Passive Treatment of Mining Influenced Water
Empire Mine State Historic Park

Presented by:
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Agenda

- Site Background
- Passive Treatment System (PTS) Design
- PTS Performance
- Oxidation Profiling
- Conclusions
- Questions
Background: Empire Mine State Historic Park

- Oldest, largest, and richest lode gold mine in California
- Produced 5.6 million ounces of gold (~$6.6 billion today) from 1850-1956
- 367 miles of underground workings
- Magenta Drain portal drains portions of the underground workings
Background – Legacy: MIW 24-7
Design: Constituents of Concern

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent Average (Maximum)</th>
<th>Interim Limit$^{1,2}$</th>
<th>Final Limit$^{1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7</td>
<td>--</td>
<td>6.5 - 8.5</td>
</tr>
<tr>
<td>Arsenic (µg/L)</td>
<td>69 (240)</td>
<td>400</td>
<td>10</td>
</tr>
<tr>
<td>Iron (µg/L)</td>
<td>5,500 (14,000)</td>
<td>11,000</td>
<td>300</td>
</tr>
<tr>
<td>Manganese (µg/L)</td>
<td>2,360 (4,100)</td>
<td>3,000</td>
<td>50</td>
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</tbody>
</table>

Notes:
1 – As defined by NPDES Permit and Time Schedule Order
2 – Interim limits in effect from startup through June 1, 2015
Design: PTS Concept

Manganese Removal Bed

Aerobic Wetland

- Settling Pond
- Irrigation Well (Proj. ~ 800 FT. SSE)
- 60-Mil HDPE Liner (Typ.)
- Fractured Bedrock
- Clays, Organic Matter, Weathered and Decomposed Bedrock
- Empire Shaft/Decline
- Flooded Mine Workings
- Magenta Drain Channel
Design: Layout

- Magenta Drain & Pump Station Intake Area
- Manganese Removal Bed
- Feed & Return Pipeline Corridor
- Pump Station
- Aerobic Wetland
- Settling Pond
PTS Design: Treatment Mechanisms

- **Settling Pond:** *Iron and Arsenic Treatment*
  - Oxidation of ferrous iron to ferric iron oxy-hydroxide
  - Adsorption/Co-precipitation of arsenic and ferric iron oxy-hydroxides

- **Aerobic Wetland:** Iron, Arsenic, and Manganese Treatment
  - Further oxidation, settling, and retention of Fe/As complexes, formation of plagues on vegetation

- **Manganese Removal Bed:** Manganese Treatment
  - Biotic and abiotic removal, catalyzation, and precipitation of manganese oxide (Pyrolusite/MnO₂)

- **Key!!:** Infuse as much oxygen into the influent as possible, wherever possible
Design: Settling Pond

- **Average HRT:** 88 hours
- **Minimum HRT:** 18 Hours
- **Surface Area:** 0.5 acres
Design: Aerobic Wetland I

- **Surface area:** 1.1 acres
- Arroyo willow (*Salix lasiolepsis*) (primary)
- Sandbar willow (*Salix exigua*) (secondary)
- Common rush (*Juncus effuses*) Baltic rush (*Juncus balticus*).
Design: Wetland II
Manganese Removal Bed (MRB)

- **Surface Area:** 1.2 acres
- **Media:** 8 inches crushed limestone rock and 12 inches of 4-6 inches limestone
- **Design Mn Removal:** 0.9 g/m²/day
Design – PTS Influent

- Influent source is the Empire Mine shallow workings

- Significant seasonal flow variation, instantaneous response to precipitation

- Bench and pilot testing various passive technologies conducted to prove design concepts

- Design hydraulic flow capacity: 1,200 gpm

- Average measured discharge flow rate: 150 gpm and peak discharge rate of 675 gpm
Design: PTS Influent – Daily Average

Weekly Average Flow Rate (gpm)

- 2011-2012 peak ~494 gpm
- 2012-2013 peak ~554 gpm
- 2013-2014 peak ~170 gpm
- 2015-2016 peak ~380 gpm
- 2016-2017 peak ~912 gpm

DROUGHT
PTS Performance: Total Iron

![Graph showing PTS performance for Total Iron over time with data points for Influent, Settling Pond, Aerobic Wetland, MRB, and Effluent Limit. The y-axis represents Total Iron in µg/L with values ranging from 1 to 100000, and the x-axis represents dates from 11/3/2011 to 10/7/2016.]
PTS Performance: Total Arsenic

Total Arsenic (µg/L)

Influent | Settling Pond | Aerobic Wetland | MRB | Effluent Limit

PTS Performance:
Total Manganese

<table>
<thead>
<tr>
<th>Total Manganese (µg/L)</th>
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<tbody>
<tr>
<td>Influent</td>
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<tr>
<td>Settling Pond</td>
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<tr>
<td>Aerobic Wetland</td>
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<tr>
<td>MRB</td>
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<tr>
<td>Effluent Limit</td>
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</tbody>
</table>
Oxidation Profile Monitoring – Multilevel Piezometers
Oxidation Profile Monitoring

Oxidation Profile Monitoring - DO

Wetland 1 Influent (Group 1)

DO, mg/L

In Soil

At Soil/Water Interface

5 Inches Above Soil/Water Interface

9 Inches Above Soil/Water Interface

Oxidation Profile Monitoring

Oxidation Profile Monitoring - DO

Wetland 1 Discharge (Group 3)

DO, mg/L

In Soil
At Soil/Water Interface
5 Inches Above Soil/Water Interface
9 Inches Above Soil/Water Interface

30-Oct...
7-Nov...
14-Nov...
18-Nov...
1-Jun...
27-Jul...
25-Feb...
Conclusions: Data

- Continually achieved PPB effluent for As, Mn, and Fe over past 6 years:
  - Arsenic averaged 3.0 µg/L
  - Manganese averaged 5.9 µg/L
  - Iron averaged 22 µg/L

- Fe and As removal occurring in Settling Pond and Aerobic Wetland:
  - Fe – 97%
  - As – 94%

- Mn removal occurring in Aerobic Wetland and MRB:
  - Mn – 77% in aerobic wetland; 4% in MRB
Conclusions: Highlights

- Interim regulatory limits achieved since Startup (November 2012)
- Final regulatory limits achieved since February 2013
- Few studies have shown passive Mn removal to ppb range at full scale and fewer are permitted to meet comparably low Mn (50 µg/L) limits
- Mn removal rates in Wetland I considerably higher than expected. More study underway
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