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NOTES TO THE PRESENTATION

The purpose of the presentation was to introduce and discuss the need for a long-term (25 year) multi-focus workplan prepared through facilitated meetings with various parties to address many inter-related community issues with abandoned mine sites, including environmental restoration, local employment, locally grown food (fish), pit restoration, AMD related products (dyes, tiles, asphalt, etc.), ecosystem services and other issues. If done well, this community-integrated, long-term approach can be used as a model in other mining and resource extraction areas in the US and the world. Some of these concepts were developed while I was president of a local sewer district. Please feel free to distribute this presentation to others.

-Jim Jacobs  geojimj@gmail.com; tel: 415-381-5195
Sustainable Remediation and Green Resource Extraction Practices of Acid Mine Drainage Sites

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&
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State Mining and Geology Board
Some of the information in this presentation was based on the research developed during the preparation of the book: *Acid Mine Drainage, Rock Drainage and Sulfate Soils: Prediction and Remediation*.

*To be published: 2013*

*John Wiley & Sons*

*Editors: J.A. Jacobs, J. Lehr, and S. M. Testa*
If 7 billion humans had an ecological footprint close to the average North American, we would need 4 Earths.
Sustainability and Resources

Human behavior and evaluation of risks are shaped by our view of resources and policy.
In A New World: New Mindset

Would resources be treated differently?
Sustainability: Conserving Resources

One of the biggest user of rare earths of any consumer object in the world:

Rare Earth Metals
Sustainability: Think Differently
Sustainability: Think Differently

Facilitated Workshop
Developed Long-Term Workplan:
1) Efficient Use of Sewer Plant
2) Focus on Safety & Training
3) Recycling and Environmental Stewardship
Sustainability: Think Differently

Detailed workplan describes each value, the mission statement, and the short-term and long-term goals, including:

Environmental Stewardship

No longer wastes; only resources

WASTEWATER PLANT ➔ RESOURCE PLANT
Sustainability: Think Differently

**WASTEWATER PLANT** = RESOURCE PLANT

Sewage = water, nutrients, methane production

Landfill = methane production

metals source area

Other: Medicine Recycling
Environmental Stewardship (US EPA)

Optimal Sustainable Revitalization

Environmental

Economic

Social

Sustainable

Viable

Equitable

Bearable
with Creative Solutions

25 Year Plan: Abandoned Mine Sites
Non-Profits, Corporations, Donors & Grants, Federal, State and Local Governments, Consultants, Contractors, Neighbors, Mining Companies, Stakeholders

Water Recycling = Save the Farmers/Cities

Employment = 1933-1942
Civilian Conservation Corps

Erosion Control

Metals Recovery from Mining Sludge
Environmental Restoration: Acid Mine Drainage

Aquaculture: Sustainable Locally Grown Food
LIFE CYCLE DIAGRAM: A CONCEPTUAL MODEL

Conventional remediation of AMD site using excavation of waste rocks & off-site disposal
Resource Extraction Factors & Sustainability Issues

- Energy requirements
- Air emissions
- Water requirements
- Issues to Community
- Costs
- Impacts on land and ecosystems
- Material consumption and waste
- Impacts on long-term stewardship
Resource Extraction:

View of Resources:
Historic and Current
Past Resources on Earth

67 lb glacial erratic (copper nugget)
Nugget lying around on surface
Present Resources on Earth

Typical Open Pit Gold Mine:
Low % (0.2%) to oz/ton;  FUTURE = Landfills
Diesel Consumption: Spectacular Display of Energy Use
Past Resources on Earth

Are all the costs accounted for?
Past Resources on Earth

Are all the costs accounted for?
Acid Mine Drainage
Small Scale Examples:
Mojave Desert Site, California
Plumas County Site, California
Impacted water draining from an abandoned underground copper mine in the Mojave Desert. California Abandoned Mine Lands Unit.
Impacted water draining from an abandoned underground copper mine in the Mojave Desert. California Abandoned Mine Lands Unit.
Acidic water draining from an underground gold mine directly into a small stream in Plumas Co. California Abandoned Mine Lands Unit.
Acid Mine Drainage Understanding

1) AMD = Changes of Redox Chemistry

2) Complex Biogeochemical Process

3) Precipitation of metals, biomining (bioleaching), remediation relates to controlling redox conditions.
Acid Mine Drainage (AMD) Complex Biogeochemical Process

- Mining for base metal sulfide minerals
  - Cd, Cu, Pb, Zn, Ag, Au, Pt, Al, etc.

