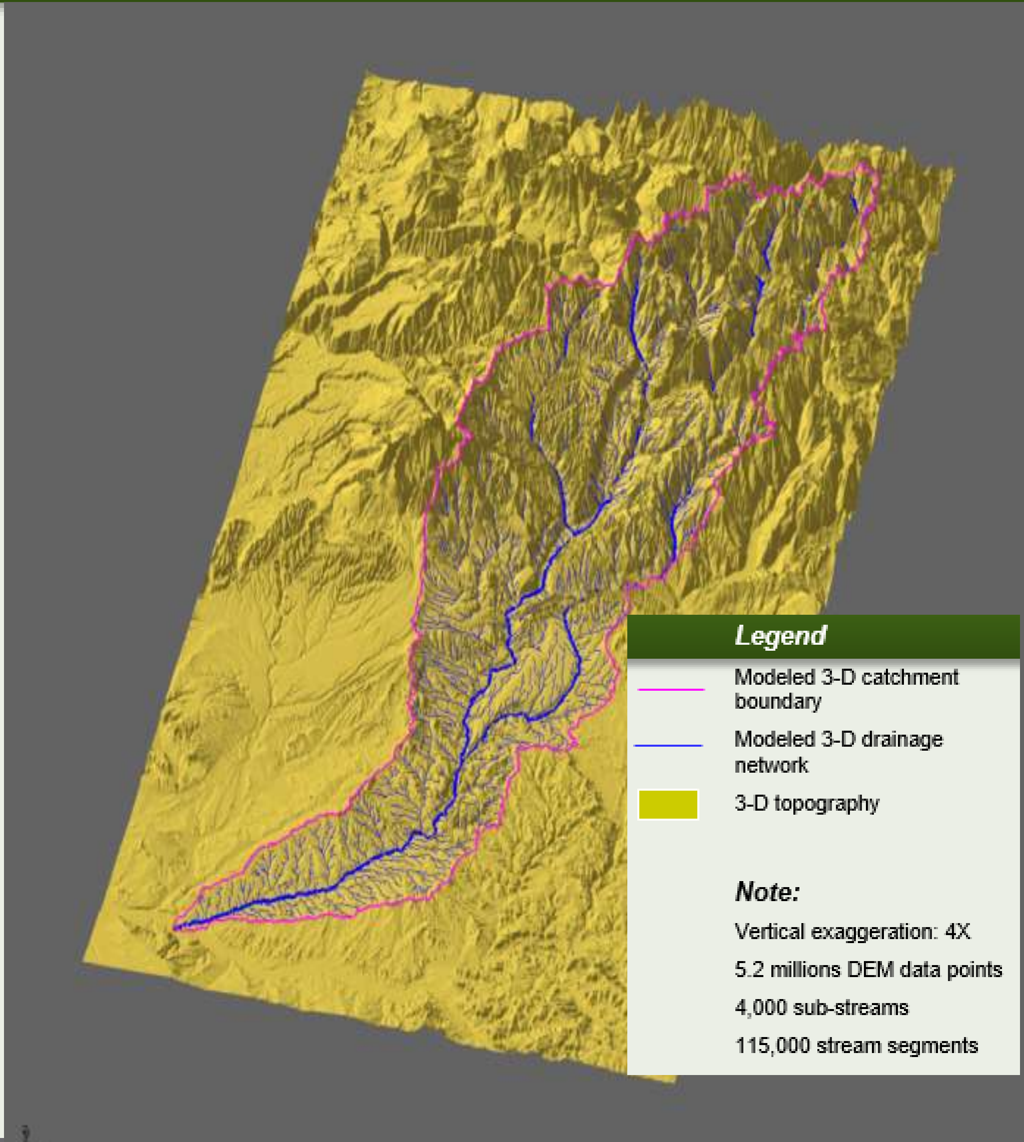
Digging Deeper

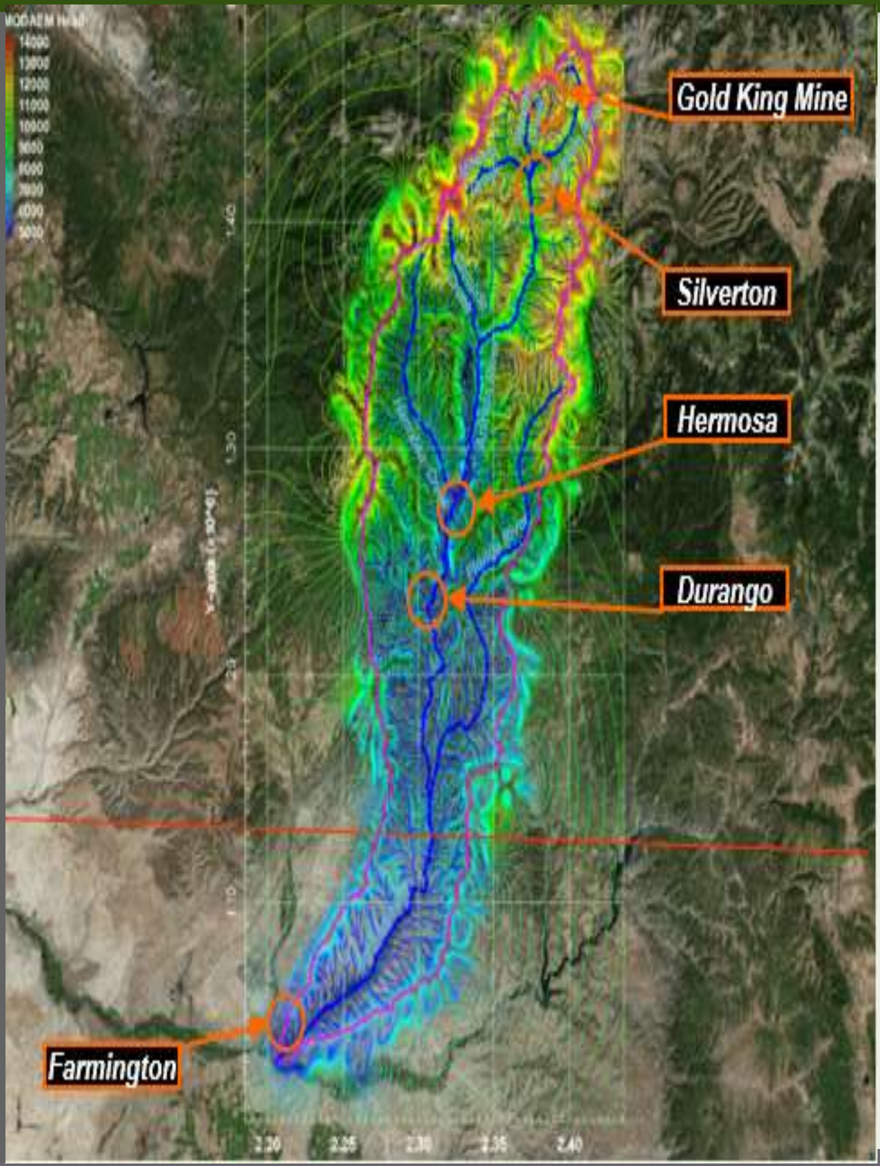
ORD Support for Innovative Technologies and the Remedial Investigation/Feasibility Study in the Bonita Peak Mining District

