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Source Control

Is it too good to be true?

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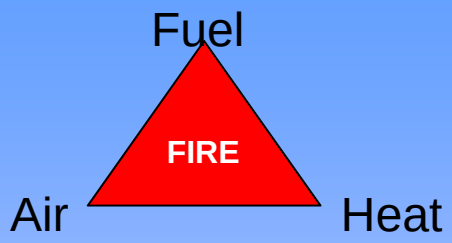
Acid Rock Drainage

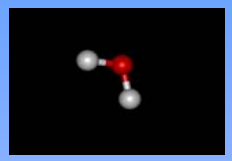
OUTLINE

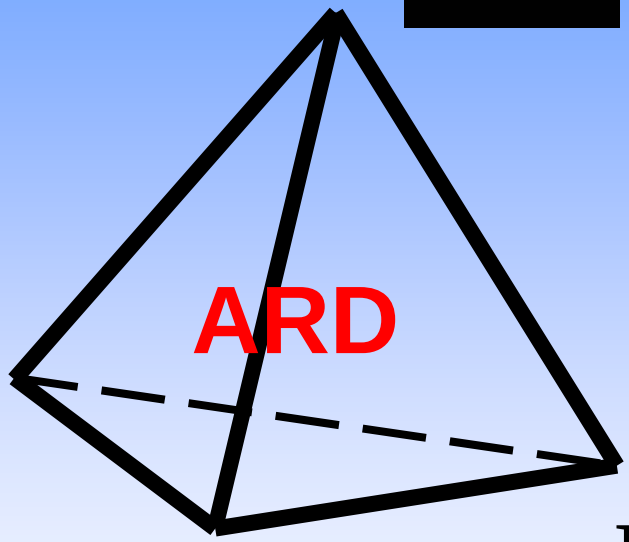
- **Source Control Background**
  - ARD Tetrahedron
  - Bactericides
    - History
    - Mechanisms
- **Three Case Histories**
- **A Pathway to Sustainable Closure?**
  - Employ New Technologies
  - **D**ecimate, **O**ut-Compete; **S**ustain [**DOS**]

Acid Rock Drainage Tetrahedron



Water





Oxidizer

(Air, Fe^{+3})

Bacteria

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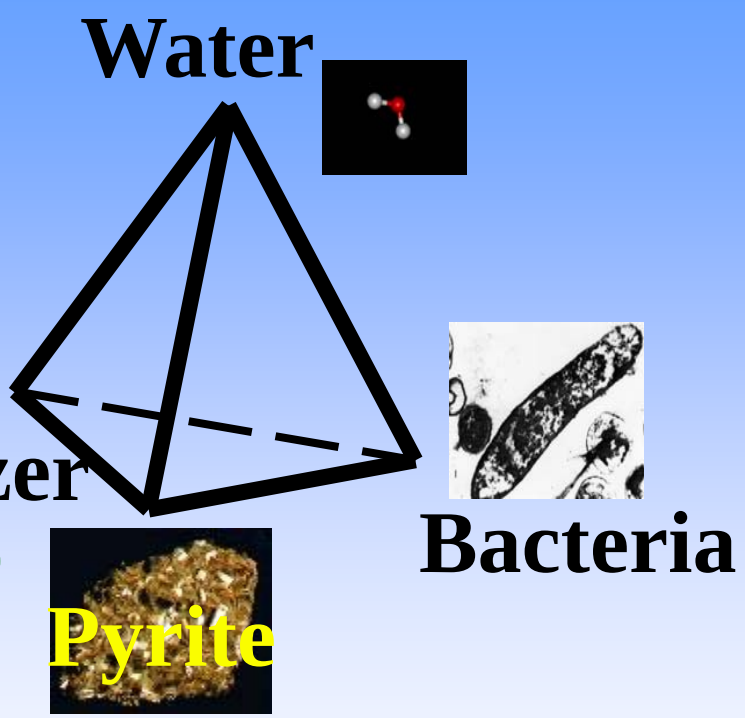
Breaking the cycle

- Pyrite
  - Avoidance
  - Processing
- Water
  - Covers
    - Impermeable
    - Evaporative



