Passive Treatment of Mining Influenced Water: From Bench Scale to O & M

BIOCHEMICAL REACTOR CONSTRUCTION, MINE POOL CHEMISTRY CHANGES, & O & M GOLINSKY MINE, CALIFORNIA

Jim Gusek, Sovereign Consulting Inc., and Rick Weaver, US Dept. of Agriculture, Forest Service
Golinsky Mine, Trinity National Forest

I. BCR Design & Construction

II. Mine Pool Improvements

III. Operation & Maintenance
Site Location & Project History

Site/Project History

- Mine Operates 1904 to 1938 (copper & gold)
- USFS acquires property in 1944 through purchase
- 2004 - Bench Test Construction & Operation
- 2004 – Design/build buried pipeline
- 2004 – 2006 Pilot Scale Construction & Operation
- 2006 – Pilot decommissioning
- 2007 - Full Scale Module 1 Design
- 2010 – Full Scale Construction
- 2011 – Full Scale Start-up
- 2012-2016 Vicinity Drought
- 2016 – O&M Activity
Bench Test & Pilot Test Setup

17 Weeks Bench Flow Range: 8.5 to 16.4 Liters/day

Pilot Average Flow: 0.9 gpm
## Mine Water Chemistry – Pilot Testing

<table>
<thead>
<tr>
<th>Influent Water (Lower Portal)</th>
<th>Pilot BCR Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH – 2.7</td>
<td>pH – 7.2</td>
</tr>
<tr>
<td>Fe – 73 mg/L</td>
<td>Fe – 0.8 mg/L</td>
</tr>
<tr>
<td>Al – 23 mg/L</td>
<td>Al – 0.06 mg/L</td>
</tr>
<tr>
<td>Mn – 0.85 mg/L</td>
<td>Mn – 2.5 mg/L</td>
</tr>
<tr>
<td>Zn – 37 mg/L</td>
<td>Zn – 0.1 mg/L</td>
</tr>
<tr>
<td>Cu – 12 mg/L</td>
<td>Cu – &lt;0.003 mg/L</td>
</tr>
<tr>
<td>Ni – 0.031 mg/L</td>
<td>Ni – 0.007 mg/L</td>
</tr>
<tr>
<td>Cd – 0.47 mg/L</td>
<td>Cd – 0.006 mg/L</td>
</tr>
<tr>
<td>SO$_4$ – 664 mg/L</td>
<td>SO$_4$ – 488 mg/L</td>
</tr>
</tbody>
</table>
Passive Treatment Chemistry 101

Redox Reactions:

**SO₄²⁻ + 2 CH₂O → HS⁻ + 2HCO₃⁻ + H⁺**  
*(Sulfate reduction and neutralization by bacteria)*

**Zn⁺² + HS⁻ → ZnS (s) + H⁺**  
*(Sulfide precipitation)*

**Fe⁺³ + 3 H₂O → Fe(OH)₃ (s) + 3 H⁺**  
*(Hydroxide precipitation)*

**H⁺ + CaCO₃ → Ca⁺² + HCO₃⁻**  
*(Limestone dissolution)*
## Module 1 Design Chemistry

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow, L/min</td>
<td>37.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Flow, gpm</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>pH S.U.</td>
<td>3.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Fe, mg/L</td>
<td>27</td>
<td>73</td>
</tr>
<tr>
<td>Cu, mg/L</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Zn, mg/L</td>
<td>67</td>
<td>37</td>
</tr>
<tr>
<td>Cd, mg/L</td>
<td>0.73</td>
<td>0.47</td>
</tr>
<tr>
<td>Al, mg/L</td>
<td>31</td>
<td>23</td>
</tr>
<tr>
<td>Mn, mg/L</td>
<td>0.42</td>
<td>0.85</td>
</tr>
<tr>
<td>Sulfate mg/L</td>
<td>&lt;500</td>
<td>664</td>
</tr>
</tbody>
</table>
Mine, Pipeline, and Abandoned Limestone Quarry
Phased Module Implementation

- Portal flow data suggests peak of 90 gpm during wet months
- No available space at the mine site itself
- Available space at the quarry only has room for 30 gpm
- Site access is restricted; it’s difficult to build full PTS capacity in a single construction season
- Limited funding supports design of 10 gpm “starter” module and monitor to see if additional modules are necessary
Overall Design Philosophy

• All flows by gravity
• Biochemical reactor sized for 10 gpm / 38 liters minute
• Any by-passed flow (>10 gpm) would be neutralized by treated water in a mixing pond
• Mixing pond effluent would be infiltrated into native ground in a “Flow Dispersion Zone”
• “Tweak” substrate recipe based on experience at other sites
## BCR Substrate Modification

