Mine Drainage Control and Treatment Options

Region 10 Webinar Workshops – Hardrock mine geochemistry and hydrology

Workshop #3: Preparing for unexpected outcomes at mine sites and means to control contamination

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1

Disclaimer

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Overview

- Definitions
- How does mine-drainage form?
- Mitigation measures
  - Design and operation
- What happens when drainage enters a stream?
  - Precipitation and sorption reactions
- Remedial options
  - Active treatment
  - Passive (semi-passive) treatment

Definitions

- Mitigation
  - All steps taken to prevent (avoid), reduce (minimize), treat, and compensate for any potential adverse impacts (risk) on the environment from a given activity (hazard)
    - Proper planning, design, construction, operation, management, and closure of waste and water containment and treatment facilities, monitoring and maintenance over all mine-life phases, including after mine closure.

Definitions

- Reclamation
  - Refers to restoring[1] a disturbed area to an acceptable form and planned use, following active mining
  - Includes actions taken to mitigate against future risks

[1]Rarely is a site able to be restored to what it was prior to mining, which is the strictest definition of restoration.

Definitions

- Remediation
  - Refers to correcting an issue that has become evident, such as cleaning up a spill or an abandoned mine site

Definitions

- Best Management Practice (BMP)
  - With respect to the CWA, this term generally applies to specific measures for managing non-point source runoff from storm water (40 CFR Part 130.2(m)).

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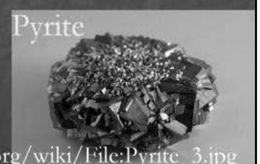
How Does Mine-Drainage Form?

- Mining Process
  - Exposes pyrite and other minerals to the atmosphere
  - Grinding processes
    - Larger surface areas for exposure (weather more quickly)



http://en.wikipedia.org/wiki/File:Pyrite_3.jpg

How Does Mine-Drainage Form?

Initiator Reaction

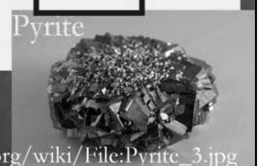
$$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

Pyrite

Propagation Cycle

$$Fe^{2+} + 0.25O_2 + H^+ \xrightarrow[10^6 \text{ x faster}]{\textit{Bacteria}} 0.5H_2O + Fe^{3+}$$

$$14Fe^{3+} + FeS_2 + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + \boxed{16H^+}$$



http://en.wikipedia.org/wiki/File:Pyrite_3.jpg

How Does Mine-Drainage Form?

- Acidic, neutral or alkaline[1]?
  - Acid-producing reactions
    - Pyritic minerals; oxyhydroxide formation
  - Acid-consuming reactions
    - Carbonate minerals (produce alkalinity)
      - E.g., limestone and dolomite
    - Aluminosilicate (clay minerals)
      - E.g., muscovite, kaolinite
  - Formation from non-pyritic minerals

[1]Mining-influenced waters (MIW) coined by Dr. Ron Schmiermund in 1997 to encompass all types

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Mitigation Measures

- Waste rock piles
- Tailings storage facilities

Measures presented are not inclusive of all options available.

Mitigation Measures
Waste Rock Piles

- Minimize leaching of acidity and ions
- Minimize exposure of water bodies to seepage/drainage
- Minimize acid generation

Mitigation Measures
Waste Rock Piles

- Minimize leaching of acidity and ions
  - Encapsulation with impermeable layer
    - Minimize infiltration, seepage, and oxygen transfer
  - Compaction
    - Minimizes voids
  - Progressive reclamation

Mitigation Measures
Waste Rock Piles

- Minimize exposure of water bodies to seepage/drainage
  - Locating piles within cone of depression
    - Drainage flows to pit and is pumped out with groundwater (GW)
  - Under-drains, diversions, GW monitoring wells, liners (clay and/or geosynthetic),

Mitigation Measures
Waste Rock Piles

- Minimize acid generation
  - Segregation of potentially acid-generating (PAG) rock with non-acid-generating (NAG) rock
  - Mining of sub-economic ore (PAG) as blending material, or at end of operations
  - Layering of PAG rock NAG rock
  - Blending with acid-consuming materials
  - Bactericide
  - Isolation (encapsulation)

Mitigation Measures
Tailings Storage Facilities

- Wet storage
  - Most common
    - Mining uses a lot of water and facility provides dual purpose as storage
  - Seismic and flood considerations
- Dry storage
  - Filtered tailings removes maximum amount of water
  - Not appropriate for PAG

Mitigation Measures
Tailings Storage Facilities

- Isolation of PAG material
  - Selective processing methods
  - Sub-aqueous disposal to minimize oxidation
  - Encapsulation

Mitigation Measures
Tailings Storage Facilities

- Minimize exposure of water bodies to seepage/drainage
  - Liners, under-drains, decant systems
  - Diversions for clean water
  - Seepage collection systems
  - Monitoring wells downstream
  - Caps on beaches, drawdown water, erosion control – closure