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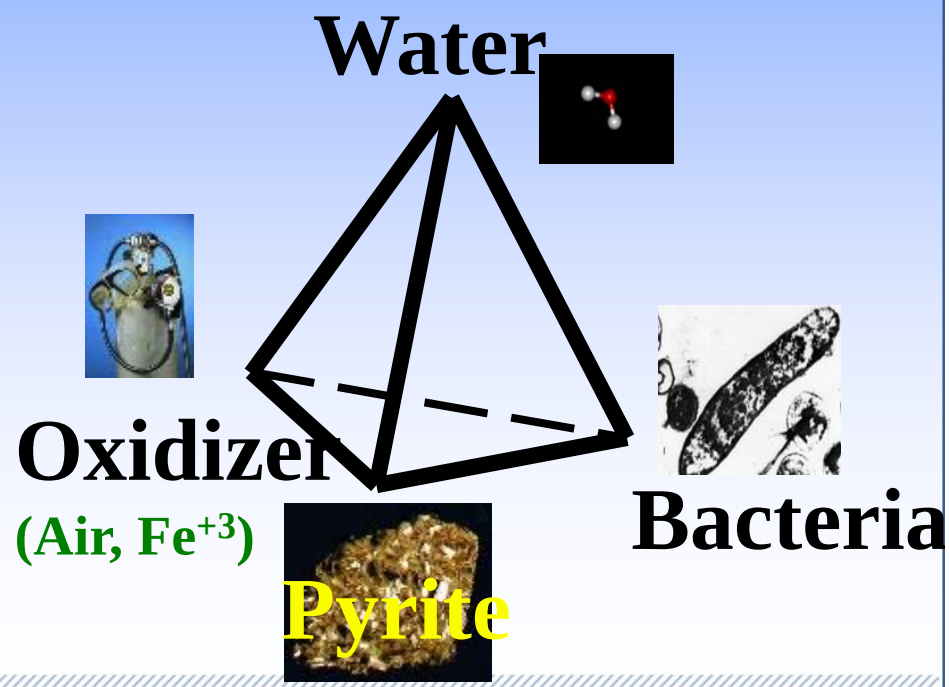
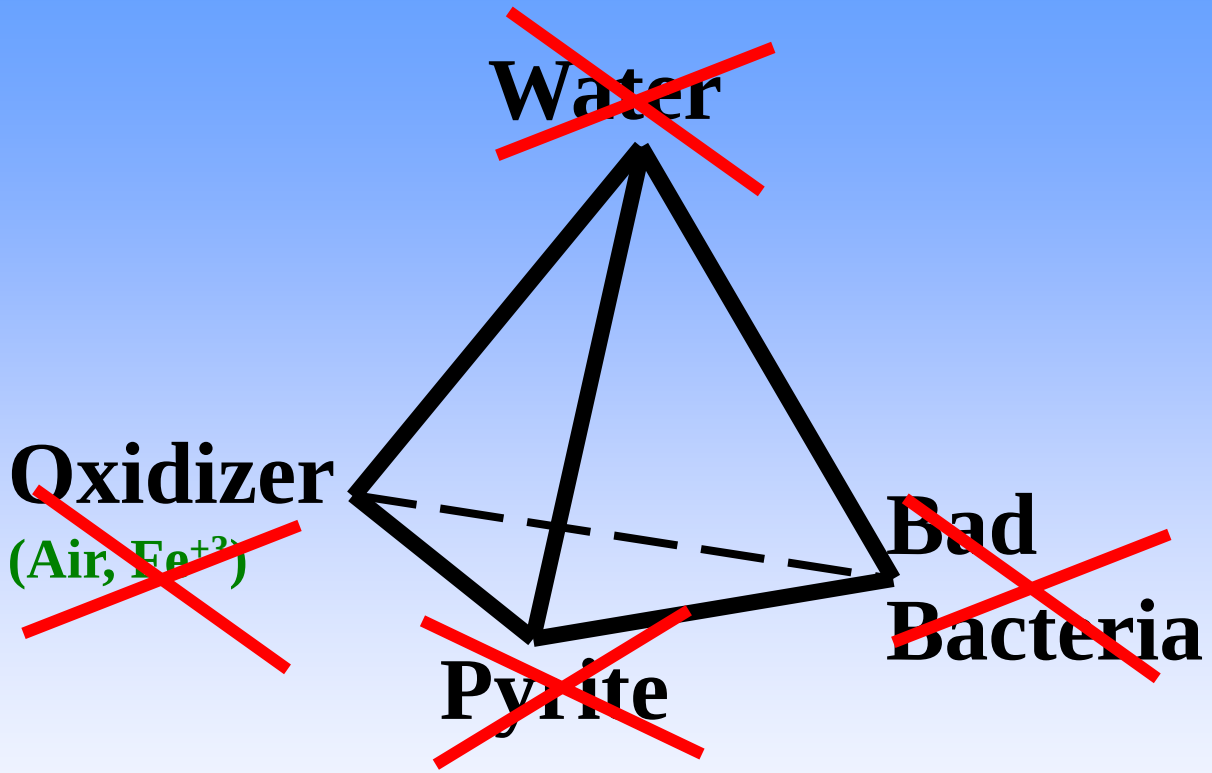
Breaking the cycle

- Oxidizer
  - Subaqueous disposal
  - Organic covers
- Bacteria
  - Bactericides
  - Organic materials