<table>
<thead>
<tr>
<th>Component</th>
<th>Pilot BCR</th>
<th>Full BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice Hulls</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Wood Chips</td>
<td>40%</td>
<td>50%</td>
</tr>
<tr>
<td>Hay</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Limestone</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Manure(^1)</td>
<td>10%</td>
<td>&lt;0.1%</td>
</tr>
</tbody>
</table>

Manure (and 6 cy of depleted pilot substrate) rototilled into upper 12 inches of substrate
**Construction Challenges**

• Lake levels are the lowest in years due to drought  
  • Good news: mobilization site close to Shasta Dam (2.4 miles from beach head)  
  • Bad news: off-loading barges will be difficult on sloping shore at beach head  

• Drought ends from El Nina rains as bid walk is conducted (March 2010)  

• Lake levels rise, and rise, and rise some more...  

• Preferred mobilization site is submerged; alternate site is 6.9 miles from beach head
Lake level recovery: too much of a good thing

Initial Contractor Mobilization Site (2.4 miles)

Final Contractor Mobilization Site (6.9 miles)
Construction Challenges (Continued)

• Storing materials at a very constricted site
Construction Challenges (Continued)

- Ground conditions in one corner of the quarry require field modification

BCR Footprint reduced by 3.6%
Construction Challenges (Continued)

• Delayed start due to weather and storm water BMP’s puts project behind schedule and reduced available construction budget
• Ground conditions in the mixing pond footprint spook contractor
• Mixing pond is dropped from the contractor’s work scope (see paper [Gusek, 2011] for details)
• Flow Dispersion Zone design is modified to minimize imported riprap
Golinsky BCR Construction, 2010 (with ARRA Funding)

Construction Cost: $1.3 million (about $0.012 per gallon for 20-yr life)
Final BCR As Built (January, 2011)
BCR Module 1 Commissioning Challenges

• Portal 3 is the only mine pool plumbed into the quarry when the BCR is ready for commissioning (we used it for soil moisture, dust control)

• **Portal 3 sulfate concentration is only 8 to 10 mg/L**

• Lower Portal pipeline is plugged with iron precipitates;

• Inclement weather prevented LP maintenance and the BCR filled with rain water

**Solutions**

- Added 20 lbs or 9.1 kg of Epsom salt to BCR inflow
- Added a 30 lbs or 13.4 kg “teabag” of agricultural gypsum to flow distribution vault
- Influent sulfate 14 mg/L; effluent 4 mg/L
- Lower Portal plumbed in January 25th 2011, no “transition” (sulfate @1,127 mg/L; pH 2.7)
BCR Receiving Lower Portal MIW
(October 12, 2016)
# BCR Results
*(6 Lower Portal MIW events)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>2.7 s.u.</td>
<td>6.45 s.u.</td>
</tr>
<tr>
<td>Iron</td>
<td>97.2 mg/L</td>
<td>6.1 mg/L</td>
</tr>
<tr>
<td>Aluminum</td>
<td>28.6 mg/L</td>
<td>0.03 mg/L</td>
</tr>
<tr>
<td>Copper</td>
<td>19.3 mg/L</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Zinc</td>
<td>40.0 mg/L</td>
<td>0.5 mg/L</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.40 mg/L</td>
<td>0.005 mg/L</td>
</tr>
<tr>
<td>Calcium</td>
<td>19 mg/L</td>
<td>206 mg/L</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.6 mg/L</td>
<td>2.1 mg/L</td>
</tr>
<tr>
<td>Sulfate</td>
<td>728 mg/L</td>
<td>324 mg/L</td>
</tr>
<tr>
<td>ORP</td>
<td>354 mv</td>
<td>-217 mv</td>
</tr>
</tbody>
</table>

97% metal removal efficiency in May 2011
PART II
PORTAL 3 MINE POOL IMPROVEMENTS
Changes in Portal 3 Chemistry 2004-2016

Lower Portal Mine Pool
Drain-down begins

2004
Changes in Portal 3 Chemistry 2004-2016
Changes in Portal 3 Chemistry 2004-2016

2007
Changes in Portal 3 Chemistry 2004-2016
Portal 3 Water Chemistry Improvements

0.07 to 0.11 gpm of Lower Portal MIW satisfies metal load in Portal 3 based on sulfate, zinc, and copper.
Final Thoughts (Parts I & II)

• Construction Cost: $1.3 million – ARRA funding with supplementary USFS funds

• Seven year span from initial bench tests in late 2003 to startup in late 2010 – fully commissioned in June 2011

• Safety record exemplary for remote site, heat stress, multiple water crossings

• After five years, system appears to be performing as intended – no surprises (yet)