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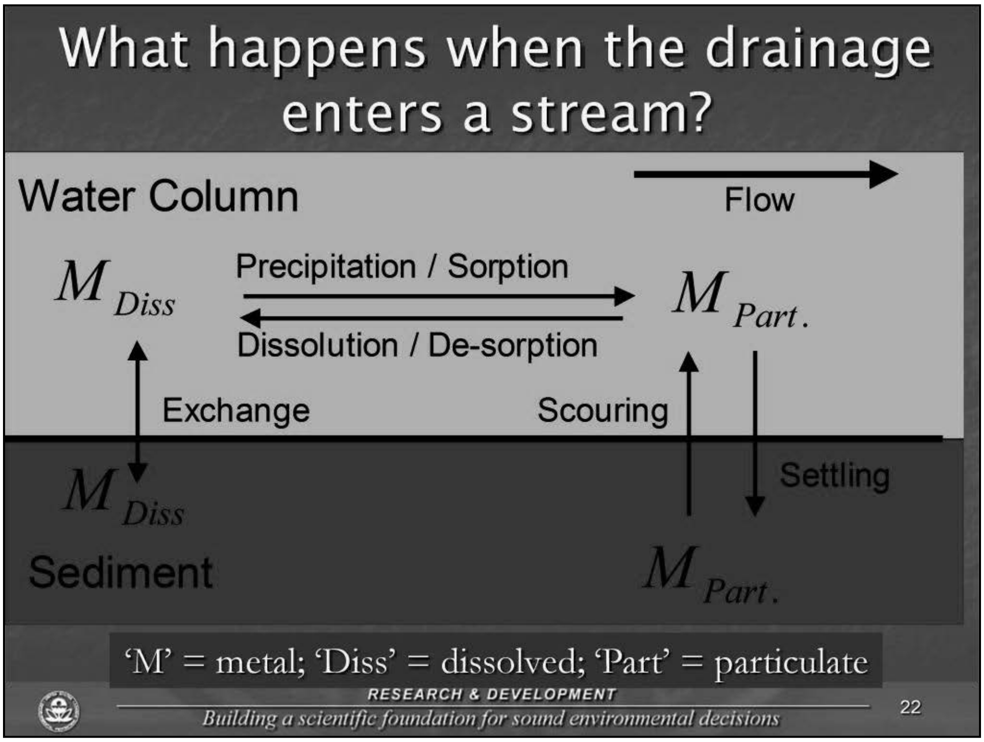
What happens when the drainage enters a stream?
Water Column
Flow
M_{Diss}
Precipitation / Sorption
Dissolution / De-sorption
$M_{Part.}$
Exchange
Scouring
Settling
M_{Diss}
Sediment
$M_{Part.}$
'M' = metal; 'Diss' = dissolved; 'Part' = particulate
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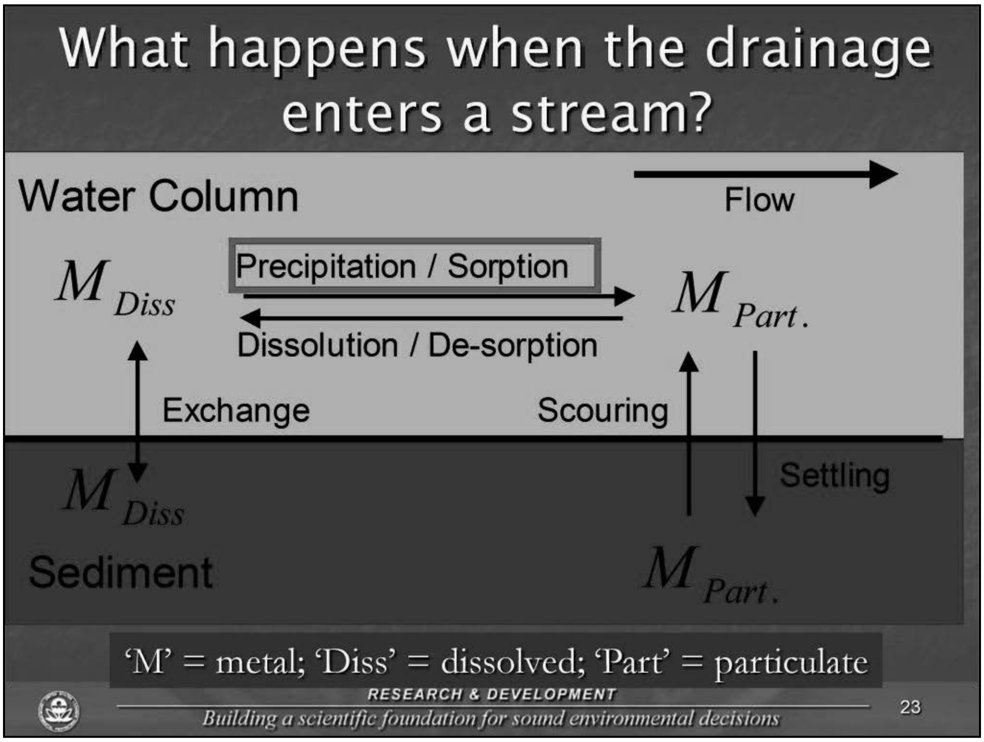
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What happens when the drainage enters a stream?

- Iron (HFO)
  - Rapid formation in water column at pH > ~ 3.5
  - Oxidation of ferrous iron precedes precipitation

What happens when the drainage enters a stream?

- Aluminum (ALO)
  - Rapid formation in water column at pH > ~ 5
  - No oxidation necessary

What happens when the drainage enters a stream?

- Manganese (HMO)
  - Requires oxidation
  - Requires a surface
  - Formation at pH > ~ 9

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What happens when the drainage enters a stream?

- Manganese (HMO)
  - Formation may be facilitated by periphyton

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What happens when the drainage enters a stream?