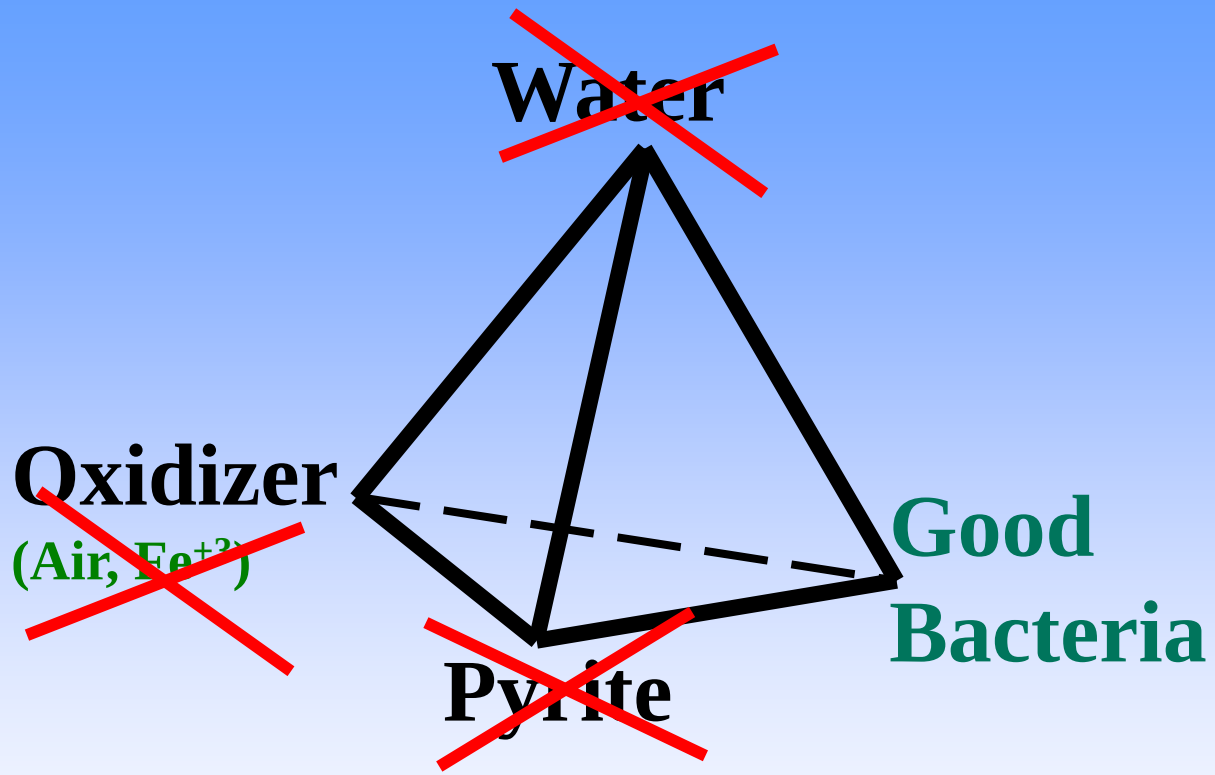
Acid Rock Drainage Tetrahedron



DO NOTHING = **PERPETUAL TREATMENT**

DO SOMETHING (anything) = **SUSTAINABLE REMEDIES**

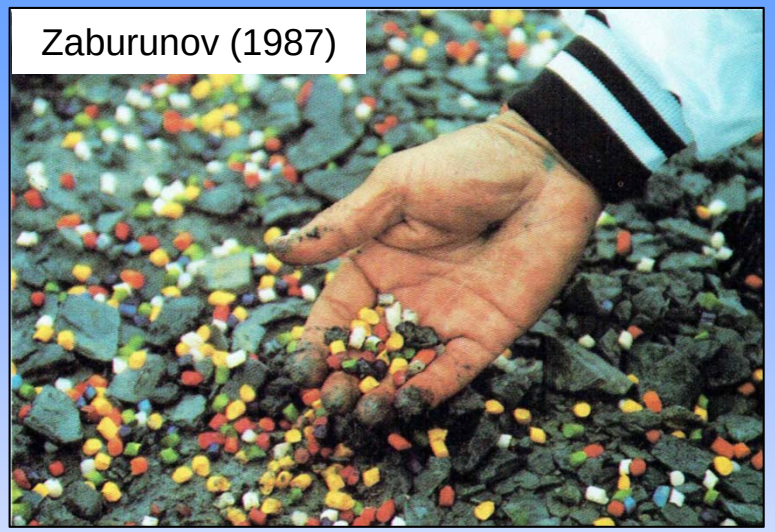
Acid Rock Drainage Tetrahedron

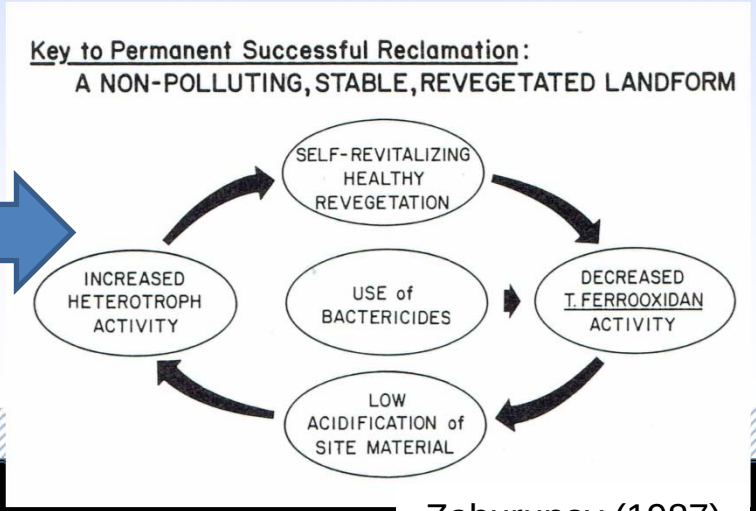


“PROBIOTIC”
SUSTAINABLE CLOSURE

History

- Bacteria are important (1950)
- Common surfactants are effective bactericides (1980s-1990s)
- Kleinmann & Erickson USBM RI 8847 (1983)
  - documented success
  - liquid application, reapply
- Development & Use of Controlled-Release Product "ProMac™" (1985 to 2000)
- Probiotic Bacteria Substitution w/Organics (1990 to 2008)
- **Revegetation is a key requirement for sustainability**


Zaburunov (1987)



Zaburunov (1987)

