Variations in ARD from the Equity Silver Waste-Rock Dumps

by

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Simplified Layout of the Waste-Rock System at Equity Silver

Main ARD Pond
Bessemer Dump
Till Plug
Main Zone Pit
Low-Grade Stockpile
Main Dump
General Groundwater Flow
Backfilled Southern Tail Pit
General Groundwater Flow
Summary of the Till Cover

- A compacted till (clay) cover, 0.5 m thick, was installed mostly in 1990-1994 over 132 ha of net-acid-generating waste rock (~80x10^6 t) for approximately CAD$5 million, or about CAD$35,000/ha (Aziz and Ferguson, 1997).

- An uncompacted upper layer, 0.3 m thick, was also included to hold excess moisture until it could evapotranspirate.

- This cover was designed so that (1) the amount of total annual precipitation entering the dump would be reduced from ~40% of precipitation to ~4% (a ten-fold reduction in the primary source of water for ARD) and (2) oxygen would no longer enter the waste rock.
Annual Precipitation (rain + snow)
Annual Flow (bottom)
Annual Flow from S. Tail Pit after 1993

Average Precipitation = 650 mm

Average Flow = 834,000 m³

Most of Cover Installed 1990-1994
Average Acidity Loading = 7490 t
Average Flow = 834,000 m³
Most of Cover Installed 1990-1994


Year

Annual Acidity Loading (tonnes)
Annual Flow (bottom)
Year

Highest-Month Acidity Loading Each Year (kg/day)

Highest-Month Flow Each Year (m³/day)

Highest-Month Flow (bottom)
Return Periods for May 2002

- Maximum 2002 snowpack: 25 years
- May 2002 total precipitation: 20 years
- Combined May 2002 snowmelt and precipitation: 35 years
- May 2002 acidity concentration: ~15 years
- May 2002 acidity loading: >200 years
- Annual 2002 acidity loading: ~50 years
What Caused the Peak Values in 2002?

- Increased rate of sulphide oxidation due to increased oxygen influx?
- Increased rate of sulphide oxidation due to, or causing, increased internal temperatures?
- Change of internal flowpaths as reflected by permanent changes in groundwater levels?
- Much higher short-term flow of water through the waste rock as indicated by short-term increases in flows into lysimeters or in groundwater levels?
Gas-Temperature Probes

- Getty Pond (GC)
- Main ARD Pond (C8)
- ARD Surge Pond (C9)
- P00-02
- P99-8S&D
- Bessmer Dump
- Till Plug
- 8000N
- 7000N
- 1000 meters

- Main Zone Pit
- Low-Grade Stockpile
- Backfilled Southern Tail Pit
- P-1
- P-2
- P-3
- P-4
- P-5
- P-6
- P-7

- Main Dump

- N (North)
Probe P-7: Centre of Main Dump

% Oxygen

Year

0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
6 m depth
10 m depth
18 m depth
Probe P-4: Southeast Side of Main Dump (Backfilled Southern Tail Pit)

1 m depth
2 m depth
3.6 m depth
3.7 m depth
4.2 m depth

% Oxygen

Year

Probe P-3: Southeast Side of Main Dump
(Backfilled Southern Tail Pit)

% Oxygen

0.5 m depth
1 m depth
2 m depth
3 m depth
5 m depth
7 m depth
10 m depth

Year

Summary of Gas Trends

- Temporal, lateral, and depth trends in oxygen are complex, and are not consistent with trends in carbon dioxide. All of this indicates the waste rock consists of numerous “cells” in which gas trends are unique.

- In any case, there were no unusual values or trends in 2002, ruling out accelerated oxidation due to increased oxygen supply.
Summary of Temperature Trends

• All temperature probes displayed general cooling trends, at least from 1993 to 2002.

• The warmer probes decreased 5-20°C over this period.

• Many probes are close to the ambient air temperature and show fast, but subdued response to warming and cooling of ambient air.

• The temperature probes show no unusual trends or values in 2002, ruling out increased oxidation as a cause or effect in 2002.
Estimated Infiltration Prior to Cover Installation

Infiltration (% of Total Precipitation)


<table>
<thead>
<tr>
<th>Year</th>
<th>Permeability (m/s)</th>
<th>Infiltration (% of total precipitation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995 (O’Kane)</td>
<td>$2.0 \times 10^{-10}$</td>
<td>5%</td>
</tr>
<tr>
<td>1998 (Saretzky)</td>
<td>$2.0 \times 10^{-9}$</td>
<td>4%</td>
</tr>
<tr>
<td>2002 (WMC)</td>
<td></td>
<td>34% (19% minimum)</td>
</tr>
<tr>
<td>2002 (Nichol &amp; Wilson)</td>
<td>$1.0 \times 10^{-8}$ to $5.0 \times 10^{-7}$</td>
<td></td>
</tr>
<tr>
<td>2003 (Johnston)</td>
<td></td>
<td>4-14%</td>
</tr>
</tbody>
</table>
Best Estimates of Sources for the ARD

• The large-scale water balance in 2002 indicates infiltration through the cover is the dominant source of water into the waste rock and thus the dominant source of ARD.

