit Lake Concentrations for Mine Pits with Sulfide Wall Rock

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Outline

• What is a probabilistic model?
• Benefits using a probabilistic approach
• Methods
• Example presentation of results
• Limitations and ongoing challenges
• Summary
Limitations of Modeling

“All models are wrong, but some are useful”
- George E.P. Box, statistician

- Scaling of lab data (temp, grain size, accelerated weathering)
- Thermodynamic database: assume constants are correct and that our system is in equilibrium
- Assume complete mixing of ponds
- Complex mechanisms (cyanide attenuation, sorption) are simplified. Some are not modeled (coprecipitation)

- We can model uncertainty using Monte Carlo methods (represent inputs as range of values to get range of outcomes)
- We can avoid scaling issues by using field testing results as much as possible
What is a probabilistic model?

**INPUTS**

- **Initial Percent Sulfide [%]**
  - Probability distribution

- **Pan Evap Coefficient [%]**
  - Uniform distribution

**OUTPUTS**

- **Total Iron [mg/L]**
  - Probability distribution
Benefits of Probabilistic Models

• Probabilistic models may reduce comments on EISs by allowing parties to “agree to disagree”

• Why is this important?
  – Rosemont (AZ): >43,000 comments;
  – NorthMet (MN): >50,000 comments;
  – Average EIS contractor cost for the DOE in 2013: $2.9 million*
  – Federal Agencies are moving towards requiring EIS’s for changes to existing projects

Benefits of Probabilistic Models

• Increases understanding of project risks
  – Helps with: closure cost estimates, alternatives analyses, etc.

• Worst-case scenario isn’t always obvious for complex, dynamic systems
Benefits of Probabilistic Models

Sulfate vs. pH
Average Concentrations by Ore Deposit Type

- Massive Sulfide
- Porphyry Copper-Molybdenum
- Carlin-Type Gold

Data from INAP Pit Lake Database
Conceptual Solute Balance

- Damaged Rock Zone
- Pit Wall Runoff
- Evapo-Concentration
- Oxidation of Sulfide Wall Rock
- Other Inflows
- Groundwater
Pit Wall Runoff

\[ \text{Pit Wall Runoff} = \text{Concentration} \times \text{Flow Rate} + \text{Solute Released from Sulfide Oxidation} \]
Available Data

• Data available for modeling depends on the phase of the project.

Static Tests
• ABA
• Whole rock
• Leach Tests (MWMP, SPLP)
• NAG

Kinetic Tests
• Humidity cells

Field Tests
• Field barrels
• Test plots

Field Data
• Site samples

Better Modeling Data
Kinetic Program Comparing FB and HC

- Field barrel acidity greater and faster
- Humidity cells have such high flush rates that they do not develop “hot spots” or acidic micro-environments where the sulphide oxidizing bacteria thrive.
• Greater flush of alkalinity in the humidity cells than in the field barrel due to high water infiltration rates and volumes
Kinetic Program Comparing FB and HC

• Greater sulphate release in the humidity cell tests than in field barrels due to lack of secondary mineral precipitation
Solute Release from Sulfide Oxidation

- Rate of sulfate formed from oxidation of sulfide wall rock was estimated based on humidity cell data.
- Defined in model by slope and y-intercept
Solute Release from Sulfide Oxidation

- Solute assumed to be released from sulfide oxidation if statistically significant correlation exists between sulfate and the solute in NAG Leachate.

- Solute release modeled as ratio to sulfate release.

![Graph showing Zinc vs. Sulfate in NAG Leachate]
Solute Release from Sulfide Oxidation

- If solute is not correlated to sulfate concentrations in NAG leachate, then it is not released with sulfide oxidation in the model.

- Solute can still be released from pit wall runoff based on leach test results.
## Damaged Rock Zone Properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness(^1)</td>
<td>3 m</td>
<td>15 m</td>
</tr>
<tr>
<td>Size Factor(^2)</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Percent in Contact with Runoff(^3)</td>
<td>30%</td>
<td>90%</td>
</tr>
<tr>
<td>Sulfate Leach Rate</td>
<td>From Humidity Cell Data</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Radian 1997; McClosky et al. 2003  
\(^2\)Malmstrom et al. 2000; Lopez et al. 1997  
\(^3\)Frostad et al. 2005; Hollings et al. 2001
Model Input

- Inflow concentrations are defined by probability distribution, in this case normal distribution, defined by mean and standard error of the mean.
Solute Balance Simulations

- GoldSim uses Monte Carlo method for propagating uncertainty in model inputs into uncertainties in model outputs.
- Simulations conducted several thousand times (realizations)
- For each realization, a different parameter value is selected from the input probability distribution.
Geochemical Controls

- Bulk concentrations from the GoldSIM are analyzed for geochemical controls using PHREEQC:
  - Atmospheric O$_2$ and CO$_2$
  - Solubility controls for probable mineral phases in pit lakes*
  - Sorption to precipitated ferrihydrite

Model Results

Fluoride

Years Since End of Mining

Concentration (mg/L)

- 90th Percentile (bulk concentration)
- 90th Percentile (chemical equilibrium)
- 50th Percentile (bulk concentration)
Model Results

Calcium

Years Since End of Mining

Concentration (mg/L)

- 90th Percentile (bulk concentration)
- 90th Percentile (chemical equilibrium)
- 50th Percentile (bulk concentration)
Model Results

Average Sulfate Loading Rates to Pit over the 100-yr Simulation Period

- Wall Runoff - Sulfide Oxidation
- Flooding Sulfide Wall Rock
- Wall Runoff
- Other Inflows
- Groundwater Inflow

LEGEND
- 90th Percentile
- 75th Percentile
- 50th Percentile
- 25th Percentile
- 10th Percentile
Model Results

Average Zinc Loading Rates to Pit over the 100-yr Simulation Period

- **Wall Runoff - Sulfide Oxidation**: High loading rates with a 90th percentile near 16 g/day, 75th percentile near 14 g/day, and 50th percentile near 12 g/day.
- **Flooding Sulfide Wall Rock**: Lower loading rates compared to wall runoff, with a 90th percentile near 6 g/day, 75th percentile near 4 g/day, and 50th percentile near 2 g/day.
- **Wall Runoff**: Similar loading rates to flooding sulfide wall rock with a 90th percentile near 6 g/day, 75th percentile near 4 g/day, and 50th percentile near 2 g/day.
- **Other Inflows**: Lower loading rates, with a 90th percentile near 2 g/day, 75th percentile near 1 g/day, and 50th percentile near 0.5 g/day.
- **Groundwater Inflow**: The lowest loading rates, with a 90th percentile near 0.1 g/day, 75th percentile near 0.05 g/day, and 50th percentile near 0.02 g/day.

**LEGEND**
- 90th Percentile
- 75th Percentile
- 50th Percentile
- 25th Percentile
- 10th Percentile
Summary

“Doubt is not a pleasant condition, but certainty is absurd”

- Voltaire

- Focus should be on capturing the uncertainty
- Oxidation of sulfide wall rock is a large source of uncertainty and commonly represented inaccurately
- Allows parties to “agree to disagree”
Ongoing Challenges

- When you set a percentile, there won’t be any interest in lower percentiles.

- 90th Percentile precedent:
  - Idaho Cobalt EIS
  - PolyMet EIS
  - Ecological Risk Assessment Guidance


International Network for Acid Prevention, Pit Lake Database <http://pitlakesdatabase.org/database/home.asp>