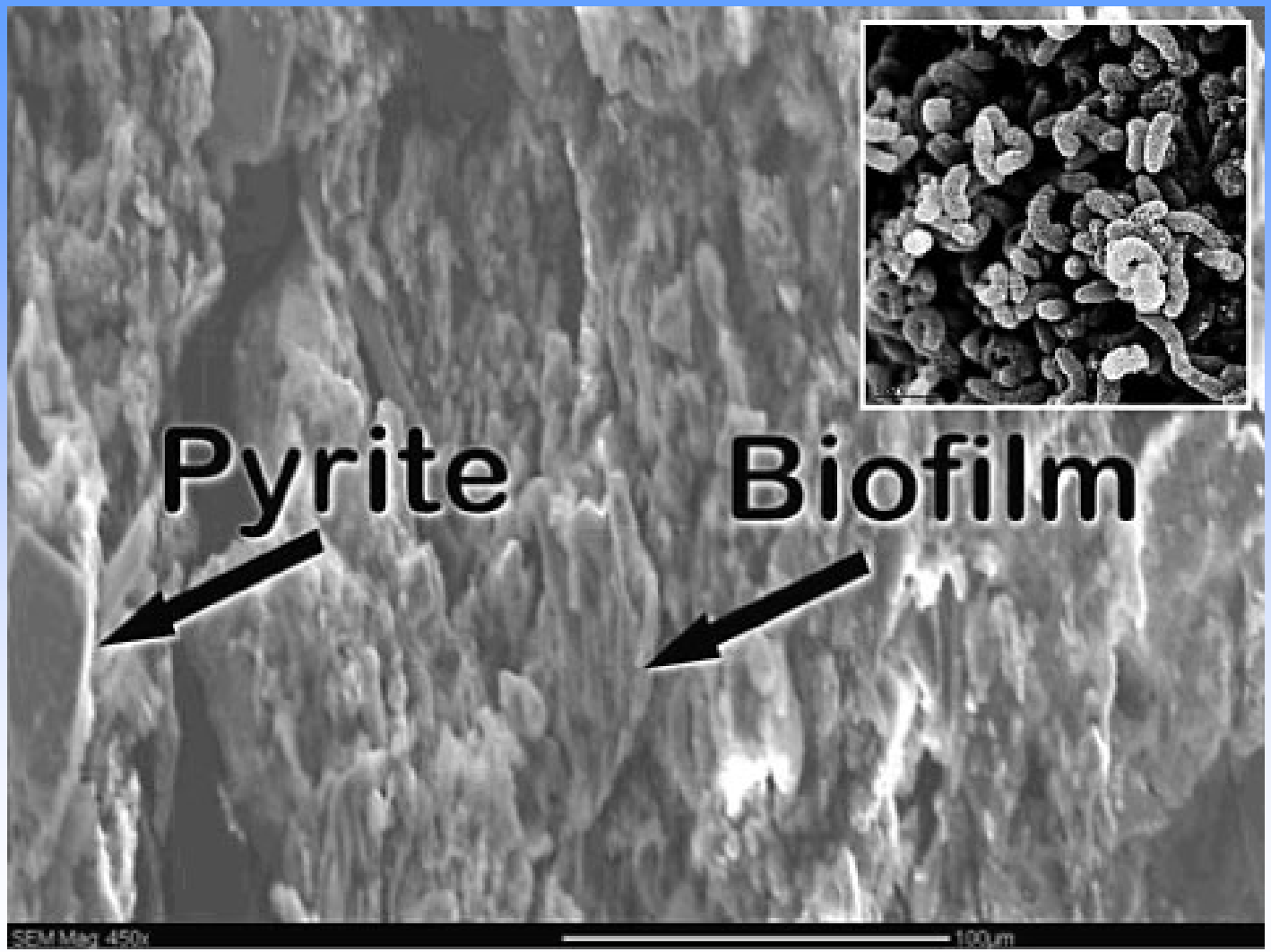
Known Bactericides

- Sodium lauryl sulfate (SLS)
- Sodium laureth sulfate (SLES)
- Slow release commercial pr… (no longer availabl…)
- Alkyl-ba… …undry detergent is …)
- …rhiocyanate (NaSCN)
- Bi-Polar Lipids (patented)
- Elevated chloride solutions (NaCl > 6,000 ppm)

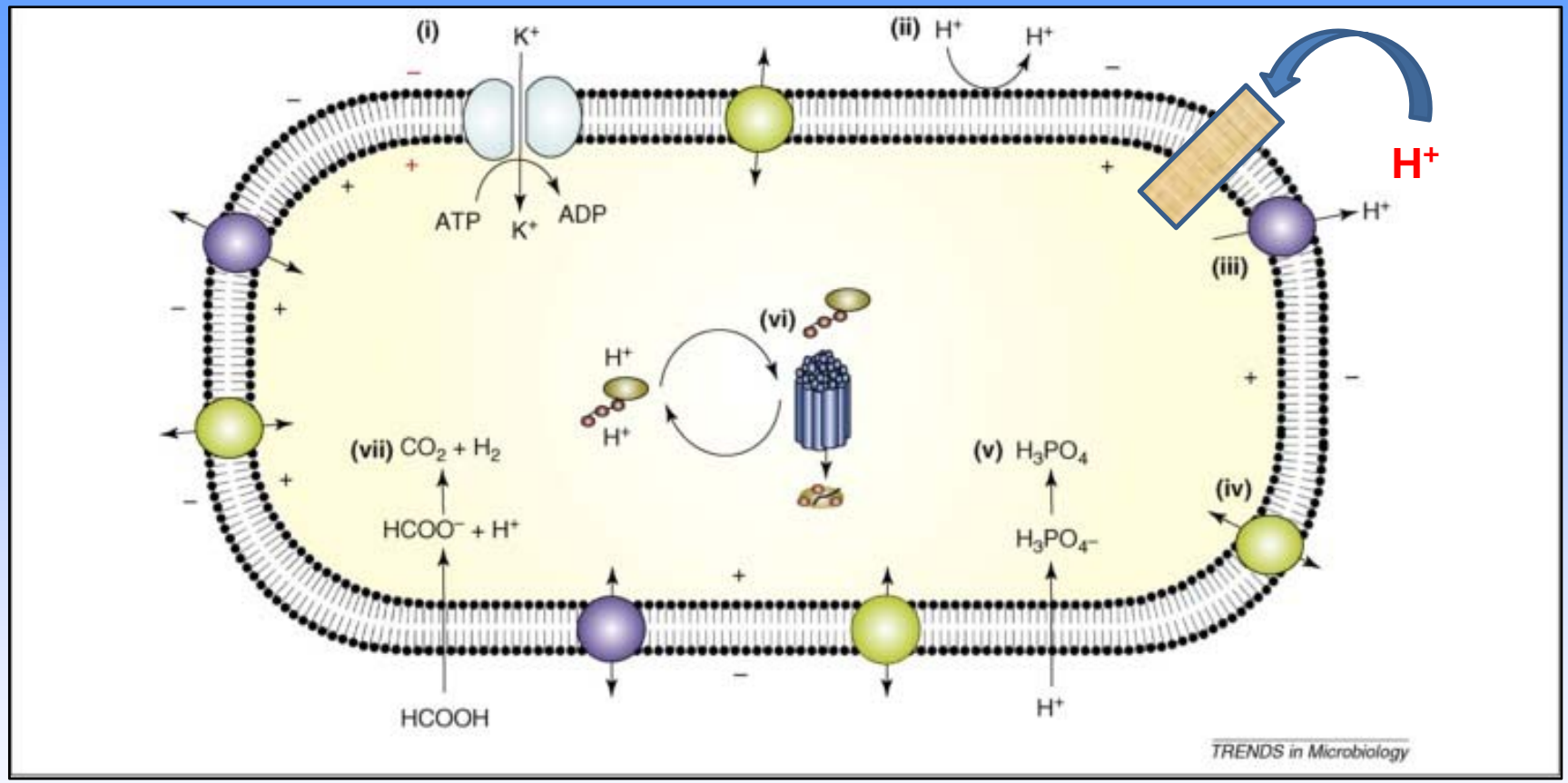
Some of these concepts are 35 years old (but might not be practical in every situation)

