

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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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 restoring¹ a disturbed area to an acceptable form and planned use, following active mining
 - Includes actions taken to mitigate against future risks

¹Rarely 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



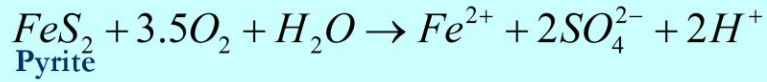
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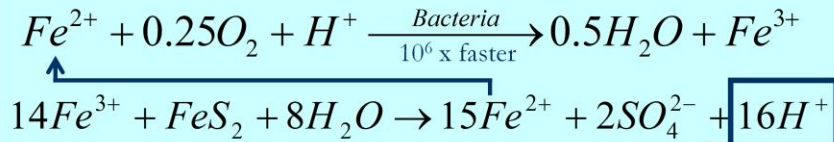
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How Does Mine-Drainage Form?

Initiator Reaction



Propagation Cycle



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



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How Does Mine-Drainage Form?

- Acidic, neutral or alkaline¹?
 - 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

¹Mining-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.



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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)



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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

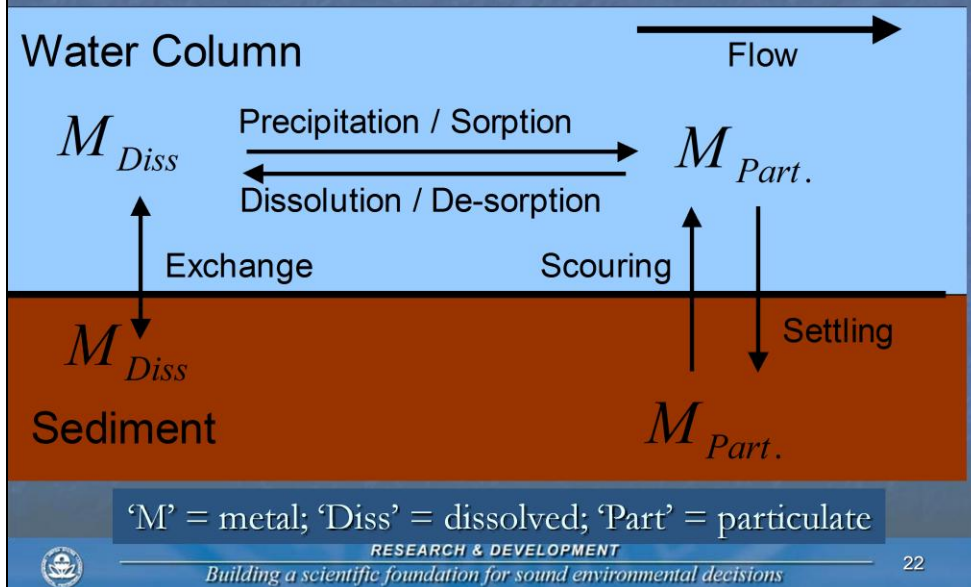


Overview

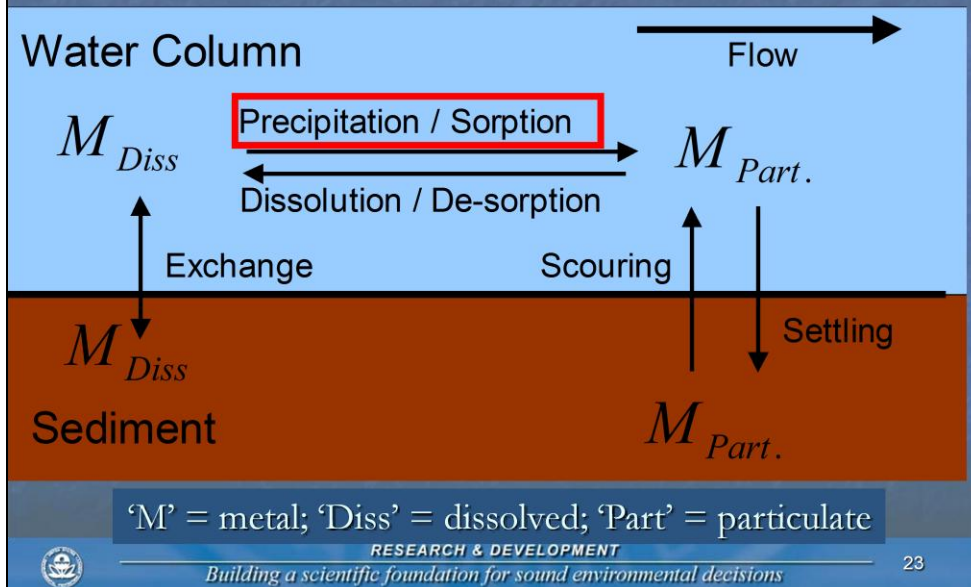
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What happens when the drainage enters a stream?



