Equity Silver Mine

Over 10 Years Experience with Dry Covers

By: Mike Aziz & Keith Ferguson
• Annual ARD volumes averaged 852,000 m$^3$ from 1985 to 2003

<table>
<thead>
<tr>
<th></th>
<th>pH</th>
<th>Acidity</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
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<tbody>
<tr>
<td>Avg</td>
<td>2.6</td>
<td>8080</td>
<td>96</td>
<td>1209</td>
<td>142</td>
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<tr>
<td>Min</td>
<td>2.1</td>
<td>1138</td>
<td>10</td>
<td>84</td>
<td>21</td>
</tr>
<tr>
<td>Max</td>
<td>3.2</td>
<td>17200</td>
<td>283</td>
<td>2730</td>
<td>394</td>
</tr>
</tbody>
</table>

All values in mg/L except pH
Lime Use 1985 to 1990

- Lime Use (t/yr): 4000, 4500, 5000, 5500, 7000, 8000
1991 Evaluation of Cover Alternatives

- Closure approaching - ARD getting worse!
  - ARD increasing at 10% per year (lime consumption)
  - lime use correlated with waste rock addition?
  - ARD at No. 1 dam seepage decreasing
  - other sites suggest a reduction after mining

- 1991 bond review
  - expect rather sharp reduction after waste rock dumping stopped, then period of less rapid decline, then levelling off
  - maximum values based on assumed acid conc.
  - significant reduction of ARD expected after installing a compacted till cover
### 1991 Comparison of Covers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing Cover</th>
<th>Compacted Cover</th>
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</thead>
<tbody>
<tr>
<td>% Increase/yr</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Peak lime (t)</td>
<td>10,000 – 15,000</td>
<td>7,500 – 10,000</td>
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<tr>
<td>Peak period (yrs)</td>
<td>2 – 5</td>
<td>1 – 5</td>
</tr>
<tr>
<td>% Decline/yr</td>
<td>4 – 10</td>
<td>10</td>
</tr>
<tr>
<td>Low-level lime (t)</td>
<td>2,000 – 3,500</td>
<td>600 – 1,200</td>
</tr>
<tr>
<td>Avg. Lime (t)*</td>
<td>2,650 – 5,980</td>
<td>1,080 – 2,270</td>
</tr>
<tr>
<td>Potential Bond ($)</td>
<td>$34.2 - $56.6 M</td>
<td>$22.8 - $32.1 M</td>
</tr>
</tbody>
</table>

* over 100 years
1991 Technical Committee Lime Scenarios

Time

Lime

Existing Covers

Compacted Clay Cover
History of the Equity Cover

- Late 1980’s placed 1.0 m uncompacted till cover over flat sections of terraced waste rock dump
- 1990 - 1997 – resloped waste dumps and replaced uncompacted till cover with a 0.5 m compacted plus 0.3 m uncompacted till cover
- Progressive revegetation of cover from 1992 to 1998
- Average cost of cover $35,000/ha (includes reslope, cap construction, and seeding)
Uncompacted cover
Main Waste Dump Cover
Waste Dump Cover Repairs & Maintenance
Cover and Ditch R&M Costs

- Repair of Bessemer runoff ditch by Tercon
- General erosion repair in ditches and pulling of woody species
Cover Monitoring

- Infiltration through cover
- Moisture content in cover
- Internal oxygen content
- Internal temperature
- Seepage chemistry and volume
- Overall ARD collection chemistry and volume
- Lime consumption
- Runoff volumes off cover
U of Saskatchewan Studies

- 5 year study to investigate performance of the cover started in 1993
  - measurements of water content and suction in the cover
  - modelling of cover performance
  - erosion study
- saturated layer that prevents oxygen ingress
- measured 4% infiltration
- modelled 3% infiltration
ARD Seeps
Flush Years

ST Pit added

FIGURE 3-6. Time-Series Plot of Annual Flow (m$^3$) and Annual Acidity Loading (t) for the Main ARD Pond (see also Figures 3-7 and 3-8). NOTE: these and other diagrams with annual flows to the Main ARD Pond include water from the Southern Tail Pit starting in 1994, leading to an approximately 10% increase in annual flow from 1994 onward and thus masking the effect of the cover.