July 25, 2017

Stephen Dyment, US EPA ORD, Denver CO

ORD Involvement- Historical, Gold King Response





ORD Involvement- 2016 Optimization

A	B	C	D	E	F	G	H	I	J	K	L
Planning Level	Project Team	Task Team	Task Focus	Action Priority Type	Level 1 Action Group Priori	Level 2 Action Item Sequen	Action Items	Details / Meeting Participant Notes / Questions	Agency Organization	Lead Personnel	Action Item Due Date
Program Planning	Response Action	Interim/Early Actions	Regulatory		1		Consider FLM Land Use Plans		EPA R8-BLM-USFS-CDI	R. Thomas, B Lewis, B. Martinez, M.	
Program Planning	Program Mgmt	Stakeholder Engagement	Regulatory				Coordinate with Natural Resource Damage Trustees		EPA R8	Rebecca Thomas, Dan Wall	
Project Planning	Characterization-Hy	Groundwater	Planning	High			Determine whether to use a loading model (such as OTEC)		EPA R8	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	MIW	High	1	1	Complete MIW Elevation, Adit Pooling and Discharge Assessments		EPA R8-BLM-USFS-CDI	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	MIW	High	3	2	Complete MIW Elevation, Adit Pooling and Discharge Assessments - Sunnyside Min		EPA R8	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	Water Balance/GW	High	1	2	Determine Relative Contribution from Each Mine Site	characterize mineralogy changes over short distances	EPA R8-BLM-USFS-CDI	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	Water Balance/GW	Low	2	2	Develop Drainage Basin-Specific Water Balances		EPA R8	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	Water Balance/GW	Low	2	3	Develop Site-Wide GW/SW Water Balance		EPA R8	Ian Bowen	
Project Planning	Characterization-Hy	Groundwater	Water Balance/GW	High	3	1	Identify Groundwater Data Gaps as Partial Basis for RI Planning		EPA R8	Ian Bowen	1/11/2017
Project Planning	Characterization-Hy	Groundwater	Water Balance/GW	Low	4	1	Confirm need for Tracer (dye, isotopic and natural) studies		EPA R8	Ian Bowen	
	Characterization-Hy	Groundwater	MIW	High			Identify locations for 2017 well installations			Ian Bowen	1/11/2017
Program Planning	Program Mgmt	Project Mgmt	Planning	Medium			Develop Contingency, Notification and Emergency Action Pla	Plan that discusses sampling/observation protocol, trigger notification, and steps for notifying stakeholders of	EPA R8-BLM-USFS-CDI	R. Thomas, C. Peterson, K. Bistrom	1/30/2017
Program Planning	Response Action	Interim/Early Actions	Gladstone IWTP				EPA R8 remedial program assumes responsibility for Gladstone WTP		EPA R8	Rebecca Thomas	1/31/2017
	Characterization-Ot	Interim/Early Actions	Gladstone IWTP	High			Review analytical results of IWTP sludge and Kittimack tailings samples		EPA R8-CDM Smith	Joyel Dhieux, Bob Re	1/31/2017
Program Planning	Program Mgmt	Stakeholder Engagement	WQS		1	1	Coordinate With Colorado Water Conservation Board about State Standards		CDPHE	Mark Rudolph	12/7/2016
Project Planning	Response Action	Interim/Early Actions	Interim/Early Actions		1	1	Limit Impacts to Recreational Use		EPA R8-BLM-USFS-CDI	R. Thomas, B Lewis, B. Martinez, M.	
Project Planning	Response Action	Interim/Early Actions	Interim/Early Actions		1	2	Prevent / Mitigate Recreational Bio-Hazards		EPA R8-BLM-USFS-CDI	R. Thomas, B Lewis, B. Martinez, M.	
	Characterization-Ot	Interim/Early Actions	Gladstone IWTP	High			Evaluate results of mixing sludge with Mayflower tailings		EPA R8-CDM Smith	Joyel Dhieux, Bob Re	1/31/2017
Project Planning	Enforcement	RI	Background		1	1	Determine whether ARARs can be developed without background		EPA R8-BLM-USFS-CDI	????	
Project Planning	Program Mgmt	Field OPS	Community Involvement		1	1	Schedule HAZWOPER training for local citizens		CDPHE	Mark Rudolph	
Program Planning	Characterization-Ot	Field OPS	Mine Access	High	1	1	Compile Recon Team Information on Physical Accessability of Mine Sites		CDM Smith	Neil Smith	2/15/2017

Optimization Products


EPA

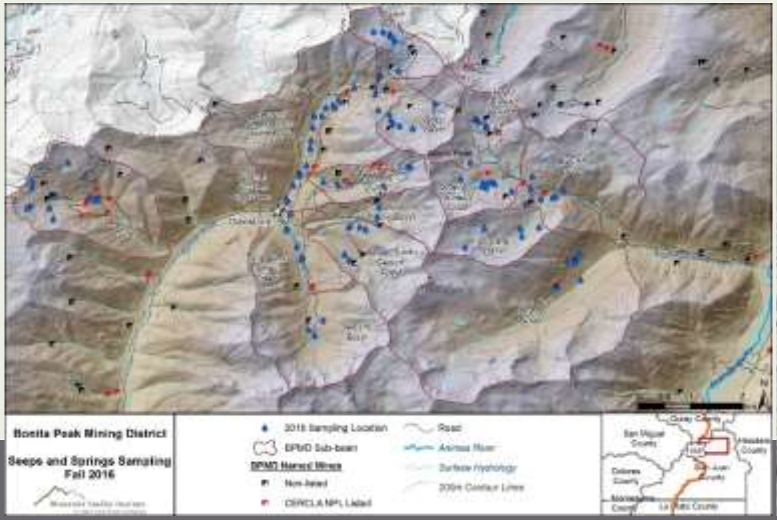
FINAL

FOCUSED OPTIMIZATION REVIEW:
GLADSTONE INTERIM WATER TREATMENT PLANT
BONITA PEAK MINING DISTRICT NPL SITE
SAN JUAN COUNTY, COLORADO

FINAL TECHNICAL MEMORANDUM

2016/2017 Remedial Investigation

- ♦ **Innovation in characterization technologies for a robust Conceptual Site Model (CSM)**
- ♦ **Initial efforts focused on water balance**
  - » Weather stations
  - » Sub-basin evaluation of GW flow paths
  - » MSI seep and spring sampling
  - » Stable Isotopes- Ratios of O^{18}/O^{16} and H^2/H^1
  - » Stream gauging