What happens when the drainage enters a stream?



What happens when the drainage enters a stream?

- Iron (HFO)
 - Rapid formation in water column at $\text{pH} > \sim 3.5$
 - Oxidation of ferrous iron precedes precipitation



What happens when the drainage enters a stream?

- Aluminum (ALO)
 - Rapid formation in water column at $\text{pH} > \sim 5$
 - No oxidation necessary



What happens when the drainage enters a stream?

- Manganese (HMO)
 - Requires oxidation
 - Requires a surface
 - Formation at $\text{pH} > \sim 9$



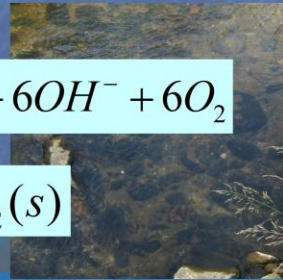
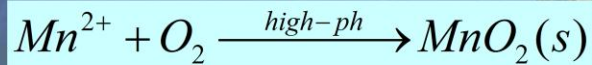
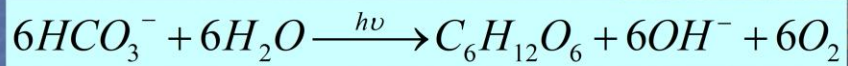
What happens when the drainage enters a stream?

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



What happens when the drainage enters a stream?

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



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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, $\text{Ca}(\text{OH})_2$, CaO , NaOH ; MgO , Carbonate, CaCO_3 , Na_2CO_3
 - Fly ash; slag; kiln dust
 - Coagulation, flocculation



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)



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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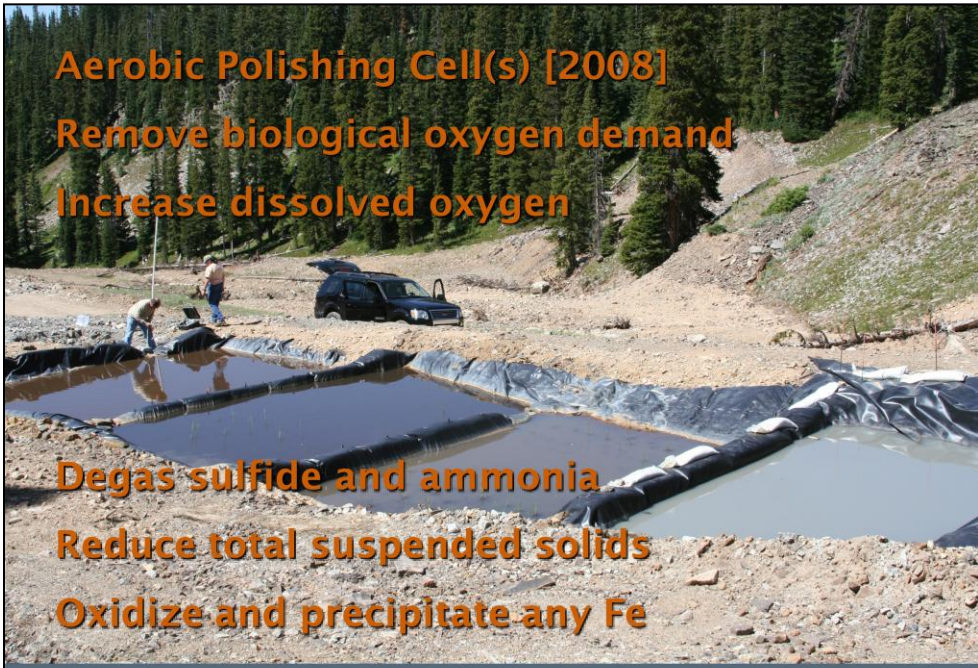
Standard Mine
Crested Butte - remote location
Constructed in 2007
11,000 ft
1.2 gpm
Cd, Cu, Fe, Pb, Mn, Zn
No electricity