Reproduced from MDAG Report to Equity 2004 (Morin & Hutt)
Actual and Projected Lime Use

Actual Lime Use:
- 1991 Com. $32 M
- 1995 Com. $21.6 M
- 1995 Com. $24 M
- 2000 Com. $23.55 M
What do we know?

- Lime use has dropped from peak and has a general decreasing trend, but predicted decrease much greater.
- Lime use is significantly higher than some early projections based on predicted cover performance.
  - much higher ARD volumes than expected even with added flows accounted for.
- Acidity loading corresponds to precipitation/runoff events.
  - no significant change in concentration year to year only seasonal variations based on dilution and flushing.
- About 3 day delay from maximum precipitation/runoff to seep flow increase (quick response).
- Increase in some ARD flows seems to be related to groundwater increases (slower response).
Where Does all the ARD Come From?

- Main Zone pit groundwater
- Tailing pond groundwater
- Southern Tail pit groundwater
- Groundwater mound in dump
- Regional groundwater (inc. leaking upslope diversion ditches)
- Infiltrating runoff around cover
- Leaking dump runoff ditches
- Infiltration through cover
URS Hydrology Study 1999 - 2001

- Piezometers installed in 1999 (15) and 2000 (13) in and around the waste rock dumps, plantsite, and pits to evaluate theory of groundwater coming in from other sources.
- Identified a potential area between Southern Tail and Main Zone pits that might convey shallow groundwater or diversion ditch runoff to waste dump and form ARD.
- The study also found that the Southern Tail pit adds some water other than the outflow, the Main Zone pit should be kept below the fractured bedrock elevation, and the tailings pond is adding a low volume to the collection system.
Where Does all the ARD Come From?

- Main Zone pit groundwater
- Tailing pond groundwater
- Southern Tail pit groundwater
- Groundwater mound in dump
- Regional groundwater (inc. leaking upslope diversion ditches)
- Infiltrating runoff around cap
- Leaking dump runoff ditches
- Infiltration through cap
Leaky diversion ditch or shallow groundwater into rubble zone &/or fault zone

Cut-off trench prior to waste dumps to intercept flow
Consequences of getting the hydrology wrong

- **1997 – Diverted low strength ARD to environment**
  - Insufficient ARD pumping capacity at Main Pond
  - Decreased ARD collection catchment, but only minor pumping improvements – see if ARD could be decreased

- **2002 – Diverted low strength ARD, under-treated ARD**
  - Insufficient ARD pumping capacity at Main Pond
  - Insufficient treatment capacity
  - Insufficient ARD storage capacity

- **Extensive upgrades to the ARD collection and treatment system**
  - New pumphouse and pipelines for Main Pond (2002)
  - Increased ARD storage and treated water capacity (2002)
  - Working on significantly increasing ARD storage (2003 - ?)
Water Management Consultants

- Produced a groundwater/surface water model based on flows and groundwater levels
- Conclusions:
  - Majority of ARD collected derived from local rainfall and snowmelt (60 to 80%)
    - Direct runoff from waste dump ~ 30%
    - Infiltration through cover ~ 30 to 50%
    - Discharge of groundwater below diversion ditches
  - Groundwater from outside the collection system (grdwr, MZ pit, tailings) ~ 10 to 15% or 35 to 40% of ARD collected
  - Infiltration through or around cover ~ 20 to 35%
    - Infiltration not through compacted cover material but through cover discontinuities (cracks or construction flaws)
## Cover Studies Since Closure