- Economic ore minerals of these metals are often hosted in pyritic rock

- Excavation and placement of mine waste at the surface
  - Produces large volumes of pyritic rock at surface
  - Opens passages into subsurface rock, allowing air, water flow

Biological Sulfur Transformations

Weathering of Pyrite (FeS$_2$)

Overall reaction:

$$\text{FeS}_2(\text{pyrite}) + 3.5\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+$$

Dominant pathway for pyrite dissolution involves oxidation of ferrous iron [Fe(II)] by oxygen:

$$14\text{Fe}^{2+} + 3.5\text{O}_2 + 14\text{H}^+ \rightarrow 14\text{Fe}^{3+} + 7\text{H}_2\text{O}$$

Followed by reduction of ferric iron [Fe(III)] by sulfide:

$$\text{FeS}_2(\text{pyrite}) + 14\text{Fe}^{3+} + 8\text{H}_2\text{O} \rightarrow 15\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+$$

(Baker and Banfield, 2003)
Acid Mine Drainage (AMD)

- Long term effects:
  Oxidation of iron and sulfide minerals by AMD microbial community:
  - Bacteria
  - Archaea
  - Protists
  - Fungi

  Flux of acidic drainage from orphan mine sites

Thiobacillus ferrooxidans

- Acidophilic bacterium (lives at pH < 2)
- Fixes C by oxidizing Fe(II) and S(-II) in pyrite
- Produces acidity
- Very common
- Complex interaction of microbial community

(Baker and Banfield, 2003)
Acid Mine Drainage Resources:
- Water Recycling
- Sulfate Salts Precipitation
- Metal Recovery
- Fish Production
- Pigments and Dyes
- Green Asphalt/Concrete
- Ecosystem Services
- AMD Environmental Restoration
Acid Mine Drainage

&

Example of One Passive Treatment
Passive Anaerobic Wetlands

Anaerobic Wetland

Organic Matter

Limestone

(C. Zipper)
Passive Anaerobic Wetlands

Anaerobic wetlands: baffles placed in to hinder short circuiting of water flow. (J. Skousen)
Passive Anaerobic Wetlands

Anaerobic wetlands: baffles placed in to hinder short circuiting of water flow. (J. Skousen)
Passive Anaerobic Wetlands

Passive acid mine drainage remediation systems optimized by a variety of methods. (J. Skousen)
If oxidized, soluble iron (Fe(II)) will form [(Fe(III)), and precipitate as rust] and plug passive systems.

Understand redox conditions and iron (J. Skousen)
Acid Mine Drainage

&

Green Asphalt/Concrete: using waste rock from abandoned mine sites as part of the asphalt or concrete materials.
Ex-Situ Cold Mix Asphalt Process

Metals from mine waste piles or sludge

Highways, driveways, bike paths, hiking trails, parking lots
Store CMA for 6+ months prior to use
Green Asphalt or Concrete

Including mine wastes (sludges, tailings, waste stockpiles, etc. in asphalt and concrete mix.

Extensive analysis and testing

Production of non-hazardous “green” product that does not leach.
Cold Mix Asphalt Process: Metals

Components

3 Basic Components of CMA:

1) Soil; fine grained component (impacted with metals)

2) Aggregate

3) Water-based emulsion

Also – lime for stability (Portland cement or fly ash)
Cold-Mix Asphalt (CMA)

Overview

CMA Mix designs play a major role in determining stability and strength.

Stability of metals-affected soil
CMA is highly stable
Performs adequately as an end product

Success:
- Chemical Stability
- Minimize Permeability
- Strong Functional Group-Aggregate Bonds
Cold Mix Asphalt Process: Metals

All wastes or by-product materials that are being considered for use, regardless of whether or not the material is exempt from regulation under RCRA, should be evaluated prior to use to fully assess the inherent hazard potential of the material, if used in the proposed application.
Cold Mix Asphalt Production Facility

Environmental risks:
- Runoff
- Leaching
- Fugitive Dust

Operations:
- Temporary Storage
- Conveying
- Mixing and Blending
- Loading
Cold Mix Asphalt Process: No Pore Space

Photomicrographs of petrographic thin sections of processed cold-mix asphalt under plain (A) and polarized light (B) showing full encapsulation with negligible pore space and connectivity once compacted (3.5 magnification) (from S. Testa, 1995)
Cold Mix Asphalt Process

Truck mounted drum mix plant
Asphalt-aggregate interface at the molecular level using space-filling and structural representations to illustrate important functional relationships

