SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

Mitigating Acid Rock Drainage with Land-Applied BCR Effluent

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Lakewood, Colorado

- ARD Refresher
- Biochemical Reactor Refresher
- Heap Leach Technology Refresher
- Vaccination versus Medication?
- Vaccination and Medication Concepts
- Medication Case Studies
- Cost Model

Acid Rock Drainage

A Medical Analogue

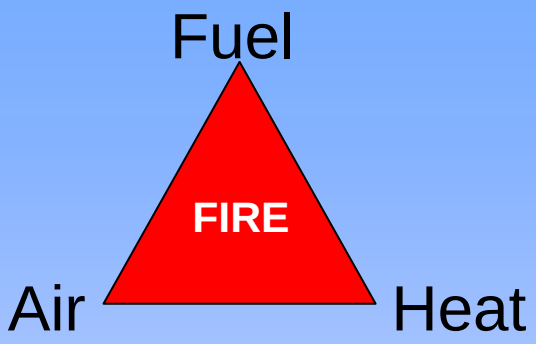
ARD is a global **bacterial infection**.

There are plenty of geo-antibiotics available but the current situation might be a lack of education. We've know about this for over 25 years.

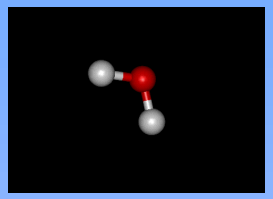
What's needed is a mining-analogue to an I-V drip of tetracycline and/or oral antibiotics.

And then there's the question: Do we need to **Vaccinate** or **Medicate**?

Acid Rock Drainage Tetrahedron

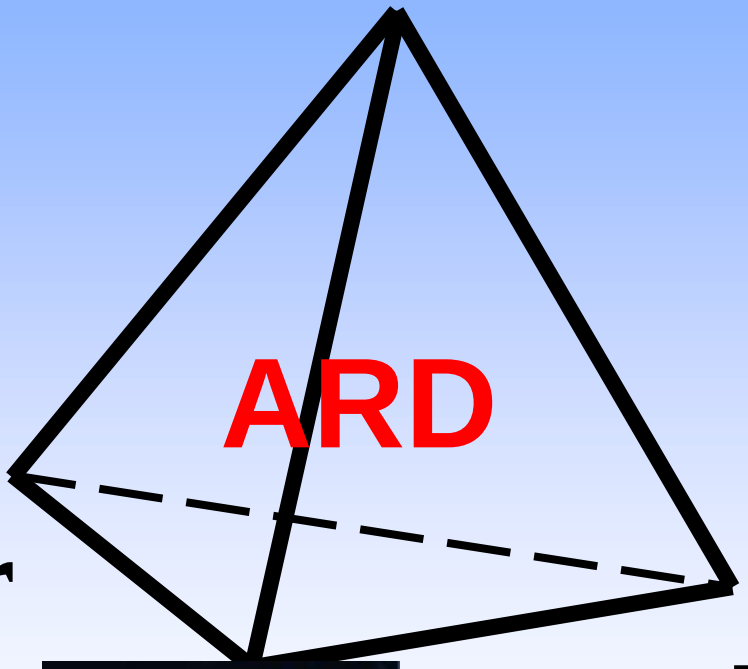


Water



Oxidizer

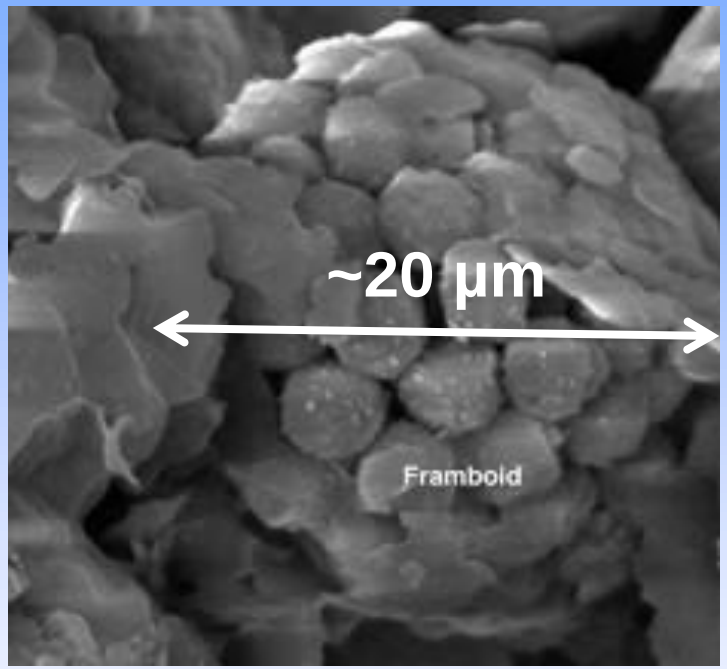
(Air, Fe^{+3})



Bacteria

Common Pyrite Forms

- Framboidal



- Crystalline

Ref: GARD Guide

Framboidal pyrite offers much more opportunity for bacterial colonization

Base Line Testing

Static Testing

- Paste pH
- Acid-Generation Potential
- % Sulfur (pyritic & total sulfur)
- Neutralization Potential

