SECTION  B.9

RISK-BASED ANALYSIS OF ACID ROCK DRAINAGE
AS IT PURPORTS TO WASTE ROCK DUMPS

George Fennemore
Geomega
Risk-Based Analysis of Acid Rock Drainage as it Purports to Waste Rock Dumps

by:

Andy Davis, Ph.D. Geomega
George Fennemore, Ph.D. Geomega
Risk-Based Analysis

Source
Characterize Constituents of Concern
Characterize Source Extent

Transport Pathway
Flow Pathway
Attenuation Mechanisms

Receptors
Human
Ecological
Waters of the State
Future Use
Risk-Based Remedial Strategy
Historical Dumps

Identify Temporal Waste Rock NCV Consortium

- YES: Potential FeS$_2$ Oxidation?
- NO: Natural Revegetation

- YES: Vadose-Zone Percolation?
- NO: Cover with ANP Rock

- YES: Lithologic Attenuation?
- NO: Cover with ANP Rock Run-on Control

YES: Hydrogeologic Pathway Analysis

YES: Extrapolate to Future Waste Rock Reactivity
## Waste Rock Program Data Needs

**Historical**
- Emplacement Era
- Leached?
- Topography
- Vegetation Cover

**Geological**
- Lithology:
  - In Dump Substrate
  - Mineralogy
  - SCS Soil Maps

**Geochemical**
- ANP/AGP
- MWMP?
- Humidity Cells
- T/O₂ Profiles
- Bulk Chemistry
- Pore Water Chemistry
- Microbial Activity
- Substrate Kd

**Geotechnical**
- Stratification
- Porosity
- Permeability
- Bulk Density
- Particle Size
- Topography/
  - Contours
  - Slope Stability

**Hydrologic**
- Precipitation
- Infiltration Rate
- Evaporation Rate
- Moisture Profile
- Spring Location
- Storm Water Drainage
- Surface Flows
Waste Rock Oxidation, ARD Fate and Transport Model
Oxide Waste Rock Dump Profiles
(Boring B-24, Kimbley Oxide Waste Rock Dump)

- **pH**
- **Percent Oxygen**
- **Specific Conductivity (micromhos)**
- **Temperature (Fahrenheit)**

S = 200 ppm
Unoxidized Sulfide Waste Rock Dump
(Boring B-11, Sunshine Waste Rock Dump)

- pH

Depth (feet)

- Specific Conductivity (micromohs)

- Overdump
  - S = 10,000 ppm

- Bedrock
  - S = 8,600 ppm

- Percent Oxygen

Depth (feet)

- Temperature (Fahrenheit)
Oxidized Sulfide Waste Rock Dump (Boring B-10, Juniper Waste Rock Dump)

- **pH**
  - Overdump: S = 400 ppm
  - Bedrock: S = 55,700 ppm

- **Specific Conductivity (micromohs)**

- **Percent Oxygen**

- **Temperature (Fahrenheit)**
Infiltration Basins in Waste Rock Dumps
# Case Study: Jupiter Dump

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Construction:</strong></td>
<td>1931 - 1970</td>
</tr>
<tr>
<td><strong>Height:</strong></td>
<td>150 feet</td>
</tr>
<tr>
<td><strong>Volume:</strong></td>
<td>13 million cubic yards</td>
</tr>
<tr>
<td><strong>Footprint:</strong></td>
<td>2.3 million square feet (53 acres)</td>
</tr>
<tr>
<td><strong>Elevation:</strong></td>
<td>6670 feet (at top)</td>
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</table>
Pyrite Oxidation

Two-dimensional diffusion-reaction model based on the Davis-Ritchie Approach

Model Parameters
Dimensions
Porosity 0.30
Particle Size 3 mm
Pyrite Content 9%

Calibration Parameters
Diffusion Rate
Calibration of Pyrite Oxidation Model to Waste Rock Profiles
Predicted Oxidation in Jupiter Dump
After 60 Years
Waste Rock Chemistry

Bulk Chemistry (in mg/kg)