Photo by Steve LeDoux, NRMRI

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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 LC₅₀
 - Percentage of water
- Control survival > 90%



Passive Treatment Case Study (Standard Mine, Colorado)

% Removal

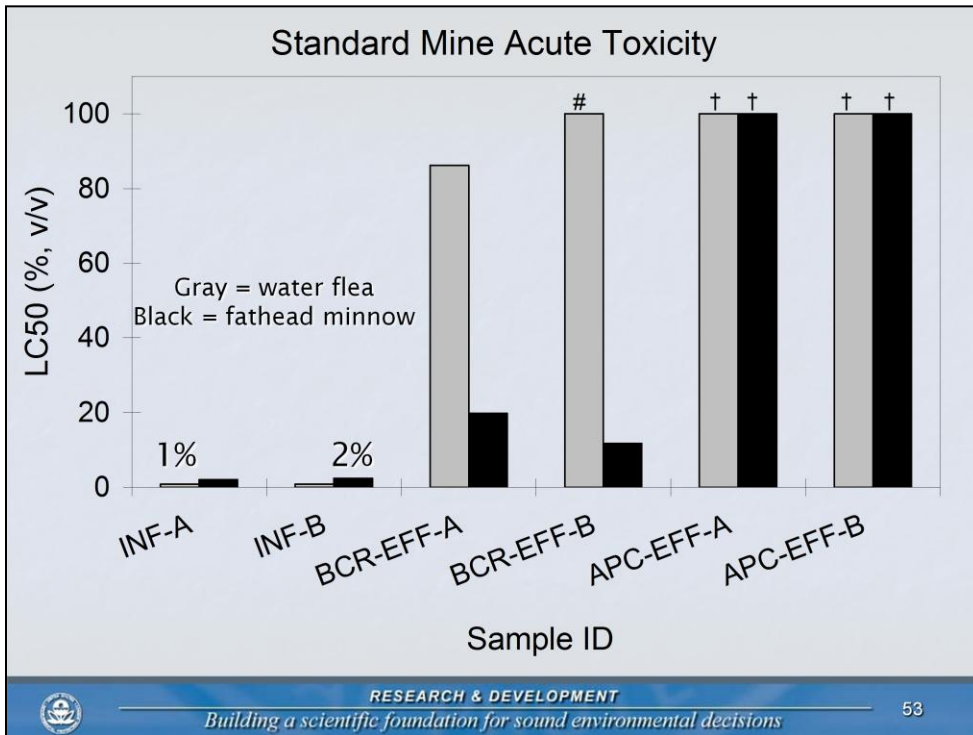
Analyte	Site	
	BCR	APC
Al	N/A	N/A
As	N/A	N/A
Cd	100 +/- 2	100 +/- 2
Cu	94 +/- 9	94 +/- 9
Fe	-266 +/- 518	100 +/- 10
Ni	N/A	N/A
Pb	94 +/- 16	91 +/- 17
Zn	100 +/- 3	100 +/- 3
SO4	39 +/- 4	72 +/- 5