More Baseline Testing

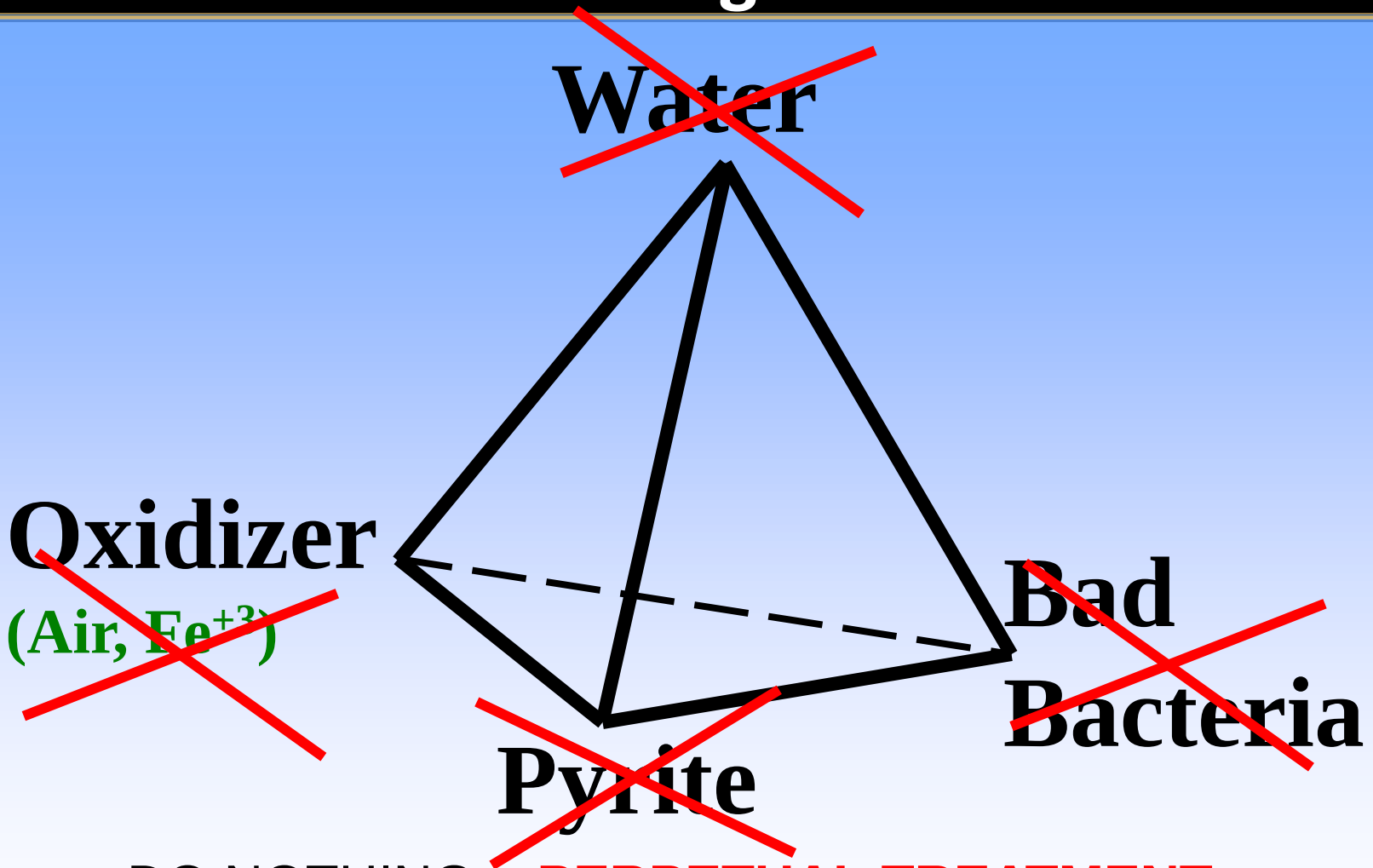
- Humidity Cells

- Column Tests

Tests rarely address potential remedies to ARD at a given site; sure, they predict that ARD will be a problem but…