<table>
<thead>
<tr>
<th>When</th>
<th>Who</th>
<th>What</th>
<th>Main Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>Swanson (U of Sask)</td>
<td>modelling of soil cover (SoilCover)</td>
<td>3% net infiltration, hydraulic cond $2.0 \times 10^{-10}$ m/s</td>
</tr>
<tr>
<td>1996</td>
<td>O'Kane (U of Sask)</td>
<td>original monitoring of soil cover</td>
<td>compacted layer well saturated, infiltration limited, oxygen reduced</td>
</tr>
<tr>
<td>1998</td>
<td>Saretzky (U of Sask)</td>
<td>first water balance of waste dump</td>
<td>$\text{ARD} = 9% \text{ runoff}, 11% \text{ infiltration}, 1% \text{ storage}, 79% \text{ groundwater}$</td>
</tr>
<tr>
<td>1998</td>
<td>Merz (Golder)</td>
<td>site hydrology study (snowmelt)</td>
<td>review of pumping and storage capacities for ARD</td>
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<tr>
<td>2000</td>
<td>Wilber (URS)</td>
<td>evaluation of groundwater contribution to ARD</td>
<td>groundwater above pits may be influencing ARD, keep MZ low</td>
</tr>
<tr>
<td>2001</td>
<td>Reinson (UBC)</td>
<td>field permeability testing on cover</td>
<td>hydraulic conductivities between $7.2 \times 10^{-8}$ to $3.7 \times 10^{-6}$ m/s</td>
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<tr>
<td>2001</td>
<td>Wilbur (URS)</td>
<td>evaluation of groundwater contribution to ARD</td>
<td>identified area between pits as potential groundwater conduit</td>
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<tr>
<td>2002</td>
<td>Parkinson (Klohn)</td>
<td>geophysical investigation into groundwater</td>
<td>diversion ditches or fault zone could be adding to ARD collection</td>
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<tr>
<td>2002</td>
<td>Smith (WMC)</td>
<td>water balance of waste dump</td>
<td>infiltration through or around cover 20 to 35%, discontinuities</td>
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<tr>
<td>2003</td>
<td>Nichol (UBC)</td>
<td>cover infiltration monitoring in field</td>
<td>hydraulic conductivities between $1.0 \times 10^{-8}$ to $5.0 \times 10^{-7}$ m/s</td>
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<td>2003</td>
<td>Johnston (UBC)</td>
<td>cover infiltration modelling</td>
<td>infiltration ranges between 4 to 14% through cover</td>
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<td>2003</td>
<td>O'Kane (for INAP)</td>
<td>long term performance of dry covers</td>
<td>upper 10 cm of compacted layer evolving through wet/dry cycles</td>
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<tr>
<td>2004</td>
<td>Morin &amp; Hutt (MDAG)</td>
<td>evaluation of ARD mechanisms</td>
<td>geochemical mass balance mechanism most likely for ARD loadings</td>
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<td>2004</td>
<td>Weeks (UBC)</td>
<td>3D energy model of cover</td>
<td>slope aspect and angle will influence evaporation and infiltration</td>
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</table>
Uncertainties and Challenges

• Identify source of additional ARD & evaluate cover performance
  – tracer study on dump cover and beyond
  – testing of diversion ditches
  – regional groundwater cut-off trench
  – problems with measuring direct runoff

• Maintenance requirements
  – erosion and woody species over long term

• Long-term evolution of cover
  – testing of cover integrity with time
  – root penetration

• New technologies
  – cover improvements
Conclusions

- Cover construction was straightforward and maintenance has been simpler and less costly than expected
- The Equity cover has reduced ARD production, but not to the degree that was predicted by various models
- Waste rock dump water balances are complicated
  - best to ensure the collection & treatment systems are designed for more volume/acidity than expected
- Other sources of water have been identified to be contributing to ARD production, but have not been able to quantify yet
- Further studies of water sources and long-term performance of the cover are required.
- The construction and monitoring of the Equity cover has progressed the knowledge base on covers for Equity and other sites and will continue to do so into the future
## Post Closure Studies Related to Cover