Used in California for berms, covers and pathways. Also used in Massachusetts

(Conca and Testa, 1992)
CMA Technology Analyses

*Advantages:*
The principal advantages of cold mix asphalt batching are: It keeps contaminated soil out of landfills. The final product is a beneficially useful material. The process is fast (up to 650 cubic yards/day); The price is cost competitive. It minimizes transportation of contaminated soils, and associated VOCs and vehicle emissions

*Disadvantages:*
Stockpiled material awaiting treatment must be covered. Extensive testing is required to determine the exact percentage of emulsion in the mix.
CMA Case Study: California

- Engineering and Chemical Analysis was performed
- Determination that CMA process would be successful
- Price competitive with Class I Landfill disposal

SUMMARY
Dozens of projects in California in the 1990s used CMA to convert 100s to 1,000+ cubic yards of hydrocarbon and metals impacted soil into CMA.

CMA was used for berms at refineries, parking lots, bike paths, hiking trails and roadways.
Acid Mine Drainage & Green Asphalt/Concrete:

For more information: Stephen M. Testa (CRC Press; 1997)
Acid Mine Drainage / Mercury

&

Restoring Mine Pit Water, Lakes and Reservoirs
Gold pan with more than 30 grams of mercury from 1 kilogram of mercury-contaminated sediments. Mercury from the Coast Range (mercury mines) and gold mines (Sierra Range) still contaminate bottom sediments and surface waters, including mine pits.

USGS Fact Sheet FS-061-00 (Alpers and Hunerlach, 2000)
Mercury in the Reservoirs and Lakes of California

Mercury bioaccumulates in fish and increases in concentration up the food chain (biomagnification)

EXPLANATION
Potential for Mercury Contamination in Sediments
- Red: High
- Dark brown: Moderate
- Beige: Low (unaffected by mining)
- Yellow: Unknown

USGS Fact Sheet FS-061-00 (Alpers and Hunerlach, 2000)
Mercury in the Estuaries of California: Reducing conditions releases methyl mercury into the water.
Algae Bloom/Methyl Mercury and Mine Pit Water
Technical Solution: Oxygen Infusion

• Lower maintenance and repairs
• Lower chemical costs
• Improve taste and water quality
• Minimize potential release of reduced metals
• Enhance environment for fish and other desirable aquatic organisms
Pilot Project Using Industrial Scale Infusion of Dissolved Oxygen

Purpose:

- Industrial generation of dissolved oxygen in lakes/pits
- Minimize algae blooms and methyl mercury formation
- Increase fish and aquatic life
- Lower maintenance costs
- Improve water quality
Oxygen Infusion Mass Transfer Tool

Microporous Hollow Fibre
Cross Section 200 µm
Inner Surface 1 µm

iSOC

ALinear™ Valves

www.remediationshop.com
RezOx for Hypolimnion Oxygenation (Deep Zone)

- Warm, Less Dense Zone (Epilimnion)
- Direct Flow
- Induced Flow
- Thermocline
- Highly Oxygenated Water
- Good DO Levels
- Anoxic Water becomes Aerobic

Water circulates through the thermocline to make up water removed from the bottom. Prevents soluble P, Mn, Fe, and H₂S from diffusing into upper waters.
Industrial Oxygen Infusion Technology

Photo of trailer mounted dissolved oxygen generation equipment.

Status of Project: Trailer and equipment have been built and are on site. The equipment is ready to install; planned for July 2012.

www.remediationshop.com
Locations of health advisories for mercury in sport fish consumption in California. Source: California Office of Environmental Health Hazard Assessment, 1999. Lake Pillsbury has interim advisory by Lake County; state advisory pending, as of May 2000.

USGS (Fact Sheet FS-061-00 (Alpers and Hunerlach))
Health advisories for sport fish consumption in California lakes and reservoirs

USGS (Fact Sheet FS-061-00 (Alpers and Hunerlach))
Guadalupe Reservoir, California
Guadalupe Reservoir, California
Guadalupe Reservoir, California
Health advisories for sport fish consumption in California lakes and reservoirs

USGS (Fact Sheet FS-061-00 (Alpers and Hunerlach))
Almaden Reservoir, California
Passive Treatment:

Water Recovery and Aquaculture
Typical Ecosystem / Tourist Services

Disturbance regulation
Golf courses over reclaimed mine sites
Water supply
Food production (fish, vegetables, fruit)
Raw materials: lumber, agricultural products
Genetic & medicinal resources
Cultural services
Preservation of historic resources (mining towns)
Ecosystem restoration: wetlands for tourism & hiking, birding, etc.
Concrete raceways for production of Rainbow Trout

(Ken Semmens)
Typical Ecosystem Services: West Virginia

Tanks for production of Rainbow Trout

(Ken Semmens)
Aquaculture using post treatment mine waters

This profile view shows the path water takes through the major components within one type of a fully-recirculating system.