The results don't provide me with any useful design data. This needs to change…

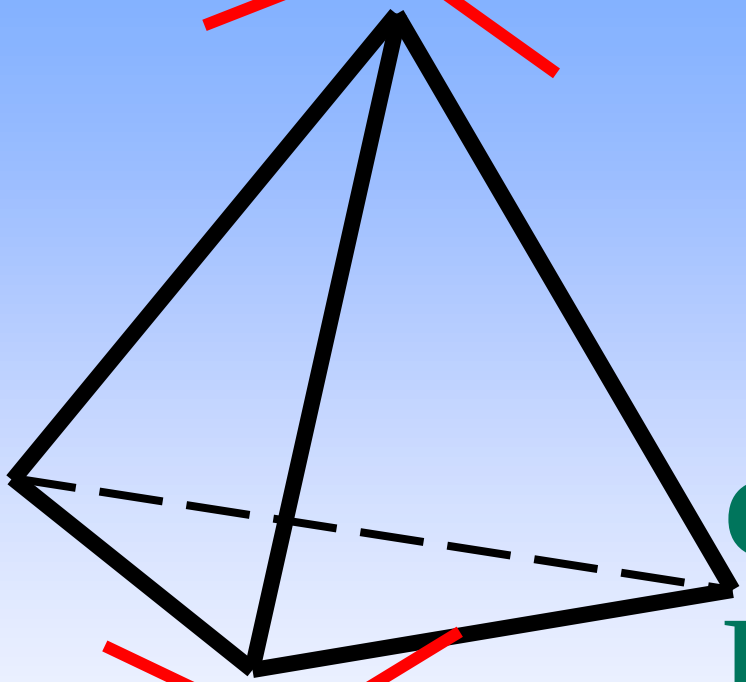
Acid Rock Drainage Tetrahedron



DO NOTHING = **PERPETUAL TREATMENT**

DO SOMETHING (anything) = **PATHWAY TO WALK-AWAY**

Acid Rock Drainage Tetrahedron



"PROBIOTIC"
PATHWAY TO WALK-AWAY

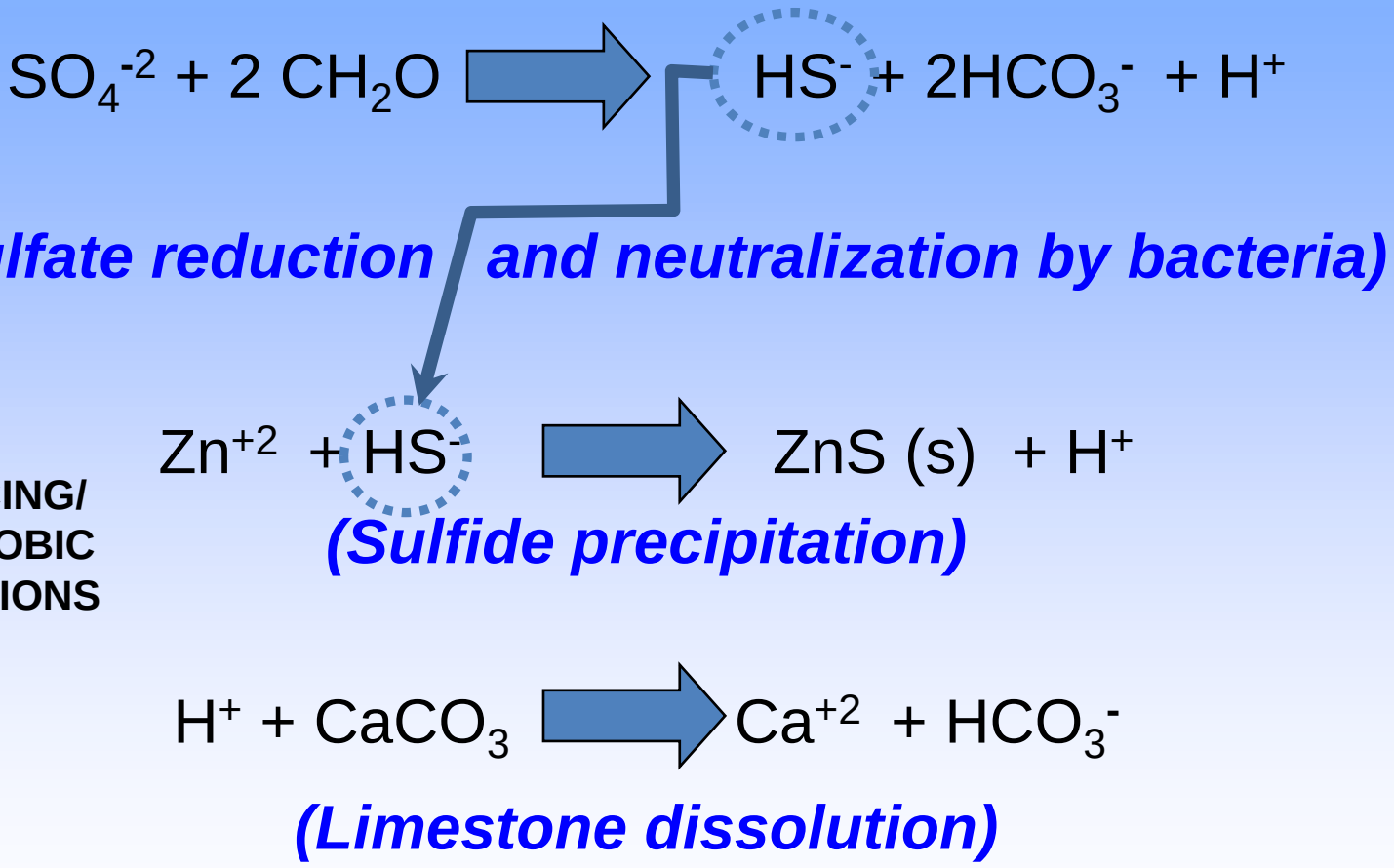
ARD Prevention Concept is Not New

"Control of acid generation for prolonged periods greatly enhances reclamation efforts and can reduce reclamation costs by reducing the amount of topsoil needed to establish vegetation. Three natural processes resulting from strong vegetative cover for three years or more can break the acid production cycle. These processes are:

- A healthy root system that competes for both oxygen and moisture with acid-producing bacteria;
- Populations of beneficial heterotrophic soil bacteria and fungi that are reestablished, resulting in the formation of organic acids that are inhibitory to T. ferrooxidans (Tuttle et al. 1977); and
- The action of plant root respiration and heterotrophic bacteria increase CO_2 levels in the spoil, resulting in an unfavorable microenvironment for growth of T. ferrooxidans."

Sobek, A. A., D.A. Benedetti, & V. Rastogi. 1990.