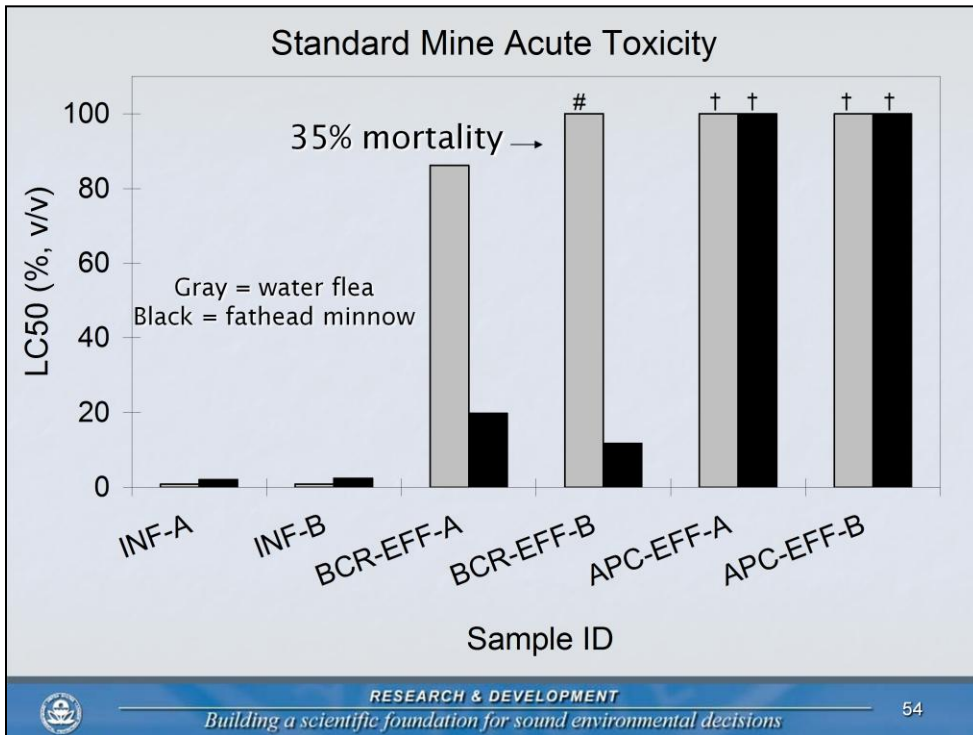


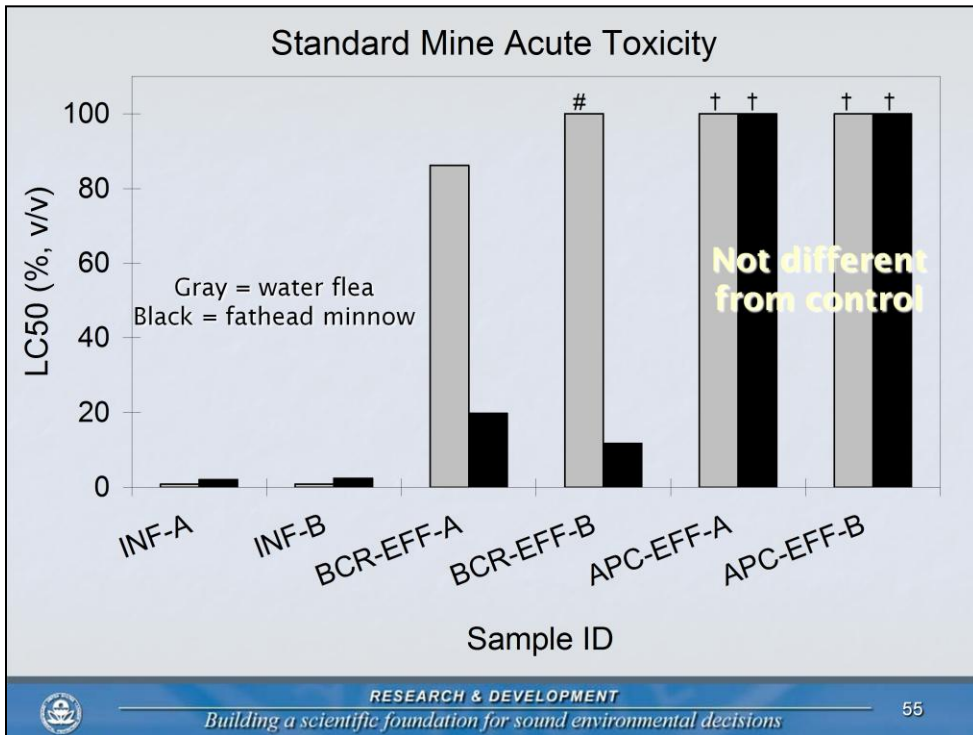
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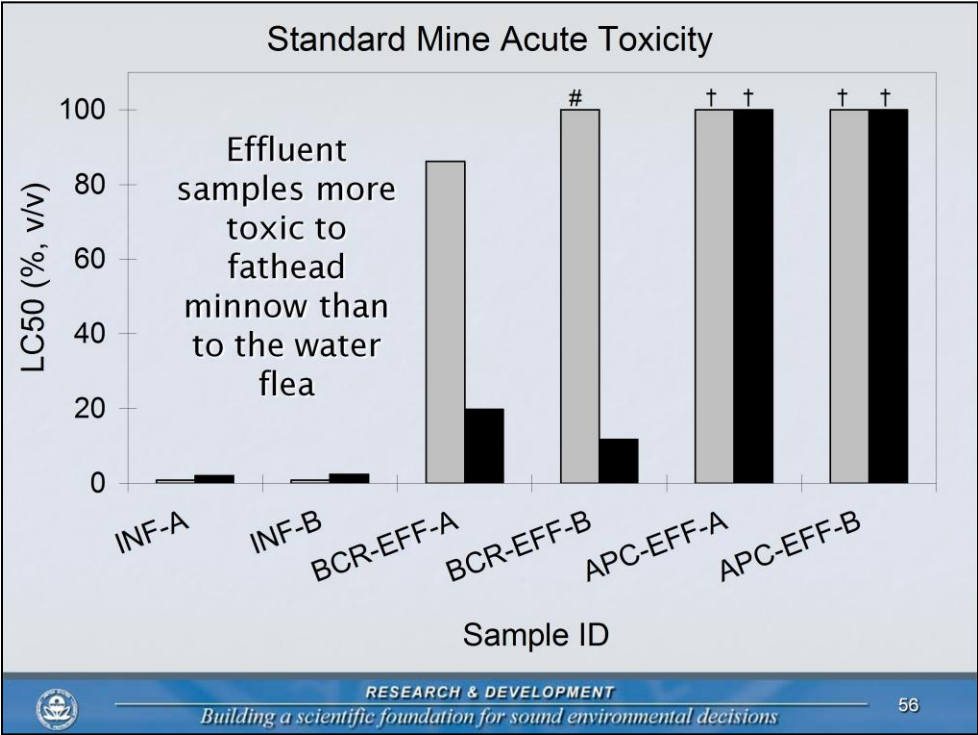