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
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<tbody>
<tr>
<td>Al</td>
<td>11,900</td>
</tr>
<tr>
<td>Ca</td>
<td>1,510</td>
</tr>
<tr>
<td>Cu</td>
<td>2,550</td>
</tr>
<tr>
<td>Fe</td>
<td>112,000</td>
</tr>
<tr>
<td>Zn</td>
<td>764</td>
</tr>
</tbody>
</table>

Mineral Phases

Quartz, Pyrite, Gypsum, Albite, Sphalerite, ...
Schematic of Proposed Waste Rock *in situ* Percolation Sampling Equipment
## Predicted Versus Measured Dissolved Concentrations

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Measured</th>
<th>Predicted</th>
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<tbody>
<tr>
<td>pH</td>
<td>1.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Al</td>
<td>1570</td>
<td>2000</td>
</tr>
<tr>
<td>As</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Cd</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Ca</td>
<td>500</td>
<td>394</td>
</tr>
<tr>
<td>Cr</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Cu</td>
<td>141</td>
<td>253</td>
</tr>
<tr>
<td>F</td>
<td>62</td>
<td>56</td>
</tr>
<tr>
<td>Fe</td>
<td>10500</td>
<td>10120</td>
</tr>
<tr>
<td>Mg</td>
<td>149</td>
<td>24</td>
</tr>
<tr>
<td>Mn</td>
<td>164</td>
<td>220</td>
</tr>
<tr>
<td>Ni</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Ag</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>37800</td>
<td>40500</td>
</tr>
<tr>
<td>Zn</td>
<td>255</td>
<td>306</td>
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</tbody>
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Fate and Transport

Transport Properties
  Rate
  Direction

Aquifer Properties
  Lithology
  Groundwater Chemistry

Reactions
  Hypothetical
  Observed
# Predicted versus Observed Water Quality

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Standard</th>
<th>Source</th>
<th>Predicted</th>
<th>W1-b</th>
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<tbody>
<tr>
<td>6.5-8.5</td>
<td>2.67</td>
<td>7.1</td>
<td></td>
<td>6.14</td>
</tr>
<tr>
<td>0.05-0.2</td>
<td>893</td>
<td>0.25</td>
<td></td>
<td>0.229</td>
</tr>
<tr>
<td>0.005</td>
<td>0.328</td>
<td>0.25</td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td>125-150</td>
<td>741</td>
<td>624</td>
<td></td>
<td>863</td>
</tr>
<tr>
<td>0.05-0.1</td>
<td>226</td>
<td>182</td>
<td></td>
<td>183</td>
</tr>
<tr>
<td>0.1</td>
<td>2.35</td>
<td>1.76</td>
<td></td>
<td>0.16</td>
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<tr>
<td>250-500</td>
<td>12,800</td>
<td>5,777</td>
<td></td>
<td>3,210</td>
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<tr>
<td>5</td>
<td>116</td>
<td>58</td>
<td></td>
<td>53</td>
</tr>
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<table>
<thead>
<tr>
<th>Analyte</th>
<th>Predicted at 1600 feet</th>
<th>Background</th>
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<tbody>
<tr>
<td>TDS</td>
<td>1960</td>
<td>1860</td>
</tr>
<tr>
<td>TSS</td>
<td>970</td>
<td>970</td>
</tr>
<tr>
<td>Copper</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Manganese</td>
<td>3</td>
<td>0.147</td>
</tr>
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</table>
Conclusions

Coupling of reactive transport models resulted in simulations verified by field data. Simulations were used to represent and predict the extent of potential risks associated with acid rock drainage.
<table>
<thead>
<tr>
<th>Issue</th>
<th>Remedy</th>
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<tbody>
<tr>
<td>Accurate prediction of pyrite oxidation</td>
<td>Borehole logging for calibration profiles</td>
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<tr>
<td>Accurate prediction of drainage water quality</td>
<td>Solid waste rock chemistry, mineralogy</td>
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<tr>
<td>Accurate prediction of fate and transport</td>
<td>Calibrated flow model, site-specific observation of attenuation mechanisms</td>
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</tbody>
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