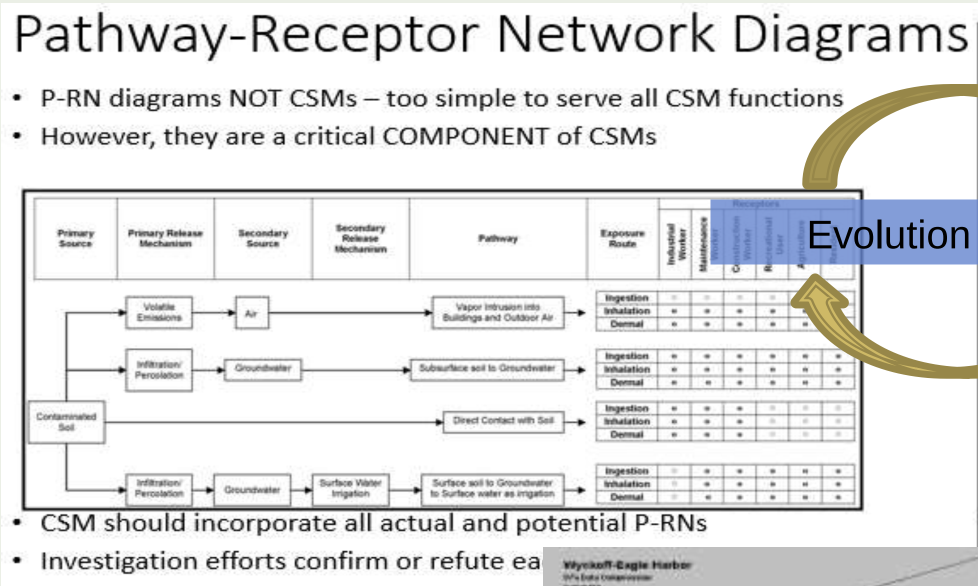


Just a Few of Future Possibilities for Characterization Technologies/Approaches in the Remedial Investigation

- **Geochemical Modeling**
  - Updates to OTEQ
  - PHREEQC- groundwater mixing and discharges (anion data)
- **Geophysics- lots of possibilities**
  - Electrical resistivity tomography (ERT)
- **Distributed temperature sensors**
- **Additional Isotope analyses- S, F, others**
- **Higher resolution LIDAR and Hyperspectral Imaging**
- **Tracers- injected, natural**
- **XRF/incremental sampling**
- **Other direct sensing and field analytics**

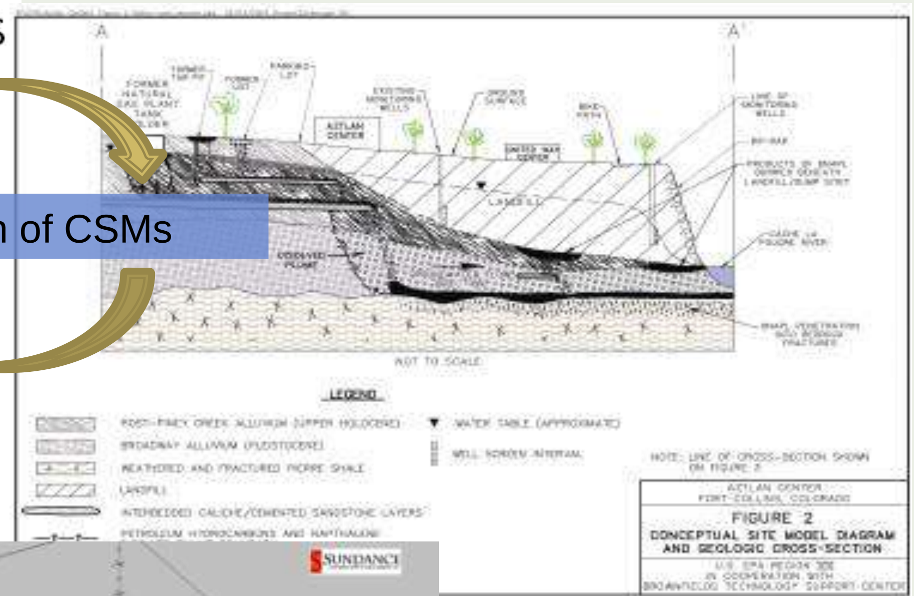
Collaborative Data Sets and Strong Data Management Leads to a Robust Conceptual Site Model