• Also, the small-scale lysimeters and SoilCover model are not providing representative data on large-scale infiltration. This may be due to:
  • The originally reported till-cover permeability of $2 \times 10^{-10}$ m/s was not achieved across all 132 ha of waste rock.
  • The permeability of the till has degraded through time.
  • Large-scale imperfections due to ongoing waste-rock settlement were not considered.
Summary of Potential Mechanisms for Peak 2002 Acidity Loading

• No significant variations that could be interpreted as causes or effects of the peak acidity loadings in 2002 were noted with:
  • internal temperatures
  • gas levels, and
  • lysimeters.

• On the other hand,
  • several piezometers in and around the waste rock showed unusually high peak water levels in spring 2002,
  • some previously dry piezometers experienced permanent increases in levels (although this could simply be trapped water), and
  • water levels in some piezometers peaked later in 2002 reflecting the spring groundwater travelling along slower flowpaths.
For pH < 3.2,
\[ \log(\text{Acidity}) = -2.270 \times \text{pH} + 9.633 \]
Standard Deviation = 0.4275

For 3.2 \leq pH < 6.0,
\[ \log(\text{Acidity}) = -0.285 \times \text{pH} + 3.243 \]
Standard Deviation = 0.3090

If data was reported as < detection limit, then half detection limit was used.
**Maximum Acidity Loading**

\[ \text{maximum log}_{10}(\text{acidity}) = \text{log}_{10}(\text{flow}) + 1.343 \]

or

\[ \text{acidity (kg/d)} = 22.00 \times \text{flow (m}^3/\text{d}) \]

**Minimum Acidity Loading**

\[ \text{minimum log}_{10}(\text{acidity}) = \text{log}_{10}(\text{flow}) + 0.564 \]

or

\[ \text{acidity (kg/d)} = 3.67 \times \text{flow (m}^3/\text{d}) \]
Maximum log_{10}(acidity) = log_{10}(flow) + 1.343
or
acidity(kg/d) = 22.00 * flow(m^3/d)

Minimum log_{10}(acidity) = log_{10}(flow) + 0.564
or
acidity(kg/d) = 3.67 * flow(m^3/d)
Best-Fit Lognormal Curve:
Mean = 4.1807
Std Dev = 0.3040 log cycles
The graph shows the relationship between monthly flow (as m³/day) and monthly acidity loading (as kg/day). The data points are categorized into different periods:

- Pre-1998 Data
- 1998 - 2001
- 2002
- 2003 (to September)

The graph includes lines for the range of the acidity data:

- Maximum: $\log_{10}(\text{acidity}) = \log_{10}(\text{flow}) + 1.343$
  or $\text{acidity (kg/d)} = 22.00 \times \text{flow (m³/d)}$

- Minimum: $\log_{10}(\text{acidity}) = \log_{10}(\text{flow}) + 0.564$
  or $\text{acidity (kg/d)} = 3.67 \times \text{flow (m³/d)}$

The factor-of-6 range is also indicated on the graph.
Concentration at Peak Loading in May 2002 = $\log_{10}(17569 \text{ mg/L}) = 4.24$

Lognormal Distribution:
mean = 3.957 (9057 mg/L)
std dev = 0.191 log cycles
count = 185

Concentration at Peak Loading in May 2002 = $\log_{10}(17569 \text{ mg/L}) = 4.24$
Average Acidity Loading = 7490 t

Average Flow = 834,000 m³

Most of Cover Installed 1990-1994
Simple Schematic Diagram of the Mass-Balance Mechanism for Acidity Flushing from Waste Rock

- Infiltration through waste-rock channels
- Basal flow towards ARD collection system
- This zone is flushed every year of its acidity
- This zone is only flushed during high flows and water levels, and thus can accumulate acidity for several years
- Cover
- Waste Rock
Conclusion

• Year 2002 produced one of the highest annual flows and the highest monthly flow on record in May.

• Statistically, the annual acidity loading for 2002 was not highly unusual but was still unexpected (once ~ every 50 years), but a loading equal to or greater than May 2002 is expected less than once every 200 years.

• Monthly variations in acidity loadings at a particular value of flow reflect the range-of-six variation in aqueous acidity concentrations resembling a lognormal distribution.
Conclusion

- Waste rock not well flushed by groundwater in some past years was flushed in 2002, releasing additional, stored acidity.

- This review of data pertaining to potential mechanisms for the peak acidity loadings in 2002 has led to the geochemical mass-balance mechanism as the best explanation. Under this mechanism, a certain amount of acidity is generated each year in zones rinsed by water. If all the acidity is not fully flushed out each year due to low flows, the remainder accumulates each year until a high flow removes the accumulation as a large loading.
Conclusion

- Based on the geochemical mass-balance mechanism, the till cover makes little difference to the annual acidity production, but can influence the amount flushed annually from the waste rock.

- Under this mechanism, the high flush in 2002 likely removed much of the accumulated acidity in relatively normal flowpaths, but the relatively low flush in 2003 (to September) has led to new accumulation.
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