Organic Amendments

- Composted sewage sludge (Pichtel & Dick, 1990)
- Composted paper mill sludge (ditto)
- Pyruvic acid (ditto)
- Water-soluble extract from composted sewage sludge (ditto)
- Spent brewery grain (Lindsay et al., 2010)
- **Waste milk & dairy products (Jin et al., 2008)**


Pyrite
Biofilm
SEM Mag 450x
100µm

How Surfactants Work



Baker-Austin & Dopson (2007)

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Selected Case Studies

A Pathway to Walk-Away? – 30 Year Old Technology to Suppress Acid Rock Drainage Revisited

Tailings and Mine Waste 2016

J. J. Gusek

Definition of "Long Term" Success

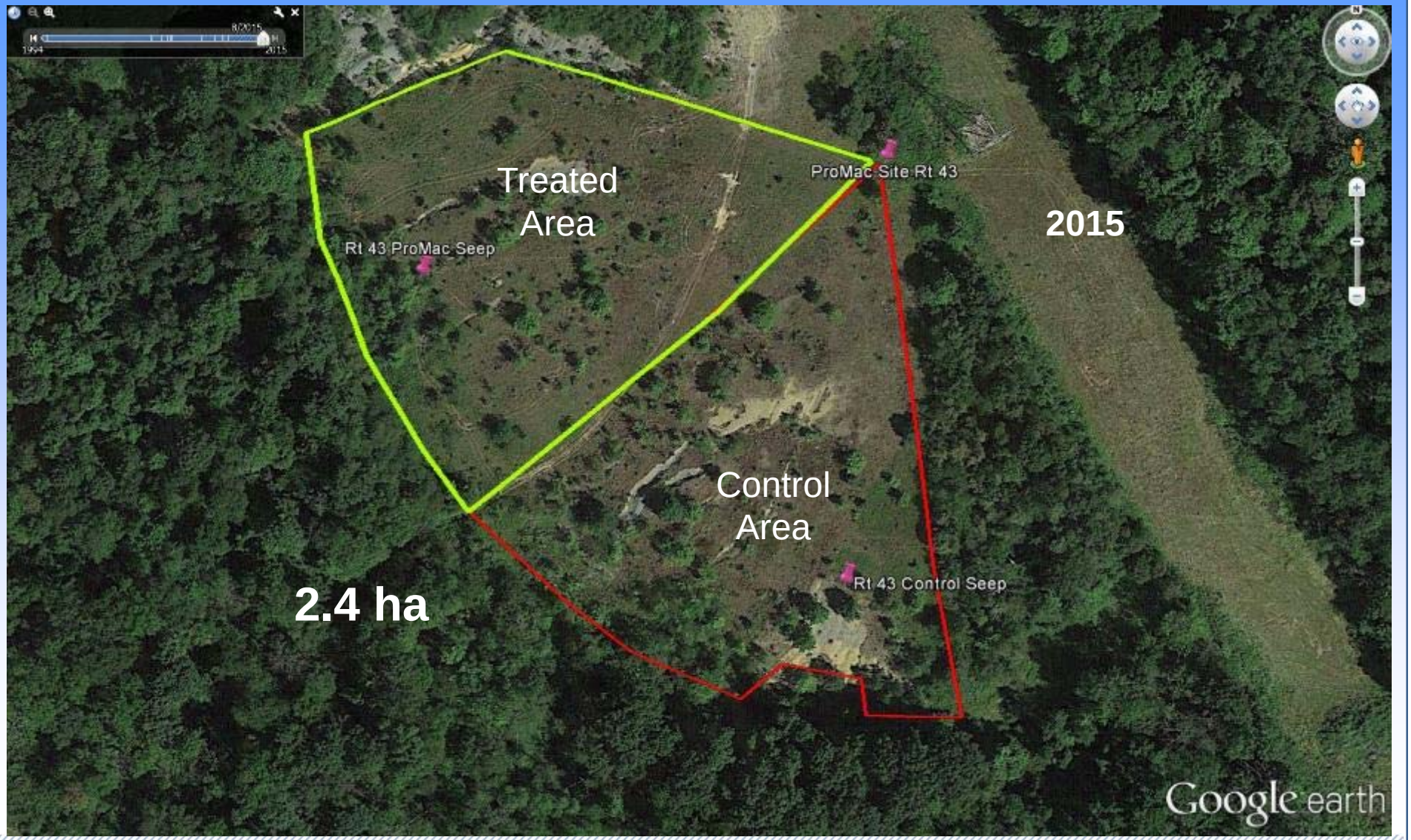
A. Site exhibits ARD and it received an engineered dose of bactericide or other material intended to disrupt ARD microbial kinetics
B. Monitoring data is available and/or
C. No evidence of ARD observed in air photo imagery and/or
D. The site has been completely dropped from regulatory sampling programs (nothing to monitor)