1980's—1990s

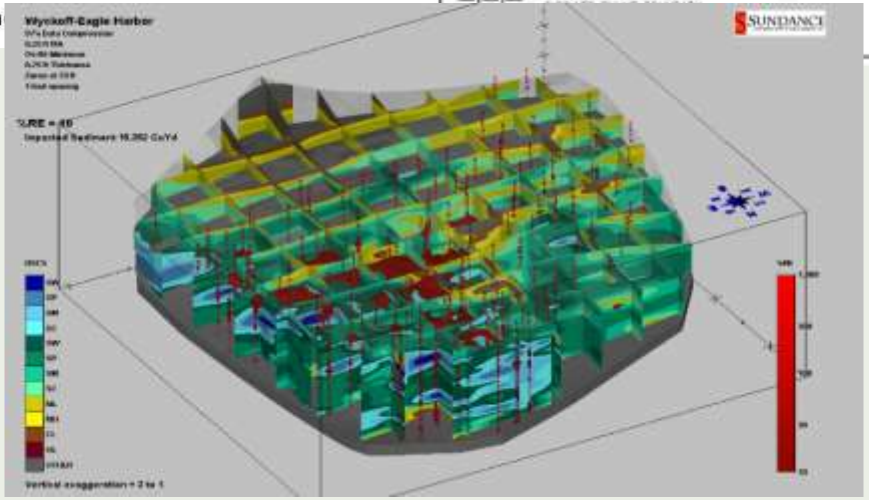


Evolution of CSMs

2000's



2010 to present



Wyckoff TarGOST

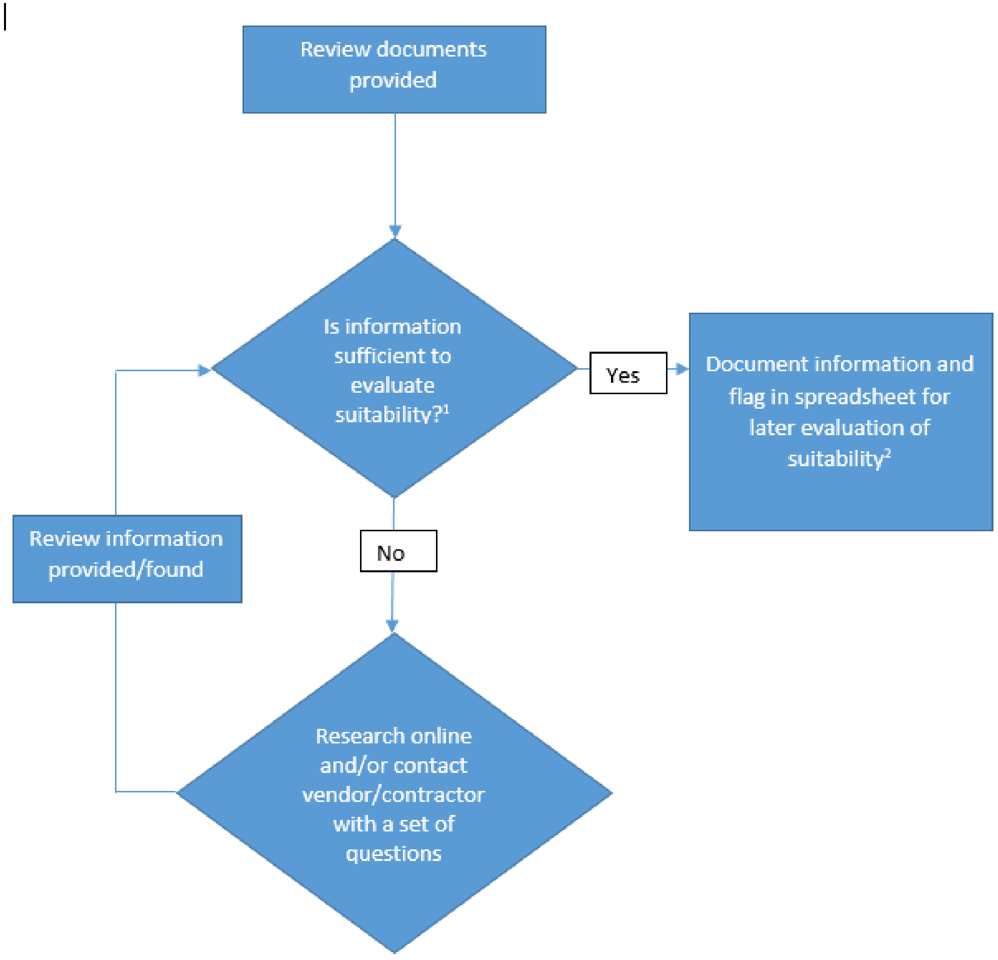
DRMS Upper Cement Creek

ORD Involvement- Remediation Technologies

- **Tracking Remediation Technologies and Vendors**

- **Suitability 1**
  - » Information vs. media and site conditions
  - » Contaminants and concentrations
  - » Min/Max treatable, Min attainable
  - » Treatment efficiency, energy requirements
  - » Scales of successful trials to date (bench, small pilot, full pilot, full scale)
  - » Level of monitoring
  - » Waste generated, volumes, disposal
  - » Known limitations, expected footprints
- **Suitability 2**
  - » In-depth comparisons of vendor info vs specific physical/chemical site characteristics
  - » Where a given technology might be most suitable

- **Process For Evaluating Remediation Technologies**



Remediation Technologies

- **Complimentary Information and Efforts**
  - OSRTI TIFSD literature search
    - 2018- Handbook of Case Study Treatment Technologies for Mining Wastes and Mining-Influenced Water. On-line "living" document
    - Consolidating case studies for systems at hard rock mining sites- operating >6 months, 35-40 SF sites, waste rock/tailings, adits, underground workings, groundwater, surface water, leachate, soil, sediment, open pits
    - Evaluating treatment trends, technology and method success/failure, future gaps for new/refined technologies, tool for technology screening
  - Full case studies
    - R1- Elizabeth Mine
    - R8- Rico/Argentine

Superfund Process- Remedial Investigation and Feasibility Study

EPA/540/G-89/004
OSWER Directive 9355.3-01
October 1988

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA

Interim Final

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, D.C. 20460

128301

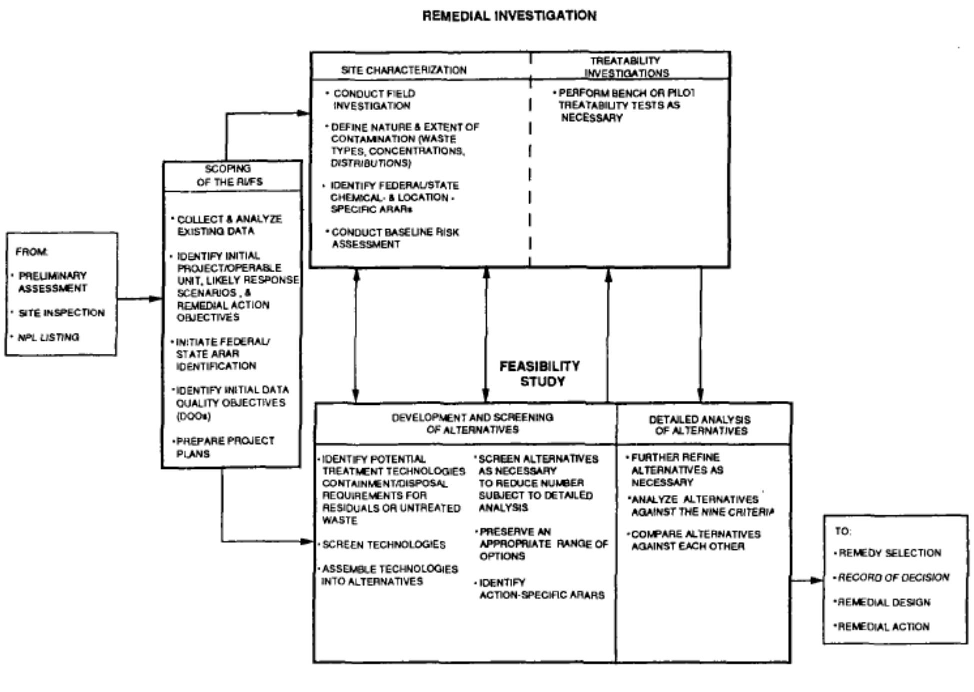


Figure 1-1. Phased RI/FS Process.