**Recirculating Aquaculture System Components**

- BIOFILTER
- CO₂ STRIPPER
- OXYGENATION
- CULTURE TANK
- DRUM FILTER
- SOLID SEPARATION
- UV STERILIZER
- PUMP
- DISCHARGE

Flow rates:
- 90% AT FLOW LOW SOLIDS
- 10% AT FLOW HIGH SOLIDS

(Ken Semmens)
Aquaculture using post treatment mine waters
Aquaculture using post treatment mine waters

Hybrid Stripped Bass

(Ken Semmens)
Aquaculture using post treatment mine waters

Hybrid Striped Bass  (Ken Semmens)
Aquaculture using post treatment mine waters

Brown Trout

(Ken Semmens)
Aquaculture using post treatment mine waters

Brook Trout (Ken Semmens)
Aquaculture using post treatment mine waters

Yellow Perch

(Ken Semmens)
Post treatment mine waters aquaculture

Angler with trout from an AMD polishing pond
(Ken Semmens)
Clothing with a conscience: AMD iron oxide pigments

“Rusted Threads”

R. Hedin; Hedin Environmental
Iron Oxide Pigment Processing: The two sludge storage tanks (right), two frame filter presses (left), conveyor, and stockpiled brown pigment (product)
Dyes and Pigments: “Rusted Threads”

Bob Hedin; Hedin Environmental
AMD
Metal Resources Recovery
An example from Battelle (2009) research
Simplified Process Flow Diagram
(Battelle, 2009)
Goal of AMD Recovery

Process Diagram (Battelle, 2009)
Stripper Mixer-Settlers (Battelle, 2009)
AMD
Ecosystem Services
Ecosystem Services

The benefits human populations derive from ecosystems.
## AMD Ecosystem Services

<table>
<thead>
<tr>
<th>Regulating Services:</th>
<th>Supporting Services:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Climate regulation</td>
<td>• Nutrient cycling</td>
</tr>
<tr>
<td>• Disturbance regulation</td>
<td>• Pollination</td>
</tr>
<tr>
<td>• Water regulation</td>
<td>• Soil formation</td>
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<tr>
<td>• Waste treatment</td>
<td>• Habitat</td>
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<th>Provisioning Services:</th>
<th>Cultural Services:</th>
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<tr>
<td>• Food production</td>
<td>• Recreation</td>
</tr>
<tr>
<td>• Raw materials</td>
<td>• Aesthetics</td>
</tr>
<tr>
<td>• Genetic resources</td>
<td>• Existence</td>
</tr>
<tr>
<td>• Medicinal resources</td>
<td>• Science / Education</td>
</tr>
</tbody>
</table>
Typical Ecosystem Services

Climate regulation
Erosion control & sediment retention
Waste treatment
Habitat

(US EPA)
Ecosystem Services Assessment

• Prior to and throughout the remediation process

• Reuse & revitalization

• Cleanup protectiveness
Acid Mine Drainage Resources:

- Water Recycling
- Sulfate Salts Precipitation
- Metal Recovery
- Fish Production
- Pigments and Dyes
- Green Asphalt/Concrete
- Ecosystem Services
- AMD Environmental Restoration
- Employment & Stewardship

25 Year Plan
Facilitated Workshop
Sierra Fund
Feds/State/Local Funds
Grants/Donors
BIO INFORMATION:

James Jacobs, P.G., C.H.G. is a geologist with over 30 years of experience as a resource geologist, focusing on sustainable practices. He teaches Sustainable Remediation for Soil and Water (X-451) at the University of California Extension Program, and has co-authored two books, one on MTBE and one on Chromium(VI). He is a Fulbright Scholar having had four teaching awards.

Stephen Testa, P.G., C.E.G. is a geologist with over 35 years of experience. He is currently the Executive Officer at the California State Mining and Geology Board which oversees SMARA. He has written extensively on acid mine drainage as well as recycling of metals impacted waste rock in his book on Reuse and Recycling of Contaminated Soils. He is a past president of the American Geological Institute and other professional organization.
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