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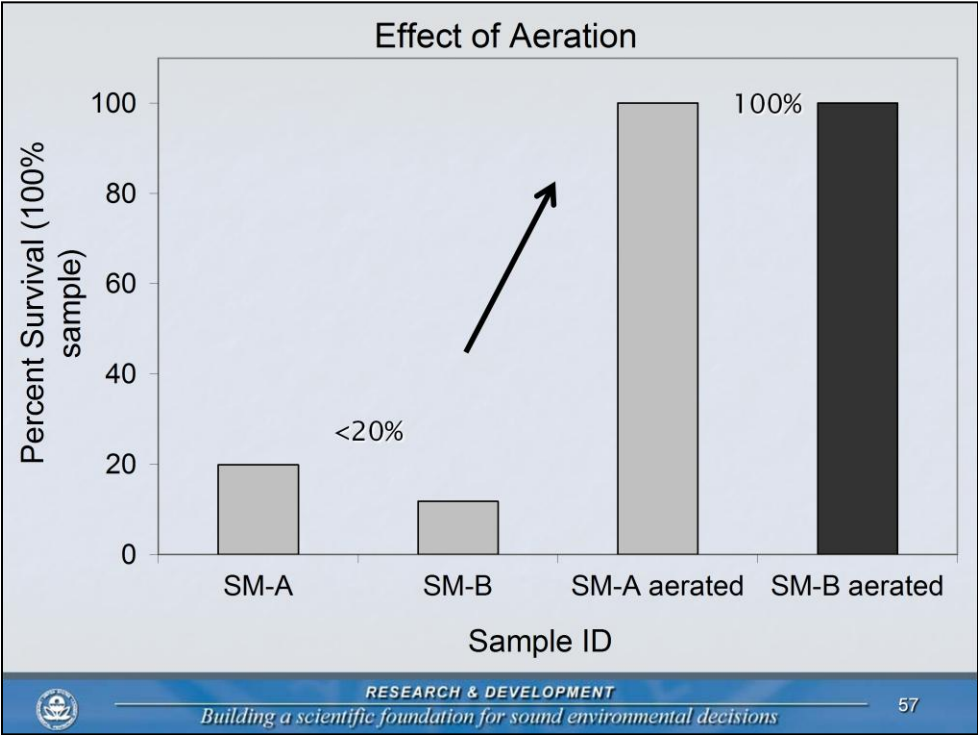
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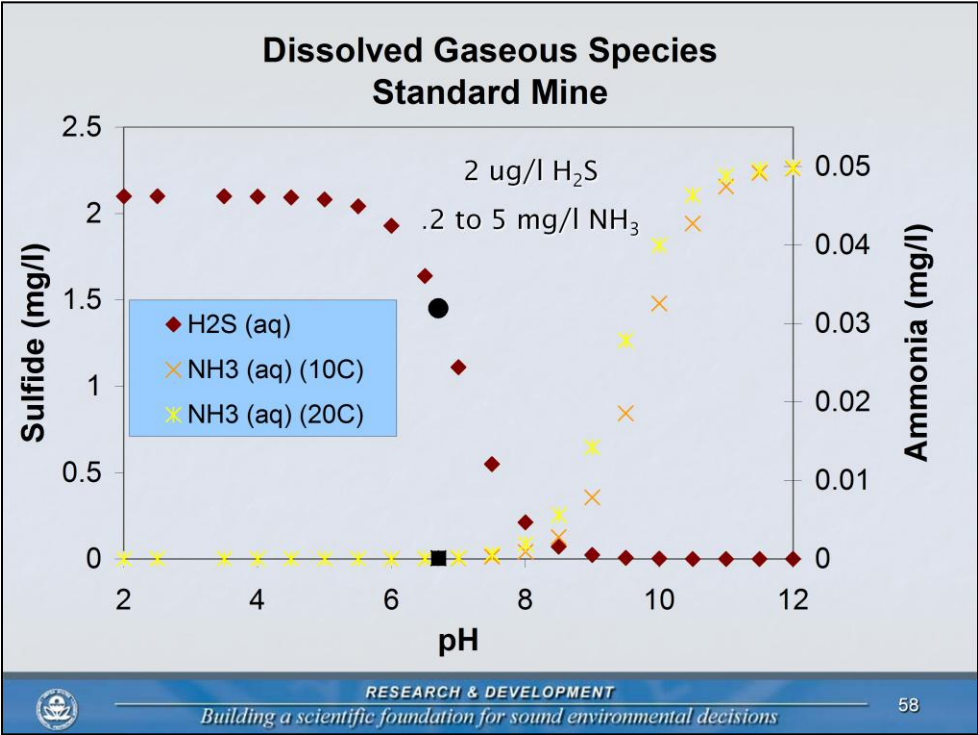












Passive Treatment Case Study (Standard Mine, Colorado)

- 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.

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