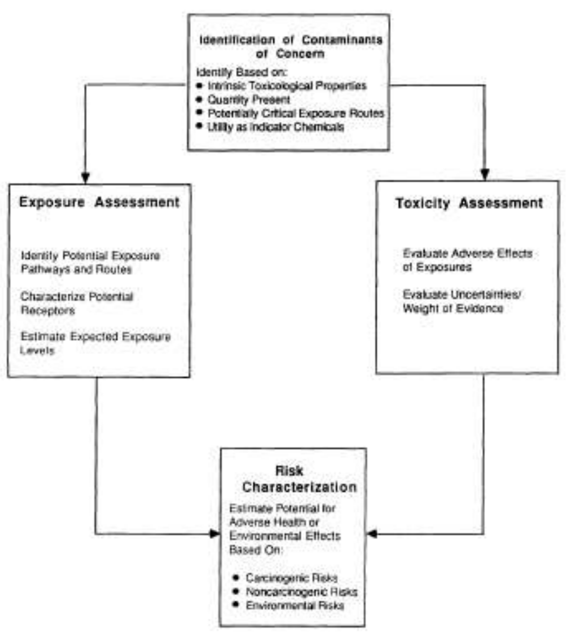
Superfund Process- Remedial Investigation and Feasibility Study

- **Used to establish nature and extent of contamination and risks**
- **Recognizes uncertainty, information necessary for a risk management approach**
- **Preference for treatment**
- **Recognizes importance of CSM**
  - Site physical characteristics
  - Contaminants and distribution
  - Fate and transport
- **Documentation, data management**
- **Data analysis**
- **Stakeholder and community engagement**
- **Process for developing/screening alternatives**

1.3.1 ***Cleanup Standards***

Section 121 (Cleanup Standards) states a strong statutory preference for remedies that are highly reliable and provide long-term protection. In addition to the requirement for remedies to be both protective of human health and the environment and cost-effective, additional remedy selection considerations in §121(b) include:

- A preference for remedial actions that employ treatment that permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element
- Offsite transport and disposal without treatment is the least favored alternative where practicable treatment technologies are available
- The need to assess the use of permanent solutions and alternative treatment technologies or resource recovery technologies and use them to the maximum extent practicable



National Contingency Plan- 9 Criteria for Remedy Selection

- NCP- Preamble to CERCLA, provides detail on SF process, when selecting SF remedies EPA must consider 9 criteria

Threshold Criteria

1. Overall Protection of Human Health and the Environment
2. Compliance with regulations (ARARs)

Balancing Criteria

3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost

Modifying Criteria

8. State Acceptance
9. Community Acceptance

Setting Expectations

- **No existing ORD technology verification programs**
  - » Historically

https://clu-in.org/

SITE
SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION

EPA ETV
www.epa.gov/etv
U.S. Environmental Protection Agency
Environmental Technology Verification

FIELD ANALYTIC TECHNOLOGIES ENCYCLOPEDIA (FATE) – AN ONLINE RESOURCE (FATE.CLU-IN.ORG)

- » Opportunities Still Exist!
  - › Superfund- Ch 5 RI/FS

Opportunities Still Exist

- **Superfund**
  - RI/FS guidance- ch 5 treatability investigations, testing (bench and field pilot scale)
  - STL extramural funding
- **ORD Regional Research**
  - Regional Applied Research Effort (RARE)
  - Regional Sustainable Environmental Science (RESES)
  - Regional Research Partnership Program (RRPP)
  - Regional/ORD Community of Science Networking (ROCsNet)
  - Other opportunities
    - Metals speciation for CO Smelter
- **ORD Innovation**
  - R8 proposal accepted on harmful algal bloom crowdsourcing
  - AML proposal and use of adventure scientists

Partnerships Beyond EPA

- **Strong partnerships with BLM and USFS**
  - Pilot opportunities
    - Green age
  - Future opportunities- Biochar/amendments
- **Other Federal Agencies- USGS, USFW**
- **Academic Institutions**
  - MSI
  - Colorado School of Mines
  - CSU, CU
  - University of CO Denver- bulkhead closure
  - Robotics
- **Private consultants/property owners**
  - Surfactant based bactericides to slow pyrite oxidation
  - Agreements for information sharing

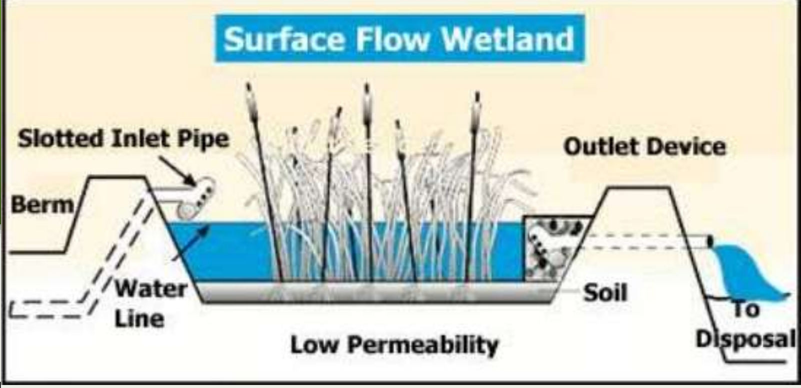
Categorizing Technologies for Tracking and Evaluation

- **Contaminated Media: Mining Influenced Water (MIW)**
  - Treatment type
    - Passive treatment
    - Active treatment (and semi-passive options)
  - Mechanism
    - Chemical
    - Biological
    - Electrochemical (active options)
    - Physical
- **Solid Mining Wastes**
  - Amendments
  - Microbiologically induced precipitation
  - Passivation
  - Stabilization/solidification
  - Caps
- **Technologies and methods that aid treatment**

Technology Examples

- **Contaminated Media: Mining Influenced Water (MIW)**
  - Passive Treatment
    - Aerobic Processes-
      - Wetlands (surface, rock)
      - Open Limestone Channels
      - Permeable reactive barriers (PRBs)
      - Adsorption processes
      - In-situ microbiological stimulation (amendment with nutrients, organic source, and/or micro-organisms)
      - In-situ neutralization and precipitation
      - Iron terraces
      - ©Aqua-fix Systems unit (semi-passive)
      - Bauxol™ mud residue from alumina production
      - Algal mat / microbial mat

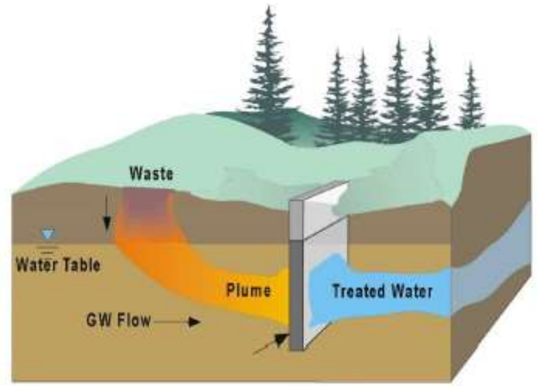
Technology Examples



- ♦ **Constructed Wetlands-**
  - » For MIW passive, aerobic
  - » Wetland plant materials on soil/crushed rock
  - » Aerobic systems similar to natural wetlands, utilizing surface flow
  - » Contaminants can be removed via precipitation, plant uptake, volatilization, and biological reduction