Biochemical Reactor Refresher



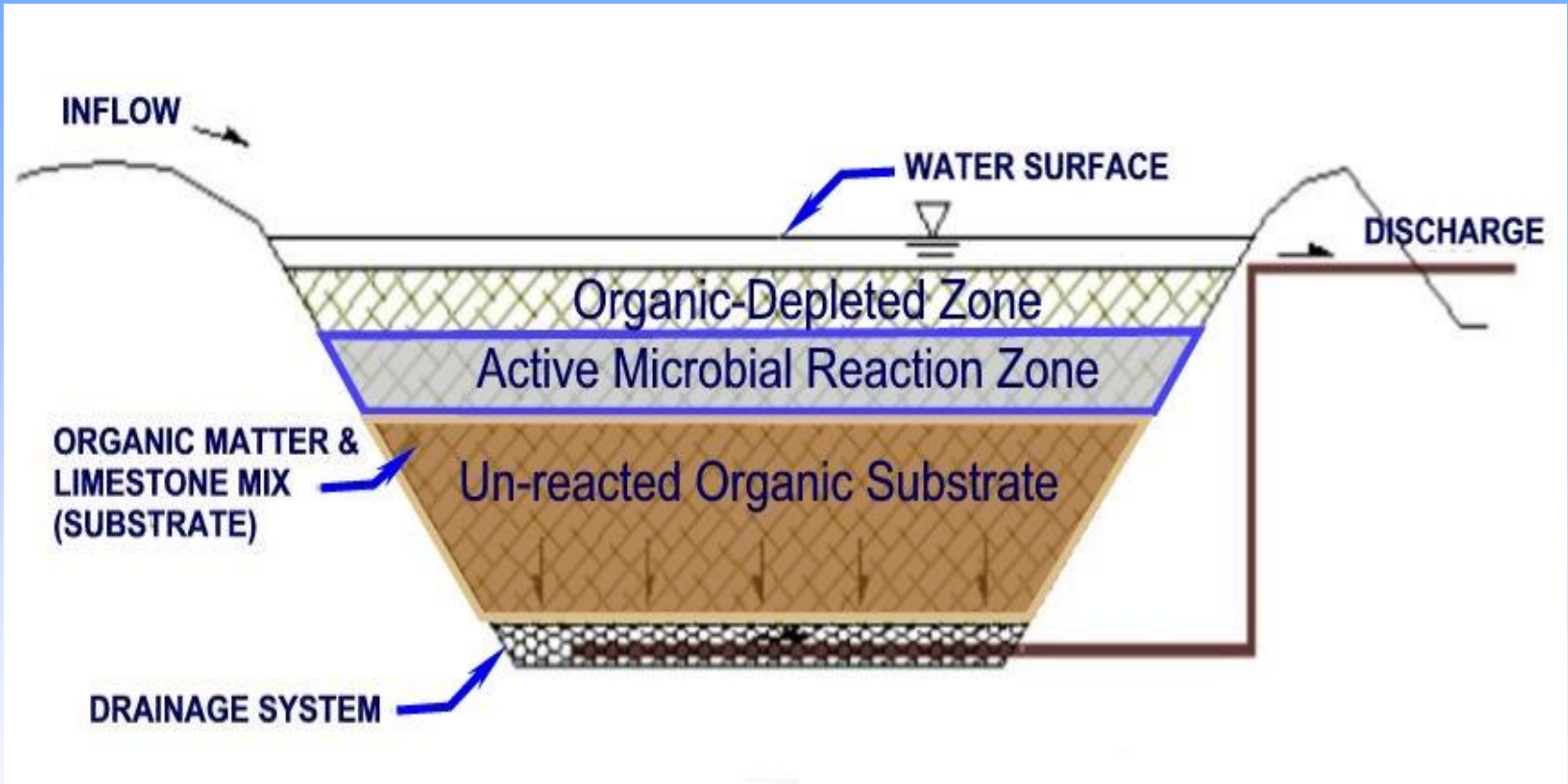
Anaerobic Biochemical Reactors (BCRs)

AKA

Vertical Flow Reactors
or
Sulfate Reducing Bioreactors (SRBRs)

Aluminum and heavy metal removal, selenium removal, de-nitrification, pH adjustment, alkalinity & hardness addition

Anaerobic Biochemical Reactors (BCRs)