<table>
<thead>
<tr>
<th>Date</th>
<th>Study Title</th>
<th>Author(s)</th>
<th>Affiliation</th>
<th>Category</th>
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<tbody>
<tr>
<td>Jan-95</td>
<td>Predictive Modelling of Moisture Movements in Engineered Soil Covers for Acid Generating Mine Wastes</td>
<td>Darren Swanson, University of Saskatchewan</td>
<td>Master’s Thesis</td>
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<tr>
<td>Aug-95</td>
<td>A Report on the Performance of the Engineered Soil Cover System at Equity Mines Ltd.</td>
<td>M. O’Kane &amp; GW Wilson, University of Saskatchewan</td>
<td>Master’s Thesis</td>
<td></td>
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<tr>
<td>Oct-95</td>
<td>An Erosion Study on the Engineered Soil Cover System at Equity Silver Mines Ltd. Final Report</td>
<td>Lawrence Owuputi, University of Saskatchewan</td>
<td>Master’s Thesis</td>
<td></td>
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<tr>
<td>Nov-95</td>
<td>Thermal Analysis of Equity Mine Waste Rock Dump</td>
<td>Greg Newman, University of Saskatchewan</td>
<td>Master’s Thesis</td>
<td></td>
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<tr>
<td>Oct-96</td>
<td>Instrumentation and Monitoring of an Engineered Soil Cover System for Acid Generating Mine Waste</td>
<td>Mike O’Kane, University of Saskatchewan</td>
<td>Master’s Thesis</td>
<td></td>
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<tr>
<td>Jul-97</td>
<td>ARD Pumping System Capacity Assessment and Improvements</td>
<td>Placer Dome Project Development Division</td>
<td>Master’s Thesis</td>
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<tr>
<td>Aug-98</td>
<td>Equity Silver Mine Hydrology Study</td>
<td>Russell Merz, Golder Associates</td>
<td>Master’s Thesis</td>
<td></td>
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<tr>
<td>Oct-98</td>
<td>Hydrological Characterization of a Sulphide Waste Rock Dump</td>
<td>Greg Saretzky, University of Saskatchewan</td>
<td>Master’s Thesis</td>
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<tr>
<td>Sep-00</td>
<td>Evaluation of Groundwater Contribution to ARD Seeps</td>
<td>Steve Wilbur, URS-Norecol Dames &amp; Moore</td>
<td>Master’s Thesis</td>
<td></td>
</tr>
<tr>
<td>Apr-01</td>
<td>Summary of 2000 Groundwater Investigation and Recommended Remedial Action, Equity Silver Mine</td>
<td>Steve Wilbur, Dave Harpley, URS Corp.</td>
<td>Master’s Thesis</td>
<td></td>
</tr>
<tr>
<td>Nov-01</td>
<td>Equity Division: Waste Dump and Tailings Dam Areas DC Resistivity and IP Geophysical Surveys</td>
<td>Graham Parkinson, Klohn Crippen</td>
<td>Master’s Thesis</td>
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<tr>
<td>Dec-02</td>
<td>Equity Silver - Waste Dump Water Balance</td>
<td>Rod Smith, Water Management Consultants</td>
<td>Master’s Thesis</td>
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<tr>
<td>Mar-03</td>
<td>Evaluation of the Long Term Performance of Dry Covers for INAP</td>
<td>M. O’Kane, O’Kane Consultants Inc.</td>
<td>Master’s Thesis</td>
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<tr>
<td>Dec-03</td>
<td>Case Study and Sensitivity Analysis of the Performance of the Waste Rock Cover System at Equity</td>
<td>K. Johnston, UBC</td>
<td>Master’s Thesis</td>
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<tr>
<td>Dec-03</td>
<td>Equity Division - 2002 Review and Prediction of Acid Rock Drainage</td>
<td>Morin &amp; Hutt, MDAG</td>
<td>Master’s Thesis</td>
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<tr>
<td>Oct-04</td>
<td>Equity Division - Review of 2003 ARD and Assessment of ARD Mechanisms</td>
<td>Morin &amp; Hutt, MDAG</td>
<td>Master’s Thesis</td>
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