- Manganese (HMO)
  - Formation may be facilitated by periphyton
    - Algal photosynthesis

$$6HCO_3^- + 6H_2O \xrightarrow{h\upsilon} C_6H_{12}O_6 + 6OH^- + 6O_2$$

$$Mn^{2+} + O_2 \xrightarrow{high-ph} MnO_2(s)$$

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  - Active treatment
  - Passive (semi-passive) treatment

Remedial Options

- Isolation, removal, treatment of source
  - Physical removal
  - Grouting reactive rock surfaces
  - Redirection of water flow
  - Adding neutralizing agents

Remedial Options

- Water treatment
  - Removal of acidity
  - Removal of metals
  - Removal of salts (Na, Mg, Ca, K)
  - Removal of sulfate
  - Ultimately – removal of toxicity

Remedial Options
Water Treatment

- Active
- Passive

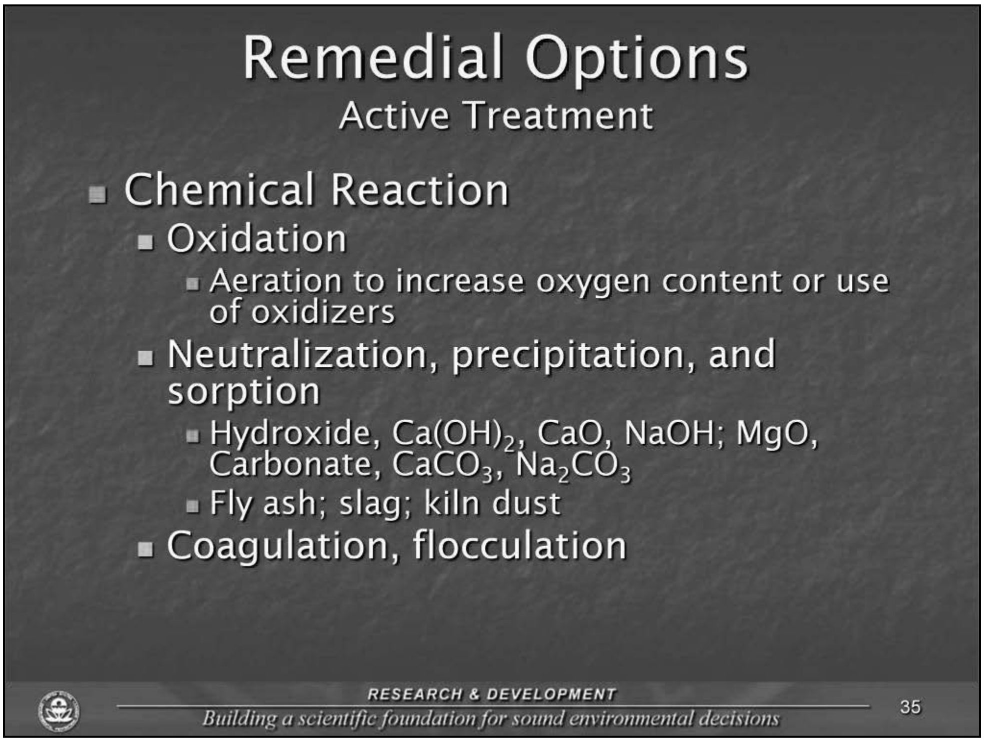
Remedial Options
Water Treatment

- Active
  - Ongoing humanly operated
  - Frequent maintenance and monitoring
  - Generally requires external energy source
  - Generally type chosen for active mining

Remedial Options

Water Treatment

- Passive (semi-passive)
  - Constant human intervention not required
  - Natural processes
  - Natural materials
  - Regeneration of materials
  - Gravity feed versus pumping


Remedial Options
Active Treatment
Chemical Reaction
Oxidation
Aeration to increase oxygen content or use of oxidizers
Neutralization, precipitation, and sorption
Hydroxide, $Ca(OH)_2$, CaO, NaOH; MgO, Carbonate, $CaCO_3$, Na_2CO_3
Fly ash; slag; kiln dust
Coagulation, flocculation
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Remedial Options
Active Treatment

- Physical
  - Membrane
  - Reverse osmosis
  - Micro, ultra, or nano-filtration
  - Ion exchange

Remedial Options

Passive/Semi-passive Treatment

- Oxidation
  - Aeration
- Neutralization and precipitation
- Ion exchange
- Sorption (organic and inorganic)
- Plant uptake

Remedial Options

Passive/Semi-passive Treatment

- Aerobic wetland
- Anoxic limestone drain (ALD)
- Anaerobic wetland
  - Sulfate-reducing bioreactor (SRBR)
  - Biochemical reactor (BCR)
- Permeable reactive barrier (PRB)

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Remedial Options

Passive/Semi-passive Treatment

- Aerobic wetland
  - Best for net alkaline drainage
  - Precipitation and sorption
  - Shallow – aeration
  - Plants – uptake

Remedial Options

Passive/Semi-passive Treatment

- Anoxic limestone drain (ALD)
  - Best for net acidic, low Fe^{3+}, low Al^{3+}, and low dissolved oxygen
  - Neutralize acidity
  - Effluent to aerobic pond

Remedial Options

Passive/Semi-passive Treatment

- Reducing alkalinity producing system (RAPS)
  - Similar to ALD, but reduces the water then adds alkalinity

Remedial Options
Passive/Semi-passive Treatment

- Anaerobic wetland (BCR)
  - Best for net acidic, low Fe^{3+}, low Al^{3+}, high metals
  - Reduction of redox active elements
  - Microbial reduction of sulfate to sulfide
  - Metal sulfide precipitation
  - Sorption of metals
    - Organic / inorganic