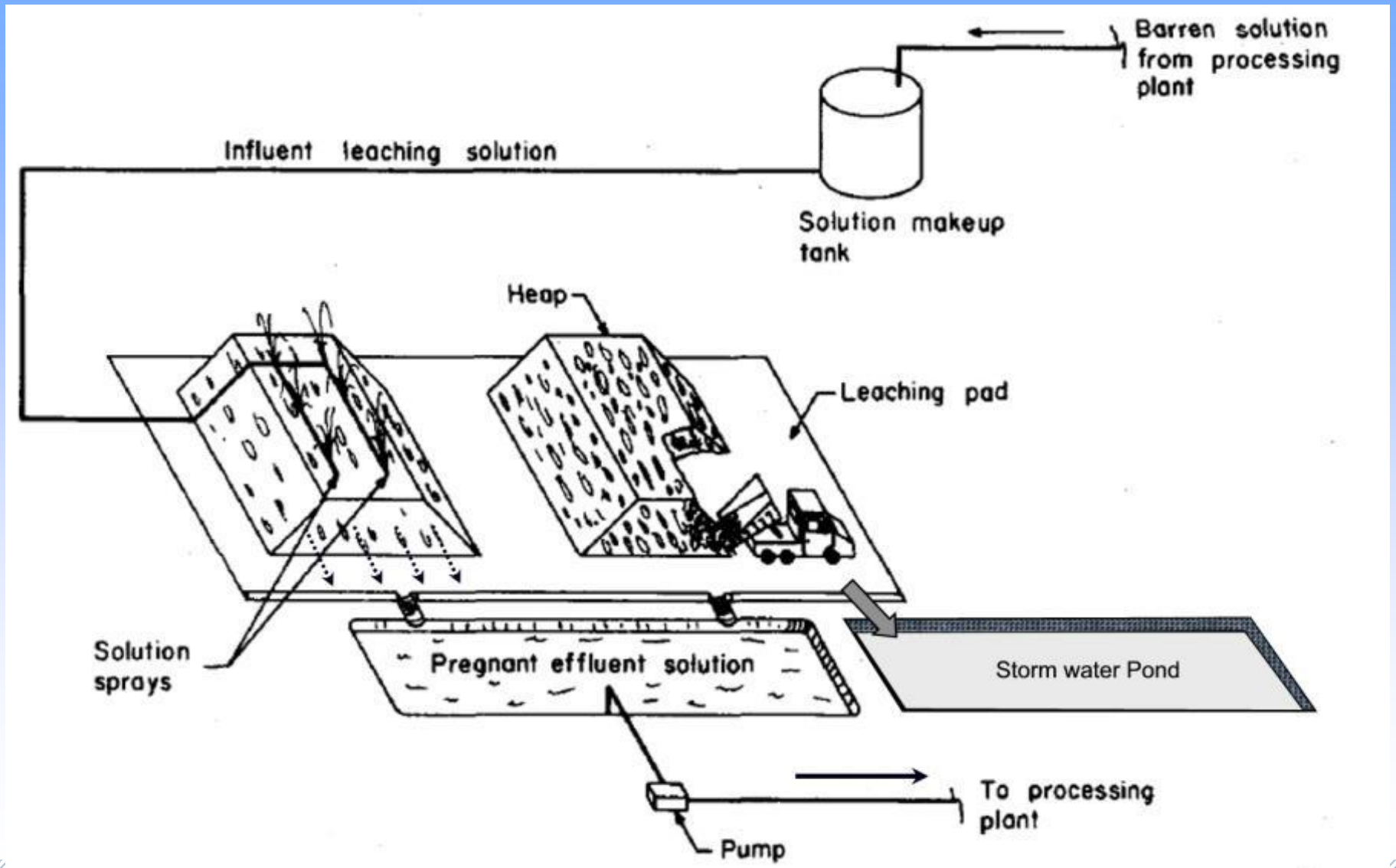


PLANTS ARE NOT REQUIRED FOR A BCR

BCR Effluent Characteristics

- Dissolved organic carbon (measured as BOD or total organic carbon [TOC])
- Bicarbonate alkalinity
- Reducing oxidation reduction potential (ORP) of – 100 mv or less
- Low dissolved oxygen [DO] (<1 mg/L)
- Dissolved sulfide ion, and
- Dissolved manganese

Heap Leach Technology



Barren Solution Delivery

- Drip Emitters

- Wobbler Sprinklers

- Reciprocating Sprinklers

- High Rate Evaporative Sprinklers

Images courtesy of Reddit.com, gtghydroponics.com, ebay, & bradshawsupply.com

Heap Leach Plumbing Layout

Courtesy of Senninger.com

Known Bactericides

- Sodium lauryl sulfate (SLS)
- Slow release commercial products
  – ProMac *(no longer available)*
- Alkyl-benzene sulfonate (laundry detergent is cheaper than SLS)
- Sodium Thiocyanate (NaSCN)
- Bi-Polar Lipids (patented)

Vaccination versus Medication?

Bactericides for Suppressing *Acidithiobacillus Ferrooxidans*

- Vaccination
- Medication
- Sequential Application or Cocktail?

Vaccination & Medication Scenarios

- Heap Leach Pads/Dump Leach Site
- Tailings Storage Facilities
- Waste Rock Repositories
- Pit Walls

Has any of these been done before?

Medication Case History #1

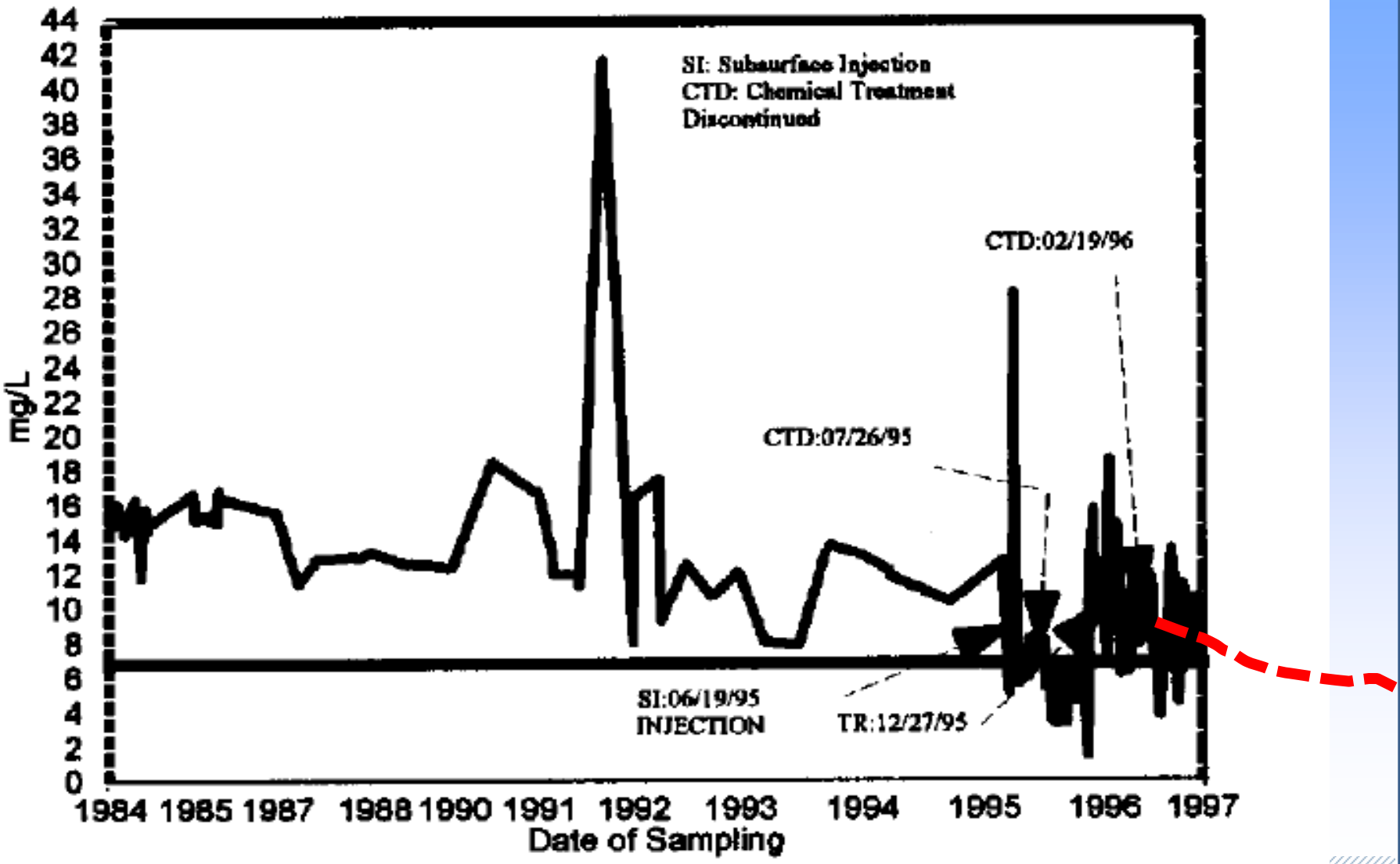
- **Fisher Coal Mine, PA – 1995 Vapco Engineering**
  - ❑Geophysics targets 3 ARD–generating zones; seep pH was 5.5; iron 17 mg/L and higher.
  - ❑Multiple injection boreholes on a tight spacing
  - ❑Injection of 20% NaOH solution simultaneously into 12 shallow (3 m deep) boreholes with packers
  - ❑Injection of 2% sodium lauryl sulfate bactericide
  - ❑Seepage continues to be net alkaline 19 years later, bond release is reportedly imminent