• No ill effects due to prolonged drought
PART III

OPERATION & MAINTENANCE
BCR Commissioned in June 2011 & function as designed through 2012.
In 2012 following dry season, flow data logger malfunctioning at BCR
Equipment mobilized to site with Landing Craft
Influence of vegetation potentially adversely affecting iron removal
Mini excavator used to pull willows
Mini excavator moving vegetation removed from BCR
BCR after willow removal
Repairing BMPs on access road using hand tools and mini excavator
Clearing access road of vegetation
Pipelines from Lower adit.
Iron hydroxide sludge blockage
Upper Adit
Link Seal and Stainless Steel Flexible Coupling installed to repair leak & stabilize pipe at bulkhead
Leak at Saddle Tee on Upper Adit Pipe
Repairing Saddle Tee with Romax Clamp
Trash bag stuck in pipe causing plug
Lower Adit Bat Gate
Sock Filter over Floor Drain
Winter to summer flow rate decrease from 4.5 gpm to 1.5 gpm between April 25 and June 6, 2016. Estimated cumulative total of 233,000 gallons received by the BCR.
Changing battery in data logger at BCR influent flume. Flow was 0.75 GPM on 10/12/16
Pipes replaced due to excessive iron hydroxide deposition
BCR at low water level on October 16, 2016 at end of dry summer
BCR on October 19, 2016 after 4 to 5 inches of rain in four days
# Mass Removal Rates from Spring Monitoring

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BCR Influent</th>
<th>BCR Effluent</th>
<th>Pounds Removed During Reporting Period</th>
<th>Pounds Removed per day During Reporting Period</th>
<th>Removal Efficiency During Reporting Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfate (mg/L)</td>
<td>1,400</td>
<td>1,500</td>
<td></td>
<td></td>
<td>See Note 1 Below</td>
</tr>
<tr>
<td>Dissolved Aluminum (µg/L)</td>
<td>34,000</td>
<td>&lt;50</td>
<td>66.1</td>
<td>1.57</td>
<td>100%</td>
</tr>
<tr>
<td>Dissolved Iron (µg/L)</td>
<td>85,000</td>
<td>150,000</td>
<td></td>
<td></td>
<td>See Note 2 Below</td>
</tr>
<tr>
<td>Dissolved Cadmium (µg/L)</td>
<td>710</td>
<td>1.8</td>
<td>1.4</td>
<td>0.03</td>
<td>99.7%</td>
</tr>
<tr>
<td>Dissolved Copper (µg/L)</td>
<td>27,000</td>
<td>2.5</td>
<td>52.5</td>
<td>1.25</td>
<td>100%</td>
</tr>
<tr>
<td>Dissolved Manganese (µg/L)</td>
<td>920</td>
<td>3,300</td>
<td></td>
<td></td>
<td>See Note 2 Below</td>
</tr>
<tr>
<td>Dissolved Zinc (µg/L)</td>
<td>76,000</td>
<td>13,000</td>
<td>122.5</td>
<td>2.92</td>
<td>83%</td>
</tr>
</tbody>
</table>

Notes:

1. Increase in sulfate concentrations may be attributable to reduced biological activity (as a result of no flow to the BCR) and associated sulfate reduction. If this is the case, future samples events should see increased sulfate reduction.

2. It is suspected that increased dissolved iron and manganese concentrations are the result of iron precipitate collecting in the discharge piping.
Conclusion of Spring Monitoring Report

- Monitoring observations and data collected by ECM have concluded that the BCR is operating within design parameters and is effectively removing metals from mine impacted water.

- The BCR appears to be treating the mine drainage successfully and the efficiency of removal for aluminum, cadmium, and copper is close to 100%, with zinc near 83% removed.
Are the exposure assumptions, toxicity data, cleanup levels, Removal Action Objectives used at the time of the removal action (RA) still valid?

- Reduce or eliminate the release of acidity and heavy metals from the Site to surface water and meet ARARs,

- Reduce or eliminate the release of acidity and heavy metals to from the Site to groundwater and meet ARARs, and

- Reduce or eliminate the potential for exposure to humans, aquatic and terrestrial biota from ingestion or direct contact with AMD and potentially contaminated aquatic life.

Data indicate that the BCR is effective at treating MIW at the design flow rate of 10 gpm. The exposure assumptions, toxicity data, cleanup levels, and RAOs used at the time of the RA are still valid & the BCR system that was installed is protective.
Storm water runoff in swale
only MIW discharged from site
Final Thoughts

• Phased design approach minimizes risk
• Bulkheading underground mine workings is not always a good idea (ARD is going to find its way out)
• Passive treatment is **LOW** maintenance, not **NO** maintenance
• Removal Action assumptions still valid; BCR system is protective
• Special thanks to:
  • Brad Shipley (ret.), USFS P.O. 2003? to 2016, and
  • ECM Consultants, the current site monitoring and O & M contractor
Questions/Discussion??