- ♦ **Advantages**
  - » Low capital investment and operation/maintenance costs
  - » Alkaline water, aeration can improve oxidation
- ♦ **Limitations**
  - » Low flow rates, reliable flow, large area vs flow
  - » Periodic dredging required
  - » Neutralization of acidic water may be needed (via ALD)
- ♦ **Keys**
  - » Biochemical processes, loading rate, retention time, slope, substrate, vegetation, sediment control, geometric configuration, seasonality, and regulatory requirements

Technology Examples



Permeable Reactive Barrier
Image Source: http://clu-in.org/download/rtdf/prb/reactbar.pdf

- **Permeable Reactive Barriers**
  - For MIW passive, aerobic
  - Direct contact with reactive media- ZVI, limestone, compost, zeolites, activated carbon, apatite
  - Immobilize
- **Advantages**
  - Common, low operation/maintenance costs- 5-10 years
  - Variety of configurations (funnel and gate, continuous) and contaminants
  - Radionuclides, trace metals, anions
- **Limitations**
  - Biofouling, precipitate clogging,
  - Media disposal for immobilization applications
- **Keys**
  - Hydrostratigraphy, plume capture, flow direction/velocity, resonance time
  - Example: U tailings in Durango- Se 359 ug/L to 8 ug/L

Technology Examples

- **Contaminated Media: Mining Influenced Water (MIW)**
  - Passive Treatment
    - Anaerobic Processes-
      - Anaerobic wetlands (also called subsurface or vertical wetlands)
      - Anoxic limestone drain
      - Reducing and alkalinity producing systems (RAPS, also previously called successive alkalinity producing systems and combines mechanisms of wetlands and ALDs)
      - Biochemical reactor (BCR, similar to anaerobic wetland, also called sulfate reducing bioreactor, or bioreactor)
      - In-situ microbial/biochemical treatment

Technology Examples

- **Anaerobic Wetlands**
  - For MIW passive, anaerobic
  - Vertical or horizontal flow configuratio
  - Subsurface flow through porous media or sand), wetland species on top of me
  - Contaminants can be removed via plar uptake, volatilization, and biological re
- **Advantages**
  - Low capital, O&M
  - Treatment train applications
- **Limitations**
  - Periodic dredging required
  - Low flow rates, reliable flow, pH changes (desorption, resolublization)
  - Neutralization of acidic water may be needed

Figure 5. Vertical Flow and Horizontal Flow Constructed Wetlands

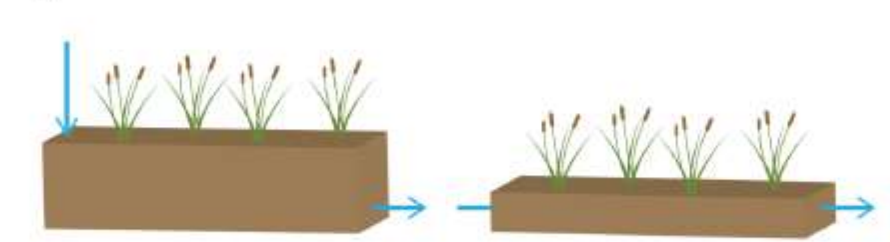
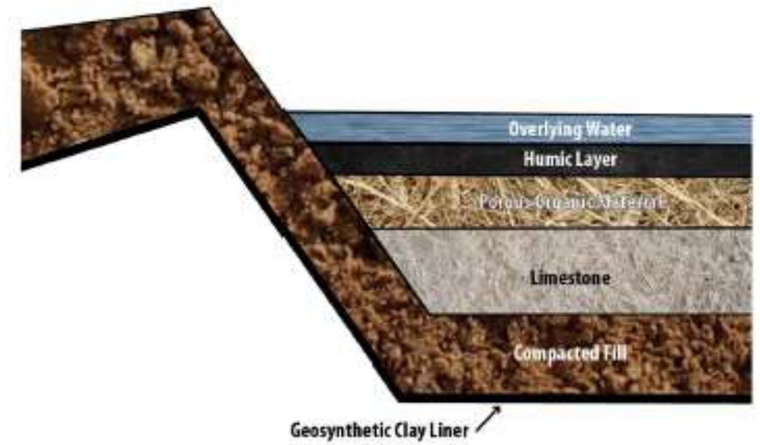
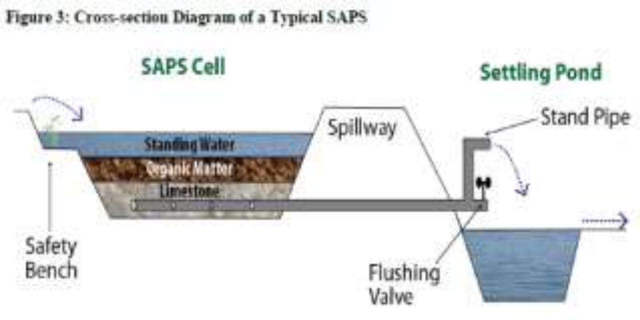


Figure 6. Cross-Section of a Constructed Wetland Design



Technology Examples

- **Reducing and Alkalinity Producing System (RAPS)/ Successive Alkalinity Producing Systems (SAPS)**
  - For MIW passive, anaerobic
  - Vertical flow configuration (top down, bottom up)
  - Combines ALD with organic substrate (straw)
  - Organic substrate creates reducing environment limestone for pH, biological reduction
- **Advantages**
  - Good Al, Fe, Cu removal rates
  - Treatment train applications
- **Limitations**
  - Decreased permeability over time, clogging, regular maintenance
  - High DO in influent can be design limitation



Technology Examples

- **Biochemical Reactors (BCRs)**
  - For MIW, passive, anaerobic
  - Uses microorganisms to remove contaminants
  - Variety of designs- open/buried ponds, trenches, flow up/down/horizontal
  - Can be aerobic or anaerobic, passive or active but….
  - Most BCRs at mine sites operate anaerobically using sulfate reducing bacteria with post treatment aeration, settling
  - Metal sulfides precipitated and removed
- **Advantages**
  - Can handle wide variety of flows, acidity, and metals loading
  - Zn, Pb, Cu, Cd, Co, Ni, As, Cr, Se, Th, U
  - Luttrell BCR (10 Mile Creek near Helena MT)- treating repository leachate since 2003 at 95-98% removal efficiency, most metals
- **Limitations**
  - Treatment train, some substrate clogging
  - May be susceptible to cold (2007 Standard Mine)
  - Odors, initial discoloration of effluent
  - Luttrell- Aeration may reduce short term toxicity (H2S)