Medication Case History #1

- **Fisher Coal Mine, PA – 1995 Vapco**

FIGURE - 7

Raw Seep Iron Concentration



Medication Case History #1

WHY DOES IT STILL WORK – 19 YEARS LATER?

1) The initial "flooding" injection of caustic neutralized the residual acidity in the mine waste so that the subsequent application of bactericide was "protected" from chemical attack;
2) The bactericide solution (2% sodium lauryl sulfate) would have followed the preferential pathways established during the stage 1 injection of caustic to inhibit the activity of the acidophilic community; and
3) The well-established revegetated surface of the site provided a steady supply of bacteria inhibiting organic acids (and continues to do so) which appears to have suppressed the "reinfection" of the site that would have otherwise occurred.

Medication Case History #2

- **Sequatchie Coal Mine, TN – 2007 Western Research Institute**
  - Geophysics used to target ARD
  - Two doses - drip application of waste milk and biosolids (as inoculant)
  - Seepage reportedly net alkaline after seven years.
  - Patent issued January, 2012
  - Check out ITRC website
  - Plans to conduct follow up research (summer 2014).

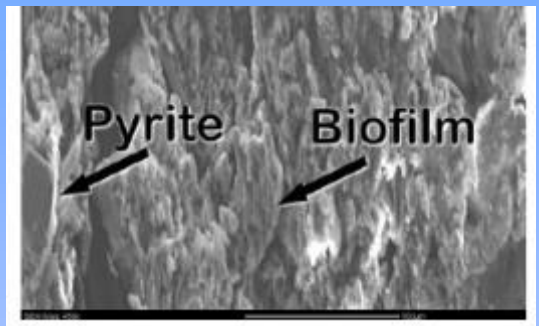


Fig. 6 Substrate dosage experiment: biofilm growing on pyrite after 213 days in a microcosm filled with ground water impacted with acid mine drainage, pyrite, 3 wt% effluent solids (*ES*) and 5× the required stoichiometric concentration of C (as returned milk) that bacteria would consume while reducing all the SO_4^{2-} in the microcosm. This image was taken at ×450 magnification with a scanning electron microscope

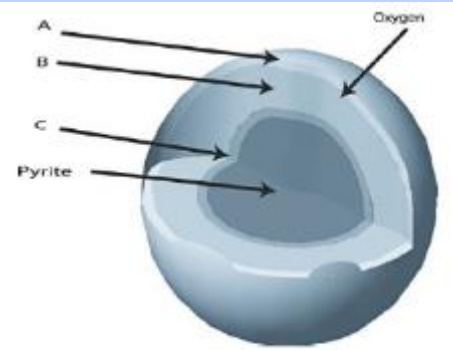


Fig. 7 Conceptual model of the community structure of biofilm growing on pyrite in microcosms. Layers A and B of the biofilm are composed of aerobic and facultatively anaerobic bacteria that consume oxygen (O_2) diffusing through the biofilm from overlying water. Layer C is an anaerobe-dominant layer containing sulfate reducing bacteria and other facultative anaerobes; therefore, oxygen diffusion to the pyrite and generation of acid mine drainage is prevented

Ref: Jin et al., 2007

http://www.itrcweb.org/miningwaste-guidance/cs31_sequatchie.htm

Medication Case History #2

WHY DOES IT STILL WORK – 7 YEARS LATER?