Remedial Options

Passive/Semi-passive Treatment

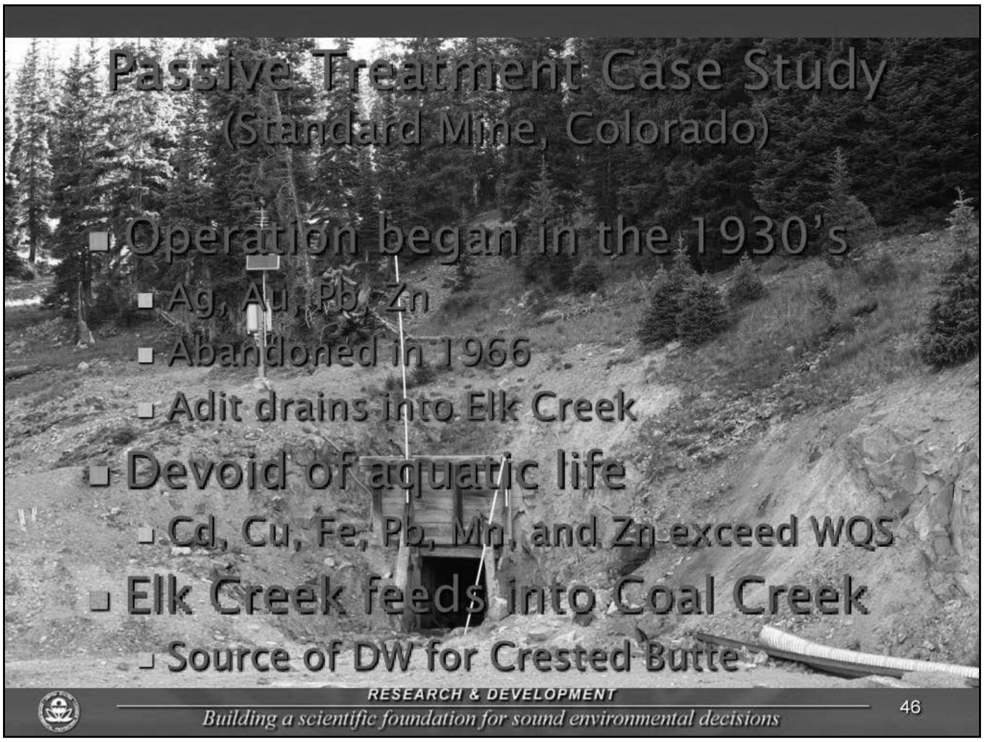
- Anaerobic wetland (BCR)
  - Natural materials
    - Hay, straw, wood chips, manure, crushed limestone
  - Layer of water
  - Generally vertical flow
  - Effluent to aerobic pond or weir

Remedial Options
Passive/Semi-passive Treatment

- Permeable Reactive Barrier (PRB)
  - Similar to BCR, but treat groundwater

Remedial Options
What to Choose?

- Choice depends on
  - Amounts - money, time, land, metals, acid, flow
  - Site access
  - Active or abandoned mine
  - Specific contaminants