Image Source:
http://www.itrcweb.org/miningwaste-guidance/to_bioreactors.htm

Categorizing Technologies for Tracking and Evaluation

- **Contaminated Media: Mining Influenced Water (MIW)**
  - Active Treatment (and semi-passive options)- chemical, biological, and electrochemical
    - Membrane technologies – reverse osmosis, ultrafiltration, nanofiltration
    - Ion exchange
    - Liquid-liquid extraction
    - Neutralization, precipitation, and sorption
    - Rotating cylinder treatment system (RCTS, developed by Ionic Water Technologies)
    - Anaerobic precipitation of metal sulfides (BioteQ® BioSulphide® and ChemSulphide®)
    - Chelation
    - Oxidation
    - Electrokinetic /electrochemical processes – electrocoagulation, electroplating, electrowinning, cementation
    - Electrobiochemical reactor (EBR)
    - Fluidized bed reactors (FBR)
    - Moving bed biological reactors (MBBRs)
    - Packed bed reactors
    - Photoreduction
    - Physical

Technology Examples

- ♦ **Membrane Technologies**
  - » Reverse Osmosis- pressure gradient, semi-permeable membrane
  - » Microfiltration
    - › Nanofilters- larger pore size (1 nanometer) vs. RO

Figure 12: Two Reverse Osmosis Treatment Racks at the BCWTP

Image Source: http://www.itrcweb.org/miningwaste-guidance/cs48_kennecott_south.htm

- ♦ **Advantages**
  - » Scalable- metals, sulfate, TDS
  - » High efficiency removal rates
  - » Effective to meet more stringent discharge requirements
  - » Se removal

Figure 21: Ceramic Microfiltration System at the Upper Blackfoot Mining Complex, Montana

Image Source: http://deq.mt.gov/StateSuperfund/UBMC/watertreatmentplant.mcpx

- ♦ **Limitations**
  - » High capital investment and operation/maintenanc
  - » Requires high operating pressures- RO 3X Nano
  - » RO with High TDS- >10,000 mg/L
  - » Pre-treatment/chemical addition for scaling/fouling
  - » Brine or permeate management
  - » Some salts added back for discharge

Technology Examples

- **Neutralization, precipitation, sorption**
  - For MIW, active and passive
  - Lime addition- oxidation/precipitation of metals
  - Flocculation, clarifiers, sludge
- **Advantages**
  - Widely used, well documented
  - Use elements in a variety of active/passive techniques
  - Generally higher flows
  - Effective to meet more stringent discharge requirements
- **Limitations**
  - Capital investments, operation and maintenance
  - Iron loading, filter systems
  - Sludge management- density, moisture c

Technology Examples

- **Rotating Cylinder Treatment Systems (RCTS)**
  - For MIW, active
  - Lime addition- oxidation/precipitation of metals
  - Cylinders agitate/oxygenate water to reduce scaling, common in lime addition systems
  - 2008 Gladstone pilot, Sudan Mine (CA), Rio Tinto Mine (NV), Elizabeth Mine (VT)
- **Advantages**
  - Can handle high acidity, high sulfate waters
  - Operate in cold weather and remote locations, low power/footprint requirements
  - Pilots have successfully treated metals to discharge requirements in most cases
  - Reduction in lime requirements
- **Limitations**
  - Removal of suspended solids to meet discharge
  - Scaling reduced but plugging may be problematic

Image Source:
http://www.asmr.us/Publications/Conference%20Proceedings/2010/papers/0248-Eger-MN-1.pdf

Categorizing Technologies for Tracking and Evaluation

- **Solid Mining Wastes**
  - Amendments
    - activated carbon
    - biosolids and other composted organic materials
    - biochar
    - zeolites
    - limestone
    - Bauxol™ mud residue from alumina production
    - Chitin
  - Caps for tailings and waste rock
    - Geotextile caps
    - Polymeric spray-on coatings for capping waste rock or tailings solids
    - Cyanobacterial crusts (best done in dry regions, and may occur naturally there) – can also include algae and moss. Stabilize against wind and erosion.
    - Phytotechnologies/Evapotranspiration Covers
    - Geosynthetic Concrete Composite Mat (GCCM)

Technology Examples

- ♦ **Biosolids**
  - » Solid mine waste materials
  - » Primary organic solid by-product of wastewater treatment
  - » High carbon content, sequester contaminants and promote plant growth
- ♦ **Advantages**
  - » Readily available
  - » Well documented, often more effective than topsoil replacement
  - » Stabilize stream banks, difficult to remove mine waste
- ♦ **Limitations**
  - » Public perceptions
  - » Nutrient loading to water bodies
  - » Moisture content
  - » Trace contaminants


ECOLOGICAL REVITALIZATION OF CONTAMINATED SITES CASE STUDY

CALIFORNIA GULCH
LAKE COUNTY, COLORADO
SUPERFUND CASE STUDY

A Once Toxic "Moonscape" from Mining and Smelting Is Returned to Fertile Pasture and Native Prairie

This case study is part of a series focused on ecological revitalization conducted during contaminated site remediation and reuse; these case studies are being compiled by the U.S. Environmental Protection Agency (EPA) Technology Innovation and Field Services Division (TIFSD). The purpose of these case studies is to provide site managers with information on ecological reuse, including principles for implementation, recommendations based on personal experience, a specific point of contact, and a network of sites with an ecological reuse component.

Historical mining in Lake County, Colorado, resulted in releases of tailings and water with high metals concentrations via California Gulch to the Upper Arkansas River and associated irrigation ditches. These releases created unvegetated mine waste deposits in the floodplain and agricultural land with areas of reduced or no productivity. Over the years, the tailings continued to erode and re-deposit along the Upper Arkansas River, creating a 9-mile stretch of river containing barren mine deposits. Many of these deposits accumulated along eroding stream banks and were coated with metals salts that washed into the river during storms. Vegetation and the soil community were limited by high metals concentrations, low pH, insufficient macro- and micro-nutrients, poor physical properties, and reduced water holding capacity.

During a series of demonstration projects and ultimately a remedial action, the fluvial deposits and irrigated meadows were amended with organic residuals, lime, and fertilizer and seeded with native and crop species to produce a stable vegetative cover that reduces dust, erosion, washing of metals into the river, and the availability and toxicity of metals contaminants. Testing conducted by EPA and the U.S. Department of Agriculture (USDA) showed that total concentrations of metals of concern in soil did not change, but that bioavailable lead,

Ecological Revitalization = the process of returning land from a contaminated state to one that supports functioning and sustainable habitat.