Case Histories

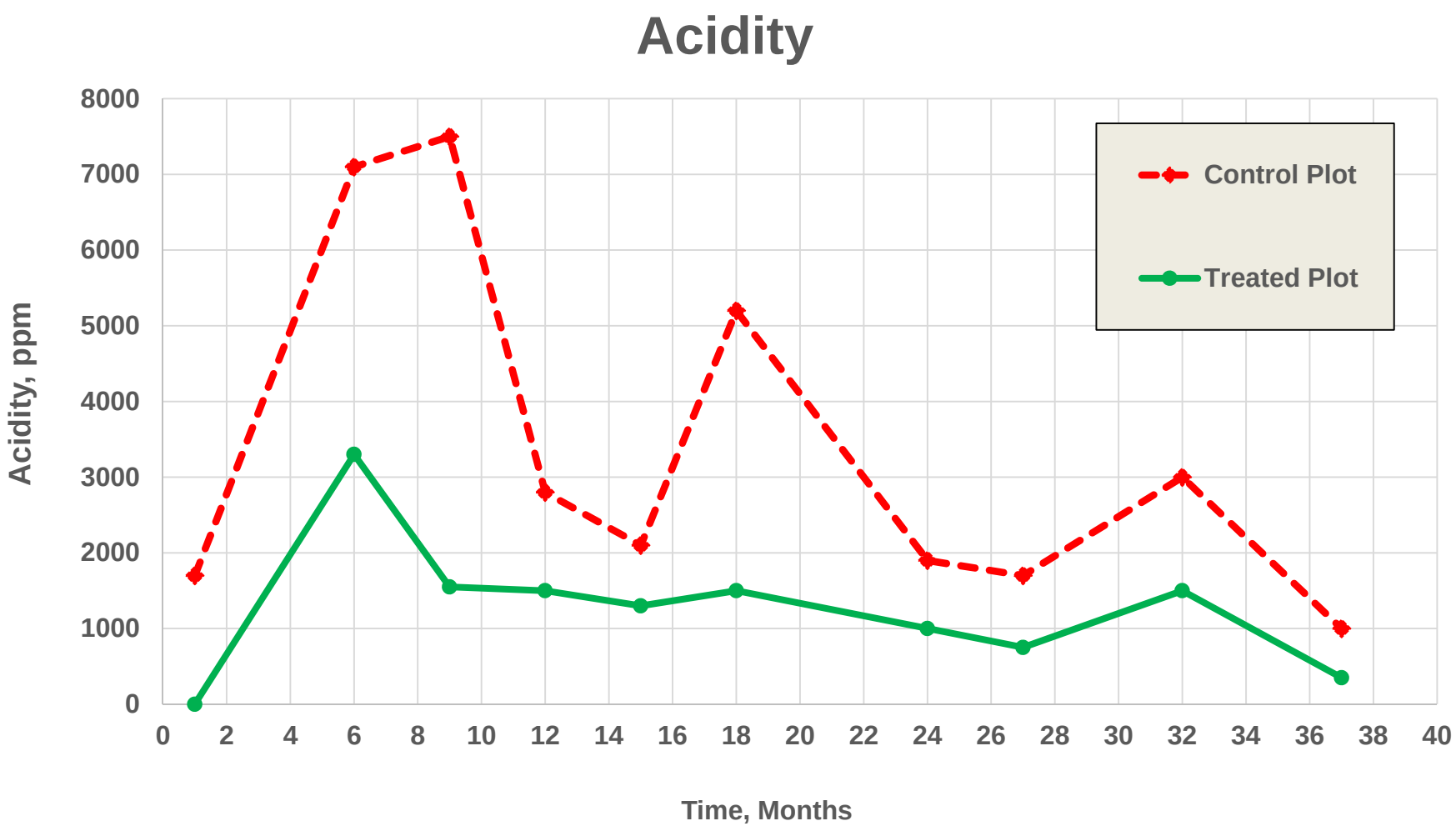
1. **Route 43, Jefferson County, OH**
2. Branchton Coal Refuse Disposal Area, Butler County, PA
3. **North Fork Coal Mine, Wise County, VA**
4. Dawmont Coal Refuse, Harrison County, WV
5. Norton Coal Refuse, Randolph County, WV
6. California Gulch Superfund Site, Lake County, CO
7. **Fisher Coal Mine, Indiana County, PA**