Passive Treatment Case Study
(Standard Mine, Colorado)
Operation began in the 1930's
Ag, Au, Pb, Zn
Abandoned in 1966
Adit drains into Elk Creek
Devoid of aquatic life
Cd, Cu, Fe, Pb, Mn, and Zn exceed WQS
Elk Creek feeds into Coal Creek
Source of DW for Crested Butte
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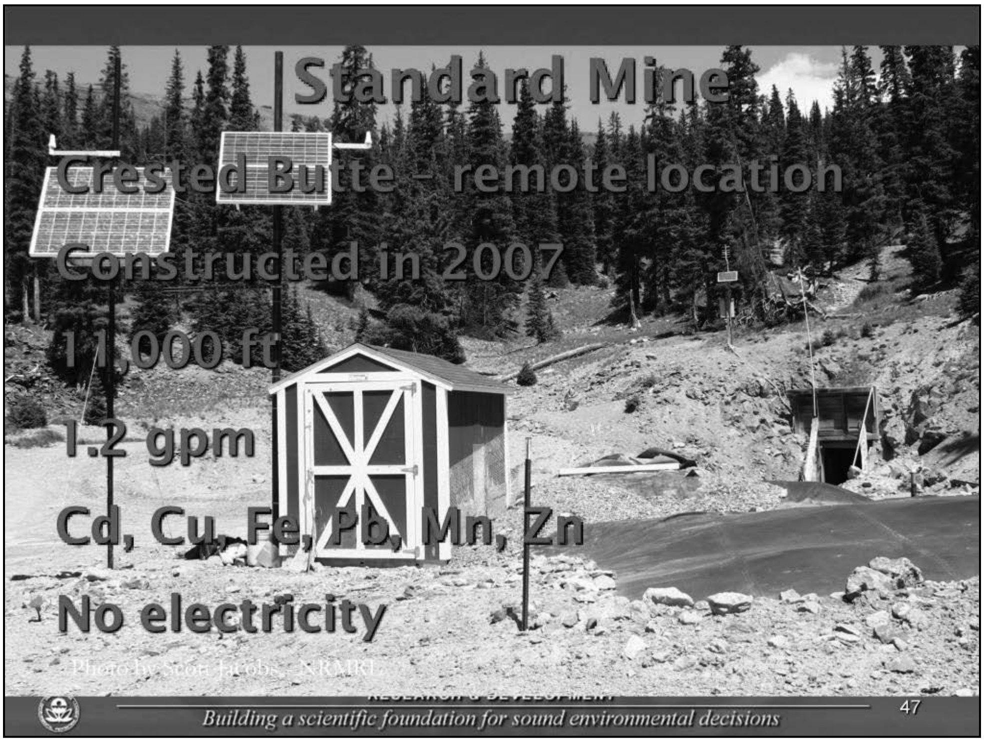
Standard Mine
Crested Butte - remote location
Constructed in 2007
11,000 ft
1.2 gpm
Cd, Cu, Fe, Pb, Mn, Zn
No electricity
Photo by Scott Jacobs - NRMRL
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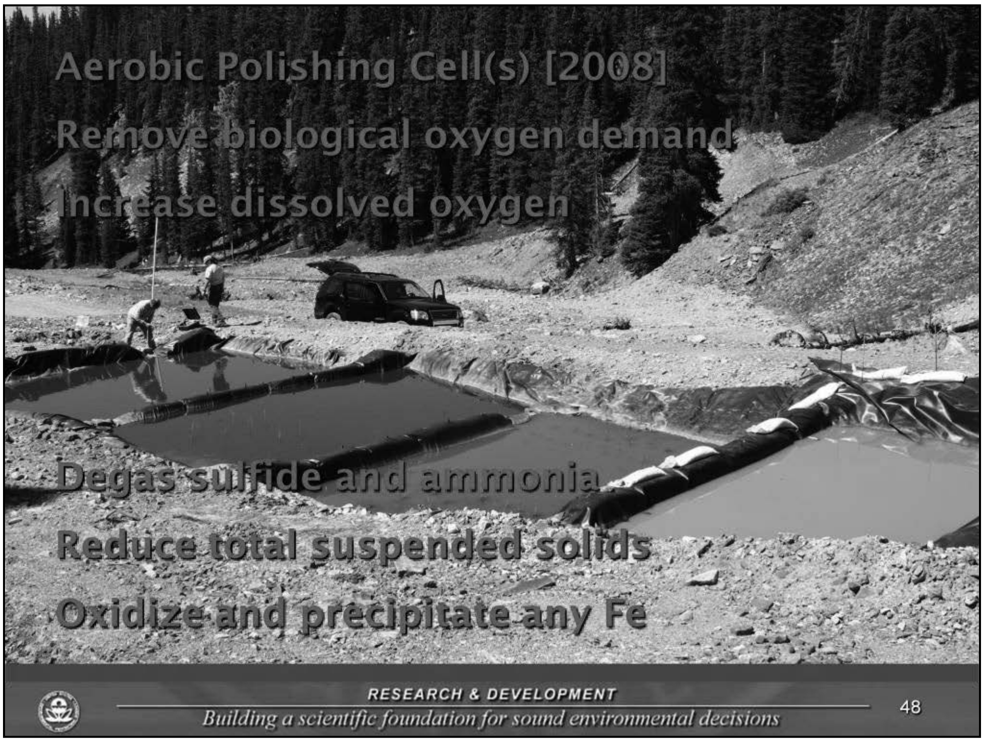
Aerobic Polishing Cell(s) [2008]
Remove biological oxygen demand
Increase dissolved oxygen
Degas sulfide and ammonia
Reduce total suspended solids
Oxidize and precipitate any Fe
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Passive Treatment Case Study
(Standard Mine, Colorado)

- Year-round treatment
- Automated sampling
  - pH, temperature, ORP
- Satellite reporting
- Protection from weather

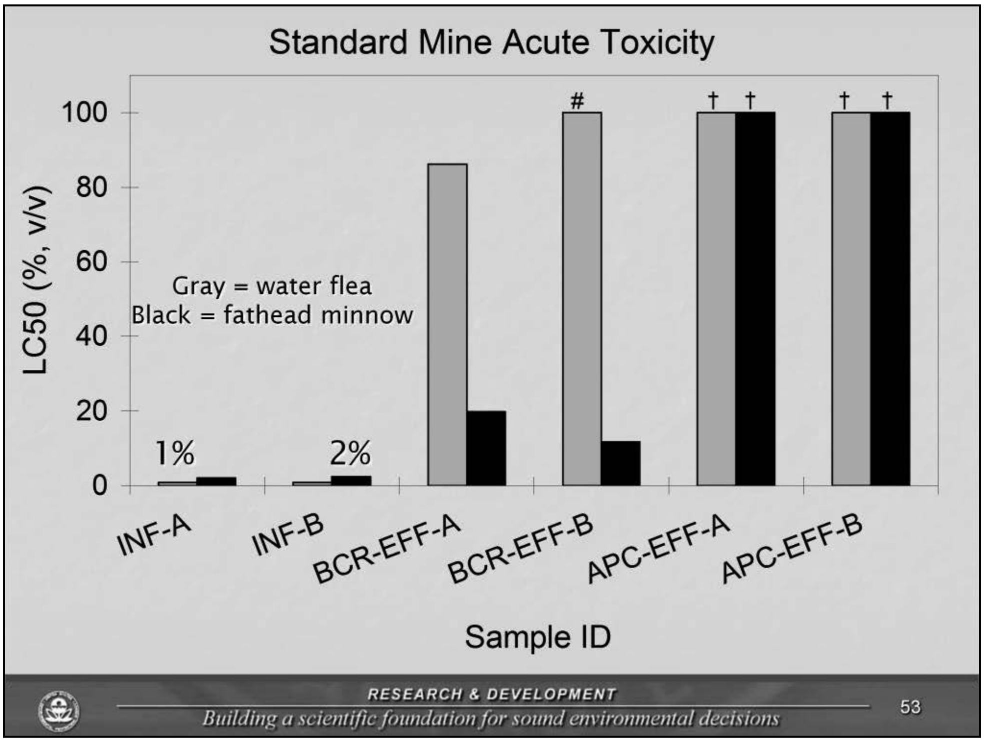

33-58 feet
annual snowfall
http://dept.ca.uky.edu/asmr/W/Full%20Papers%202008/0892-Reisman-OH.pdf
50