1) No formal “bactericide” in the mixture, just milk?
2) Casein in the waste milk curdles when it encounters pH <4.6 conditions
3) This might create a *“heat-seeking missile”* effect that is pyrite-surface selective
4) Curdled milk is a protein, which is slow to degrade and would provide a long-term electron donor source for heterotrophic bacteria
5) Revegetated surface of the site provides a steady (sustainable) supply of acidophile-inhibiting organic acids. (Similar to Fisher Site)

Similarities and Differences

BCR Effluent would behave more like milk than the sequential approach by Plocus & Rastogi

BCR effluent may oxidize more quickly when it encounters acidic conditions on a pyrite grain surface to form a biofilm

BCR effluent-derived biofilm wouldn't contain much long-lived protein

BCR effluent will probably contain manganese, which should form abiotic coatings (over any surface) deeper in the mine waste column

Application Concept: Mine Dumps

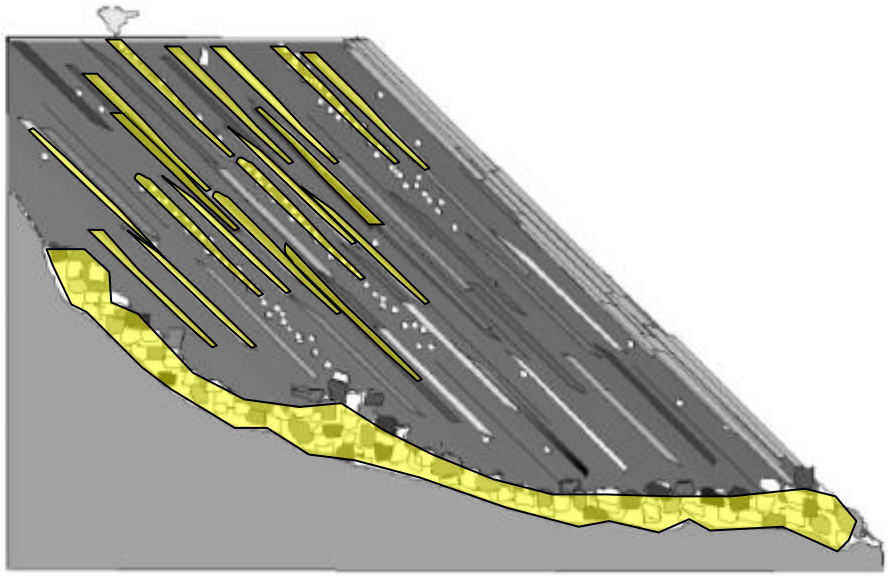
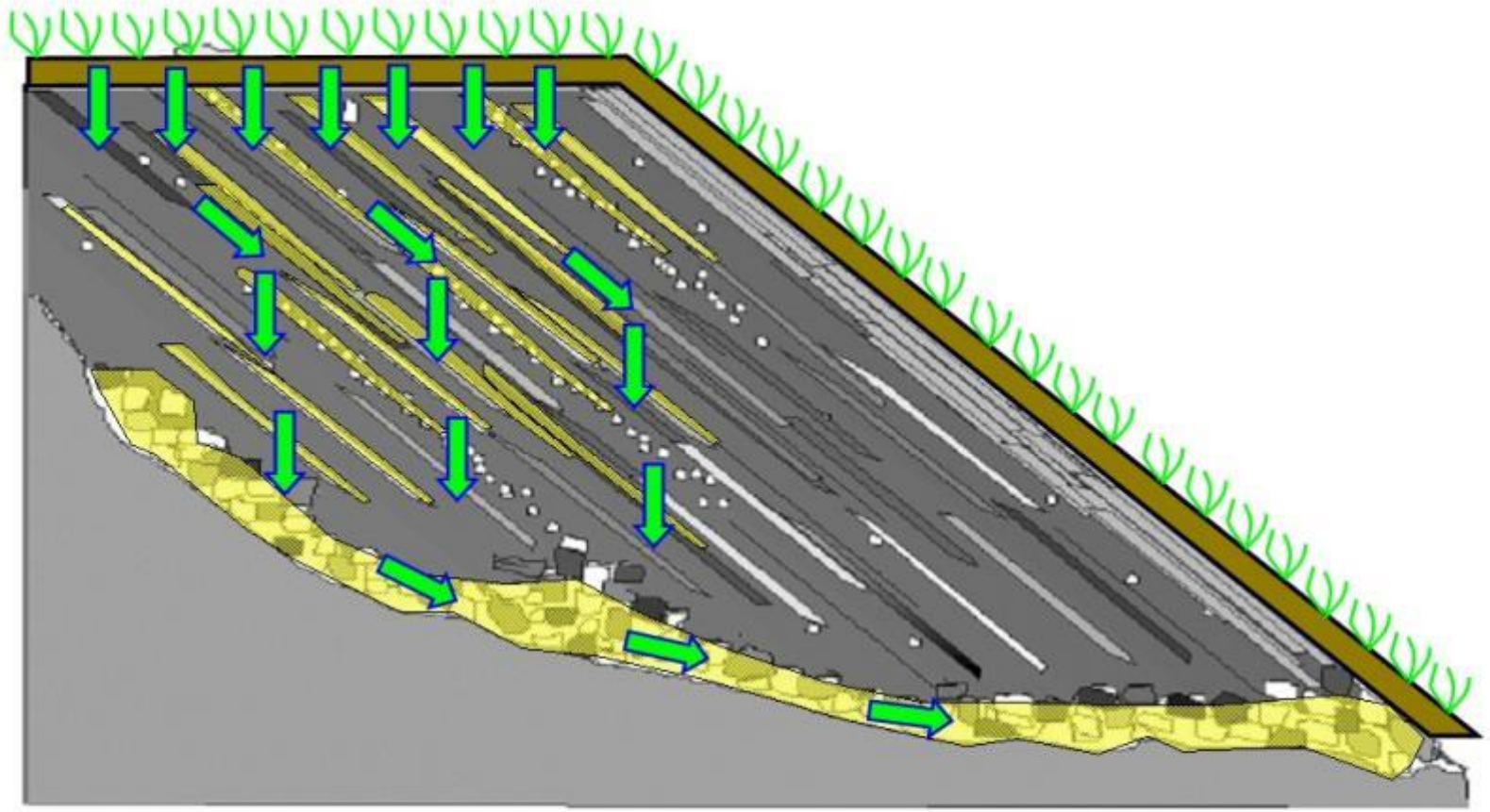


Figure 1. Gravity segregation and resulting interbedded structure in waste rock dumps.