See: Gusek, J. Tailings and Mine Waste 2016 Paper for details on all 7 sites

Route 43, Jefferson County, OH

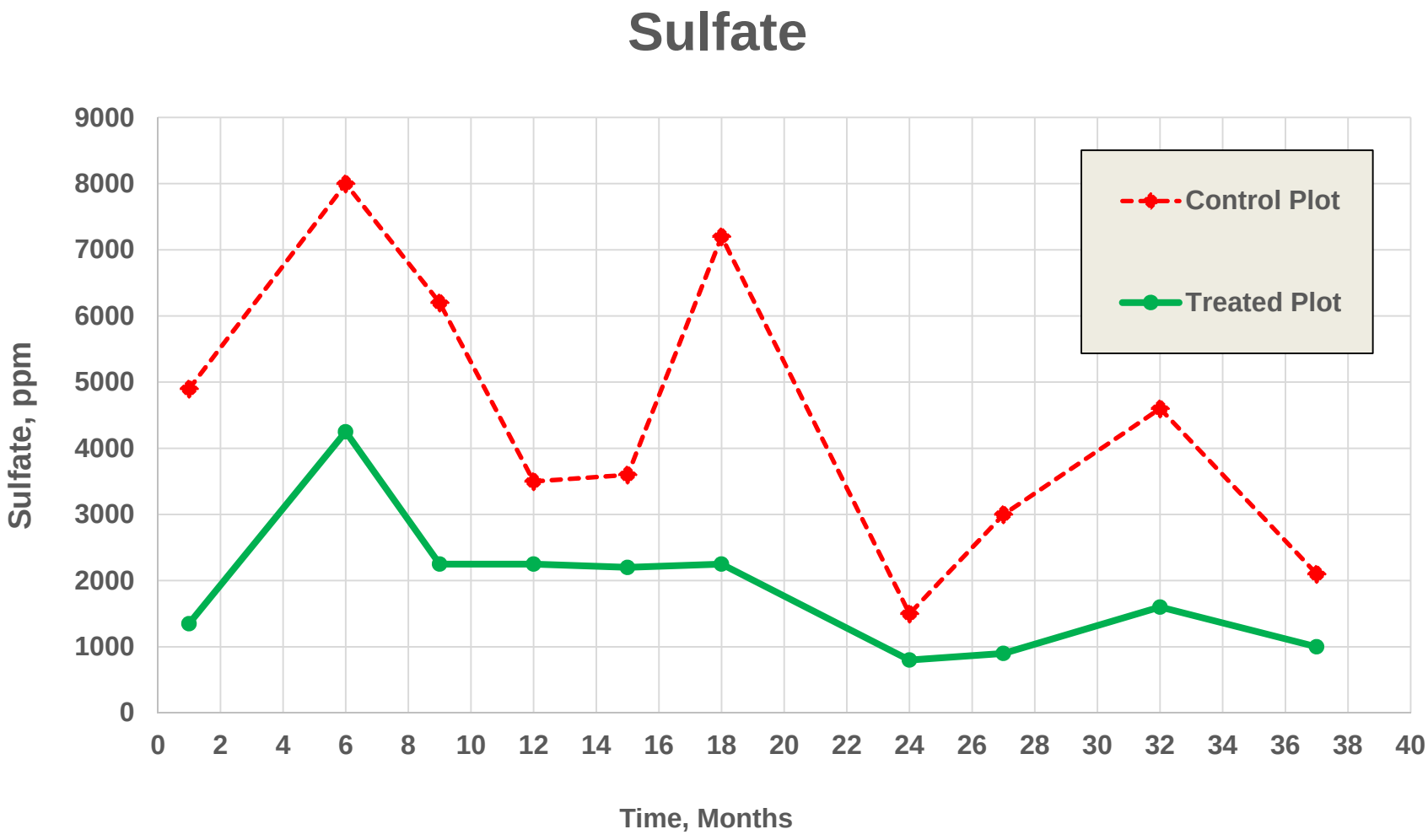


Route 43, Jefferson County, OH



Sobek, et al., 1990

Route 43, Jefferson County, OH



Sobek, et al., 1990

Route 43, Jefferson County, OH

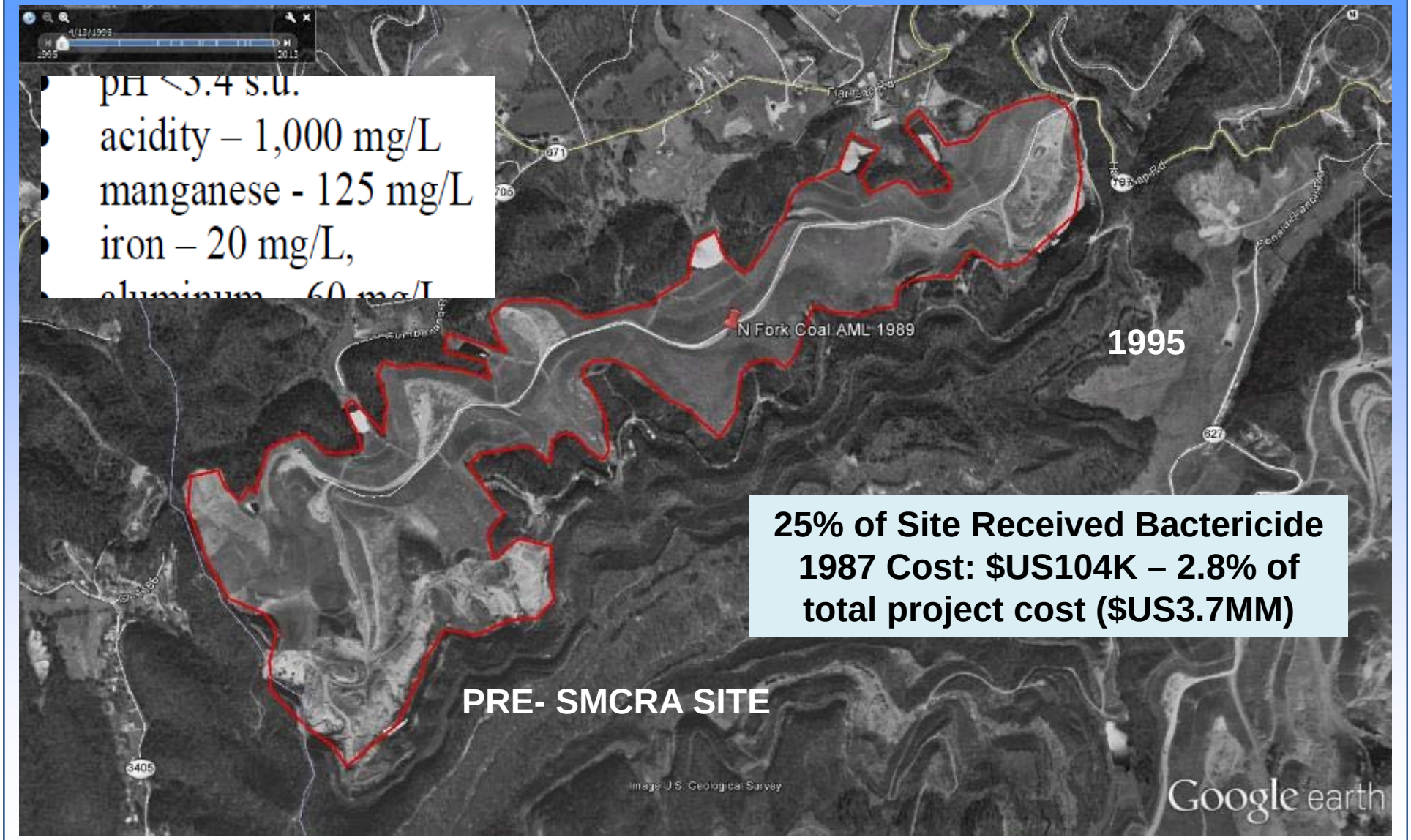
Three Years After Bactericide Application

Parameter	Control	Bactericide-Treated
pH (S.U.)	2.6	5.9
Acidity (mg/L)	844	19
Aluminum (mg/L)	38.7	0.5
Iron	104	<0.2
Manganese	6.1	0.3
Sulfate	2,040	100
Specific Conductance	2,910 µs	590
Vegetation health	"destroyed by seep"	"high quality vegetation"
TBFO populations in refuse sample	1.76×10^7	5.61×10^5
Heterotroph populations in refuse sample	6.43×10^5	3.47×10^7
Ratio of TBFO to Heterotroph population	1014:1	0.22:1