Passive Treatment Case Study
(Standard Mine, Colorado)

- Methods
  - Whole effluent toxicity tests (WET)
    - *Ceriodaphnia dubia* (water flea)
    - *Pimephales promelas* (fathead minnow)
  - Acute 48-hr LC_{50}
    - Percentage of water
  - Control survival > 90%

Passive Treatment Case Study
(Standard Mine, Colorado)
% Removal

Analyte	Site	
	BCR	APC
Al	N/A	N/A
As	N/A	N/A
Cd	100 +/- 2	100 +/- 2
Cu	94 +/- 9	94 +/- 9
Fe	-266 +/- 518	100 +/- 10
Ni	N/A	N/A
Pb	94 +/- 16	91 +/- 17
Zn	100 +/- 3	100 +/-3
SO4	39 +/- 4	72+/- 5



Standard Mine Acute Toxicity
LC50 (%, v/v)
100
80
60
40
20
0
Gray = water flea
Black = fathead minnow
1%
2%
#
† †
† †
INF-A
INF-B
BCR-EFF-A
BCR-EFF-B
APC-EFF-A
APC-EFF-B
Sample ID
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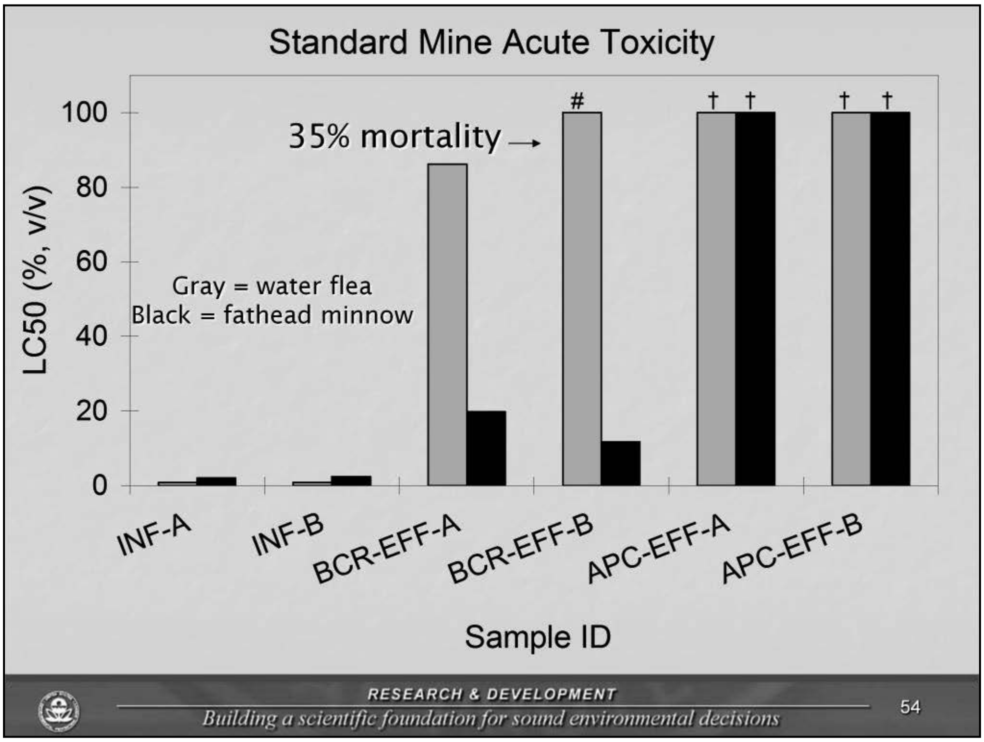
Standard Mine Acute Toxicity
LC50 (%, v/v)
100
80
60
40
20
0
35% mortality
#
† †
† †
Gray = water flea
Black = fathead minnow
INF-A
INF-B
BCR-EFF-A
BCR-EFF-B
APC-EFF-A
APC-EFF-B
Sample ID
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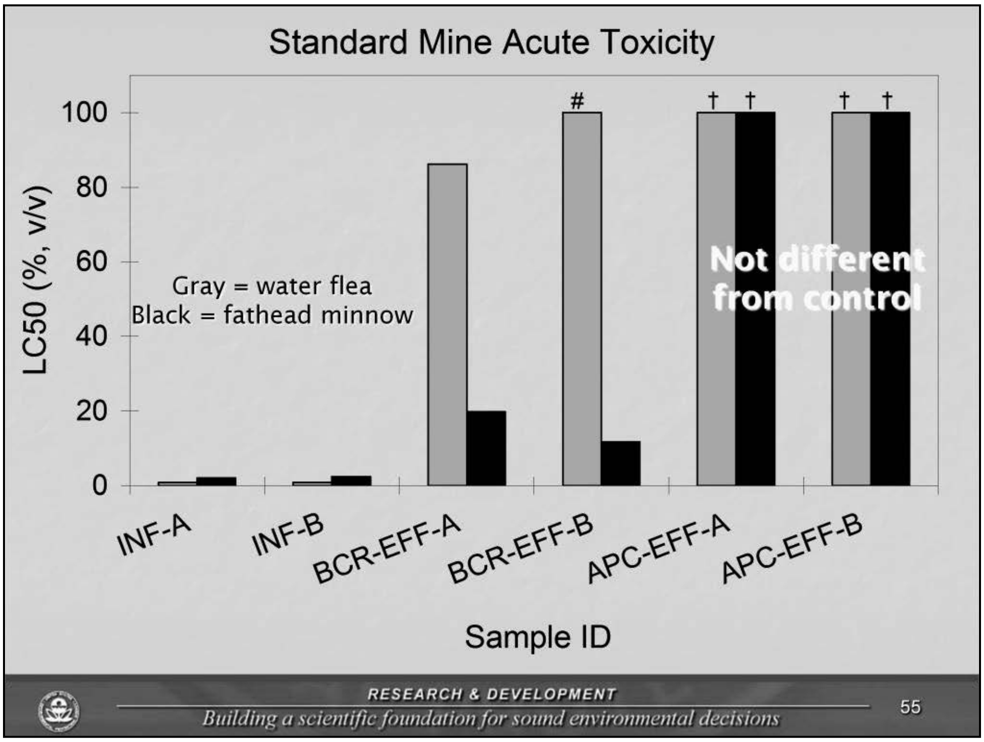