Topics Highlighted in this Case Study:
✓ Attractive Nuisance
✓ Bioavailability
✓ Erosion
• Invasive Species
• Predator Control
✓ Recreation
✓ Soil Amendments
✓ Use of Native Plants
• Use of Volunteers
• Water Management
• Wildlife Habitat
• Freshwater Wetland
✓ Prairie
• Saltwater Wetland
• Savannah
✓ Stream
• Woodland

May 2011, EPA542-F-11-007 www.cluin.org/ecotools 1

Technology Examples

- **Biochar**
  - Solid mine waste materials
  - Organic materials exposed to elevated temperature/no O2 (Pyrolysis)
  - High carbon content, sequester contaminants and promote plant growth
  - MSI 2010-2012, R7 Biochar study
- **Advantages**
  - Readily available
  - Can be engineered towards desired properties
- **Limitations**
  - Plot studies to consider larger scale performance
  - Feedstock source material and temperature
  - Some biochars can add Fe, Mn to SPLP

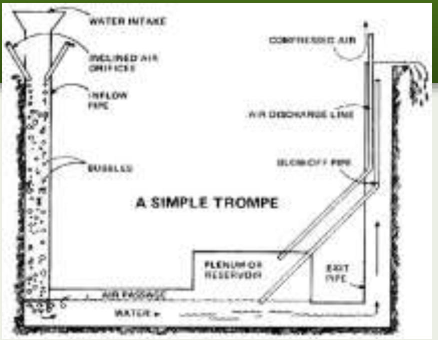
Technology Examples

- **Bauxsol ™**
  - Solid mine waste materials, collected water
  - Mud residues from alumina production
  - Soil amendment, added to damned/ponded water- precipitation 48 hrs
  - Guilt Edge Mine (SD)- trench, passive, pit lake application, solids in drums
- **Advantages**
  - Relatively inexpensive, no treatment plant infrastructure
  - Reusing waste from alumina production to treat a waste in water, solids
  - Sequesters high levels (designed 99.99%) of metals in soil and water
  - High acid neutralization capacity due to elevated crystalline minerals
- **Limitations**
  - As in the form of arsenite, As uptake interference with some anions
  - Additives like ferrous sulfate, ferric chloride, aluminum sulfate, jarosite minerals can create more + charges on minerals in Bauxsol™
  - Most of initial metals sorption happens quickly (24 hrs) but stability of metals can require longer contact time

Other Technologies/Considerations for Solid Mining Wastes

- **Microbially-induced calcium carbonate precipitation (MICCP) via urea hydrolysis, such as by using the bacterium *Sporosarcina pasteurii***
- **Passivation (coatings) – material applied to mitigate oxygen and water infiltration.**
  - pHoam™ - developed by Golder Associates (Jim Gusek)
  - Grout to coat and chemically stabilize waste rock and pit or tunnel walls
- **Stabilization/solidification – addition of a material to chemically and/or physically stabilize/solidify waste rock or tailings after being mixed into it.**
- **Sulfur polymer stabilization/solidification (SPSS) for mercury waste**
- **Other reagents/binders for stabilization – cement, phosphate**

Categorizing Technologies for Tracking and Evaluation



- **Technologies/methods that aid treatment technologies:**
  - Cavitation – provides sonication
  - Coagulation and flocculation – help create a denser sludge from precipitates
  - Evaporation/crystallization – a method to reduce waste water created from reverse osmosis or other membrane technologies
  - Trompe air compressor - use to supply energy
  - Diversion- surface water/groundwater
  - Solar panels and wind generators – to supply energy
  - Remote Sensing
  - Remote data collection
  - Weirs for aeration – precipitate iron; strips sulfide and adds oxygen to BCR/SRBR treated water

Technologies/Approaches To Aid Treatment

- **Water Diversion**
  - » Surface water- drainage ditches, trenches
  - » Groundwater- shallow trenches, engineered diversions, hydraulic controls
- **Advantages**
  - » Relatively inexpensive
  - » Keep “clean water clean”, limit influent/flows
  - » Better manage flows

Technologies/Approaches To Aid Treatment

- **Renewable Energy**
  - » Wind, solar, hydro
- **Advantages**
  - » Lower environmental footprint
    - › Energy, water, emissions
    - › Recycling/reuse of materials
    - › Minimizing human health and ecological impacts

Green Remediation Best Management Practices:
Integrating Renewable Energy into Site Cleanup

Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

Green Remediation Best Management Practices:
Mining Sites

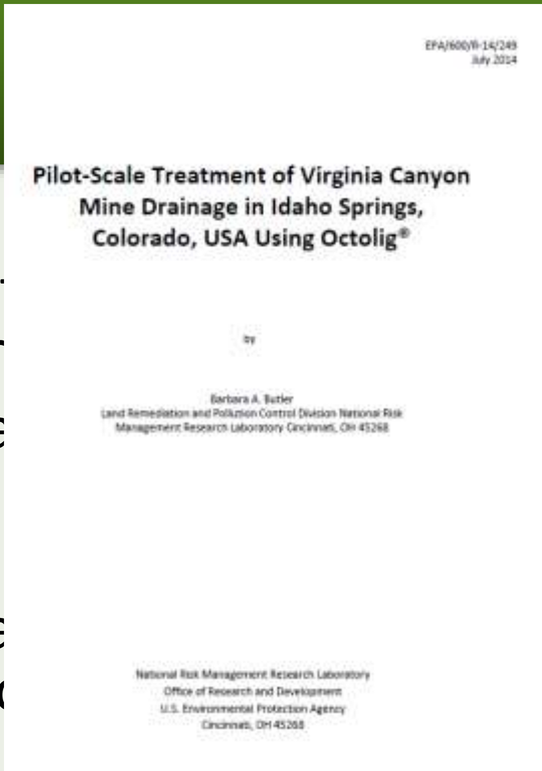
Office of Superfund Remediation and Technology Innovation — Quick Reference Fact Sheet

Technologies/Approaches To Aid Treatment

- **Weirs for Aeration**
  - » Precipitate Fe, strip sulfide,
  - » Add oxygen to BCR/SRBR treated water
  - » Decarbonation to remove CO2 prior to pH adjustment
- **Advantages**
  - » Relatively inexpensive
  - » Effective pretreatment to improve influent characteristics
  - » Improve post treatment effluent in BCR/SRBR systems

Economic Viability in Recovery?

- **There's gold in them hills!**
  - » Wellington Oro Mine (French Gulch)- Precipita
    addition), Cd/Zn Sulfide shipped to smelter for
  - » Berkeley Pit- Cementation (run water over scra
    cans), Cu recovery profitable (one report- 400,
    lbs/month)
  - » RARE project- Octolig process pilot 2014 (chela
    ligand), useful lessons learned however produ
    suitable for economic reuse



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Pilot-Scale Treatment of Virginia Canyon Mine Drainage in Idaho Springs, Colorado, USA Using Octolig®

by

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- **Be mindful of removal vs. recovery**
  - » For achievable recovery end product must be minimally processed to recover metals in a saleable form
  - » Selective precipitation, cementation, and electrowinning are examples of processes requiring little manipulation post treatment. Limitations depend on ionic composition/concentrations

Back to the Future

- **Continued ORD technical support**
  - Characterization
  - Remediation
- **Chase EPA funding opportunities**
- **Expand existing, develop new relationships**
- **Work closely with researchers (Fed/State/Tribal), academic and private researchers, identify opportunities for collaboration**
  - Access
  - Provide QAPPs, planning documents and information
  - Review/comment on approaches, sampling frequencies, etc. for vendor demonstrations

Questions and Discussion