After G.W. Wilson, 2008

Application Concept: Mine Dumps



Preliminary "Medication" Cost Model

- Waste Rock Repository – 100 acres divided into 20-acre application zones
- Add 60 inches (152 cm) of BCR effluent for a year (34 m^3/day)
- 8 hrs/day yields about 24 gpm
- Drip row spacing of 3 ft (1 meter)

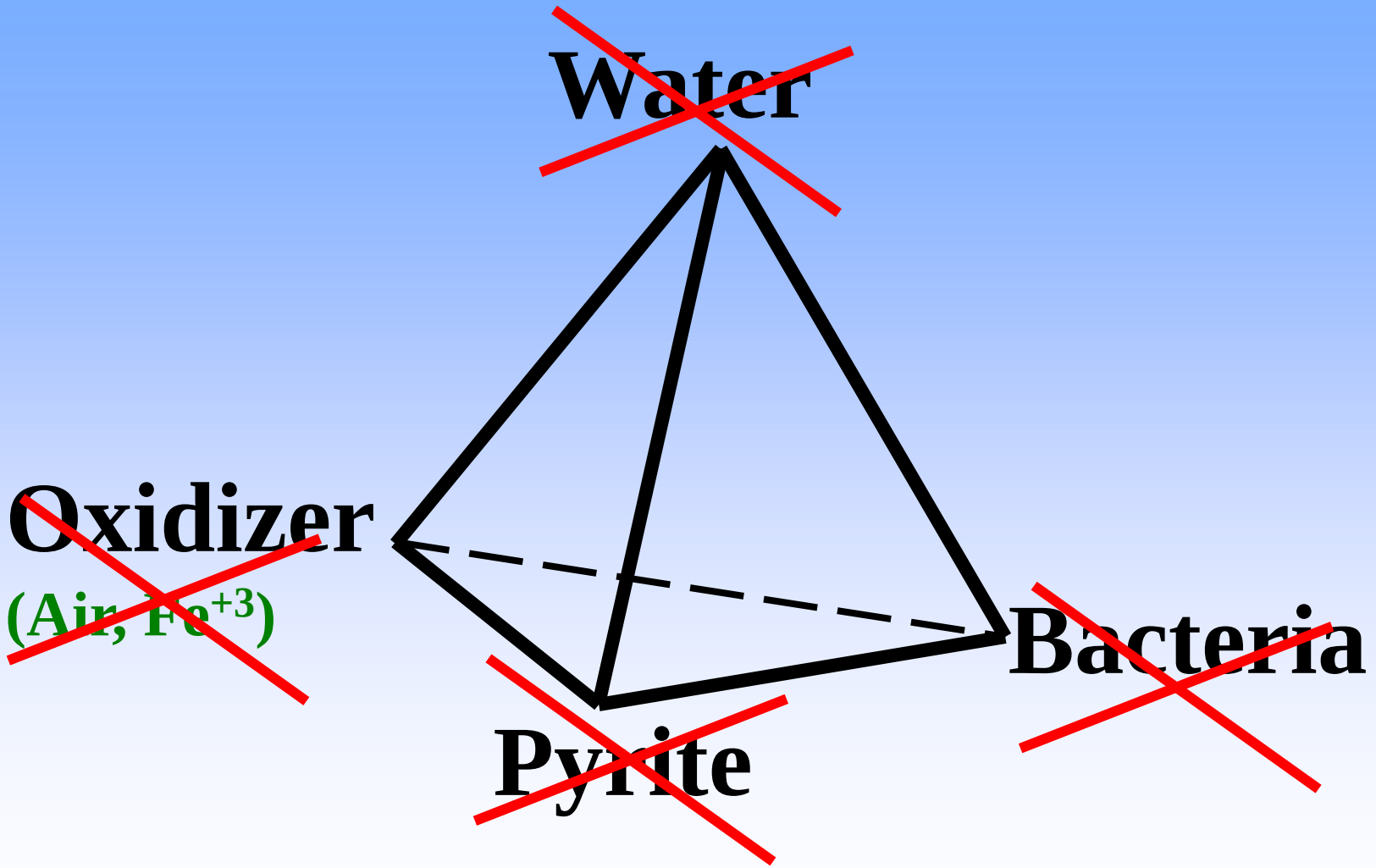
Preliminary "Medication" Cost Model

- Capital cost $14,500 co… to fixed cost of $7,200/yr.
- Operating…
- Total …st: $26,000/yr. for 20 a…
- BCR effluent $0.31/m^3 or $4,000/yr.

COMPARE TO PERPETUAL TREATMENT

Total cost of $30,000/annum or $1,500/acre treated ($3,700/ha)

Acid Rock Drainage Tetrahedron



GO FORTH & IRRIGATE

Thank You

DO SOMETHING (anything) as a first step on the

PATHWAY TO WALK-AWAY

jgusek@sovcon.com

Introducing: the Sovereign Mining Resource Database (SMRD)

www.sovcon.com/index.php/resources/sovereign-mining-resource-database-june-2014

"A super Google Search on steroids for mine remediation papers."
ICARD, ASMR, WV Task Force, Tailings & Mine Waste, etc.