Standard Mine Acute Toxicity
LC50 (%, v/v)
100
80
60
40
20
0
#
† †
† †
Gray = water flea
Black = fathead minnow
Not different from control
INF-A
INF-B
BCR-EFF-A
BCR-EFF-B
APC-EFF-A
APC-EFF-B
Sample ID
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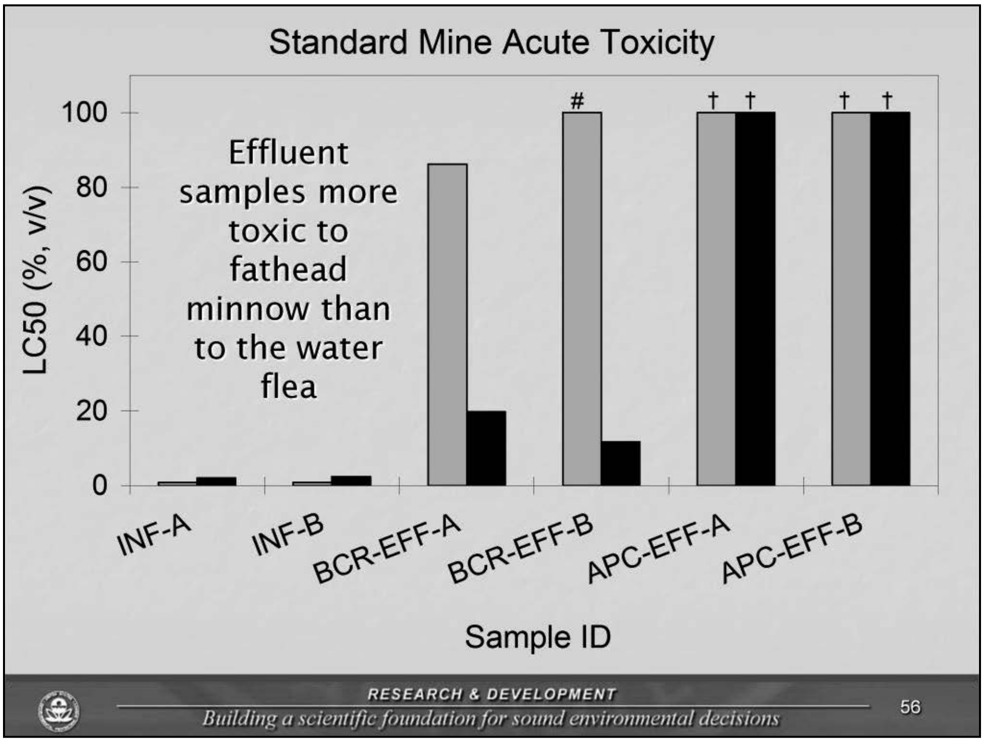
Standard Mine Acute Toxicity
LC50 (%, v/v)
100
80
60
40
20
0
Effluent samples more toxic to fathead minnow than to the water flea
#
† †
† †
INF-A
INF-B
BCR-EFF-A
BCR-EFF-B
APC-EFF-A
APC-EFF-B
Sample ID
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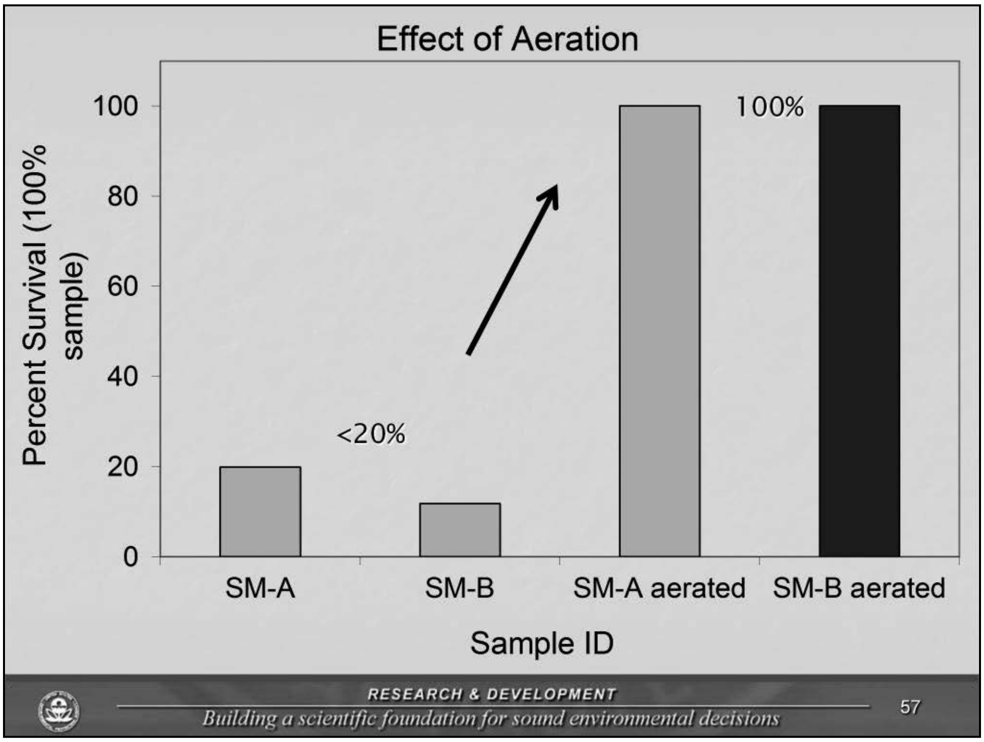
Effect of Aeration
Percent Survival (100% sample)
100
80
60
40
20
0
<20%
100%
SM-A
SM-B
SM-A aerated
SM-B aerated
Sample ID
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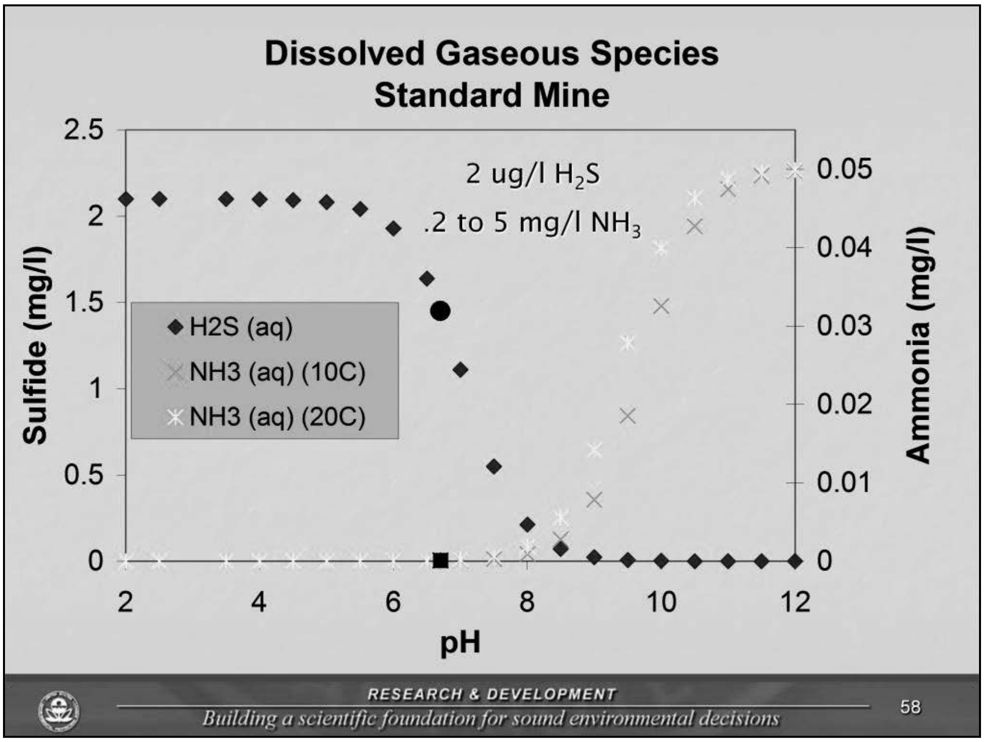
57



Dissolved Gaseous Species
Standard Mine
2 ug/l H2S
.2 to 5 mg/l NH3
H2S (aq)
NH3 (aq) (10C)
NH3 (aq) (20C)
Sulfide (mg/l)
Ammonia (mg/l)
pH
2.5
2
1.5
1
0.5
0
0.05
0.04
0.03
0.02
0.01
0
2
4
6
8
10
12
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Passive Treatment Case Study
(Standard Mine, Colorado)

- Concluding remarks
  - Results strongly suggest toxicity from dissolved hydrogen sulfide gas
  - Other BCRs may have different toxicants, depending on:
    - Contaminants present and efficiency of removal
    - Concentrations of dissolved gases
    - pH of effluent


Thank you!
Study at Standard Mine and 3 other sites:
Butler, BA, Smith, ME, Reisman, DJ, Lazorchak, JM. 2011. Metal removal efficiency and ecotoxicological assessment of field-scale passive treatment biochemical reactors. Environmental Toxicology & Chemistry. 30(2):385-392.
60