PENN MINE ECOSYSTEM RESTORATION PROJECT

Effective Soil Remediation and Revegetation Techniques on Pyritic Mineral Deposits

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Ecological Consultants
Pyritic Waste Rock Deposits = Unprocessed Ore and Mine Tailings
Acid Rock Drainage

Pyrite + Oxygen + Water $\rightarrow$ Ferric Hydroxide + Sulfuric Acid

High Acidity/Low Pore Water pH + Elevated Heavy Metal Concentrations
Site History
Site History
Site History
Project Alternatives for Long-term Solution
Project Objectives

- Improve Water Quality
- Restore Habitat
- Monitor
Restoration Design and Implementation
Restoration Design Elements
Soil Remediation – Moderate Slope Treatment

1. Mine Waste Rock
2. Residual Acidic Mine Waste
3. Dicalcium Silicate + Calcium Phosphate
4. Cover Soil
5. Composted Organic Matter
Soil Remediation – Steep Slope Treatment

1. Mine Waste Rock
2. Residual Acidic Mine Waste
3. Dicalcium Silicate + Calcium Phosphate
Moderate and Steep Slope Treatment
Moderate Slope Treatment
Moderate Slope Treatment
Creek Channel Restoration
Magnesium Hydroxide Slurry
Creek Channel Restoration
Adit Treatment in Hinkley Run

Exposed Adit - Mine Shaft #4
Plugged Adit with Clay
Placed Cement Mix at Adit & Covered
Revegetation
(1999 - 2004)
# Herbaceous Cover Establishment

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Pounds of Pure Live Seed/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Vulpia myuros</em></td>
<td>15</td>
</tr>
<tr>
<td><em>Vulpia microstachys</em></td>
<td>20</td>
</tr>
<tr>
<td><em>Hordeum brachyantherum</em></td>
<td>20</td>
</tr>
<tr>
<td><em>Bromus carinatus</em></td>
<td>30</td>
</tr>
<tr>
<td><em>Lupinus succulentus</em></td>
<td>8</td>
</tr>
<tr>
<td><em>Lotus purshianus</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Lupinus albifrons</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Lotus scoparius</em></td>
<td>2</td>
</tr>
<tr>
<td><em>Eschscholzia californica</em></td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>103</strong></td>
</tr>
</tbody>
</table>
Pilot Woodland and Riparian Revegetation
Acorn Installation
Pilot Woodland and Riparian Revegetation
Post-Restoration Condition and Monitoring Results
Soil Remediation-Slope Treatment Effect
Tree Establishment - 1 Year After Installation
(September 2001)
Tree Establishment - 2 Years After Installation
(September 2002)
Pilot Tree Establishment –
4.5 Years After Tree Installation
(June 2004)
Pilot Tree Establishment

Moderate to High Tree Survival Rates

<table>
<thead>
<tr>
<th>Year</th>
<th>Blue Oak</th>
<th>Valley Oak</th>
<th>California Buckeye</th>
<th>Blue Elderberry</th>
<th>Red Willow</th>
<th>Fremont Cottonwood</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 (Year 1)</td>
<td>86%</td>
<td>84%</td>
<td>95%</td>
<td>70%</td>
<td>56%</td>
<td>14%</td>
<td>76%</td>
</tr>
<tr>
<td>2002 (Year 2)</td>
<td>86%</td>
<td>65%</td>
<td>80%</td>
<td>64%</td>
<td>73%</td>
<td>14%</td>
<td>76%</td>
</tr>
<tr>
<td>2003 (Year 3)</td>
<td>91%</td>
<td>70%</td>
<td>90%</td>
<td>55%</td>
<td>58%</td>
<td>14%</td>
<td>74%</td>
</tr>
</tbody>
</table>

Increasing Average Tree Height (ft)

<table>
<thead>
<tr>
<th>Year</th>
<th>Blue Oak</th>
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<th>Blue Elderberry</th>
<th>Red Willow</th>
<th>Fremont Cottonwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001 (Year 1)</td>
<td>0.46</td>
<td>0.73</td>
<td>2.73</td>
<td>1.14</td>
<td>1.7</td>
<td>2.43</td>
</tr>
<tr>
<td>2002 (Year 2)</td>
<td>0.94</td>
<td>2.3</td>
<td>2.85</td>
<td>0.9</td>
<td>5.43</td>
<td>8.21</td>
</tr>
<tr>
<td>2003 (Year 3)</td>
<td>2.2</td>
<td>3.6</td>
<td>2.9</td>
<td>2.4</td>
<td>6.1</td>
<td>10.8</td>
</tr>
</tbody>
</table>
Remediation of Acidic Soils
or
Plant Tolerance to Acidic Conditions?
Subgrade Soil Paste pH

Effect of Soil Remediation Approach on Subgrade Soil Paste pH

Average Soil Paste pH (± SE)

- Pre-Restoration (1999) Subgrade (n=7)
- Post-Restoration (2004) Subgrade (Moderate Slope Approach) (n=7)
- Post-Restoration (2004) Subgrade (Steep Slope Approach) (n=5)
Moderate Slope Treatment - Soil Cover Structure
(2004)
# Soil Cover Fertility

## Soil Chemistry Parameter

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Organic Matter (% dry wt)</td>
<td>1.8 (0.3)</td>
<td>0.1 (0.0)</td>
<td>2.2 (0.6)</td>
</tr>
<tr>
<td>pH</td>
<td>5.5 (0.3)</td>
<td>7.9 (0.2)</td>
<td>6.8 (0.1)</td>
</tr>
</tbody>
</table>
Soil pH and Pilot Riparian Seedling Establishment
### Soil pH and Pilot Riparian Seedling Establishment

<table>
<thead>
<tr>
<th></th>
<th>Hinkley Run Surface Water</th>
<th>Hinkley Run Floodplain Topsoil</th>
</tr>
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<tbody>
<tr>
<td>pH average (summer) (n = 10)</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td>pH range (summer) (n = 10)</td>
<td>2.5 - 5.8</td>
<td>2.4 - 5.5</td>
</tr>
</tbody>
</table>

Native willow trees (*Salix laevigata; S. exigua*) exhibit high survival and health/vigor.
Copper and Zinc - Total Mass Loading

- 99% reduction in copper
- 90-95% reduction in zinc
How is Penn Mine Doing Now?
April 2012

Same View of Hinkley Run
Hinkley Run-Downstream Reach

April 2012
Conclusions
Questions - Discussion?