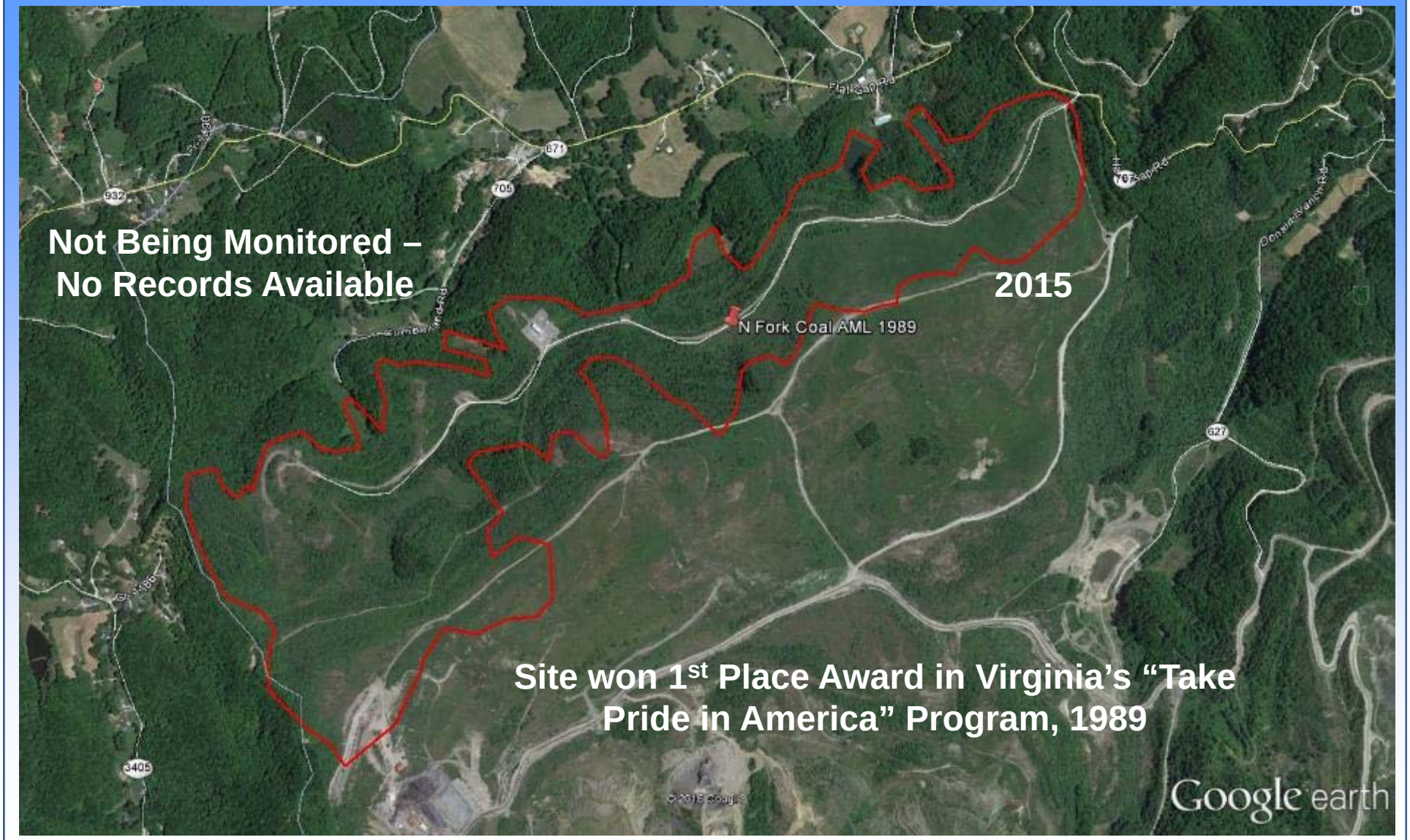
Dramatic change in microbial community

Maierhofer, 1988

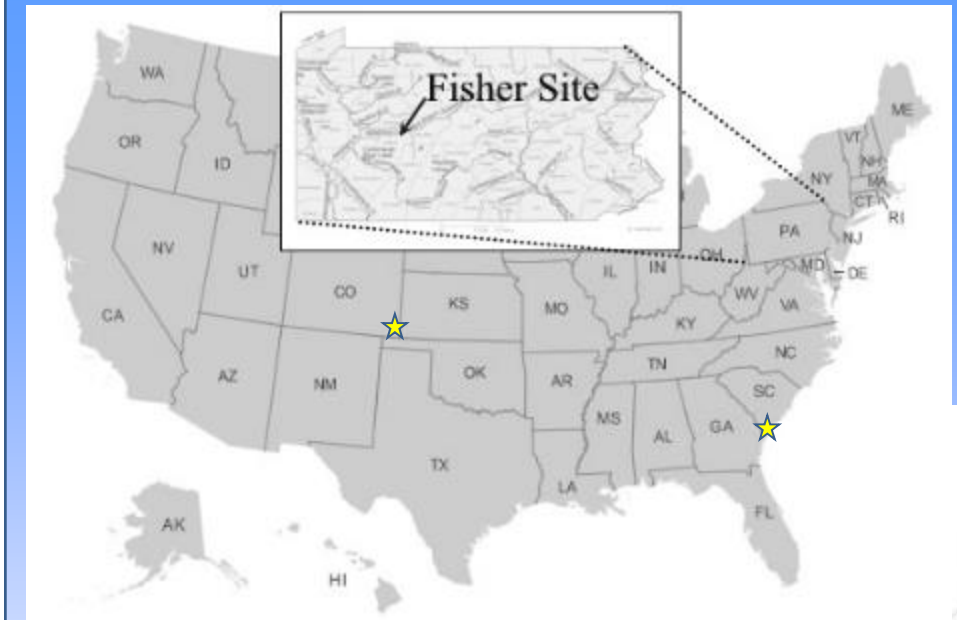
North Fork Coal Mine, VA



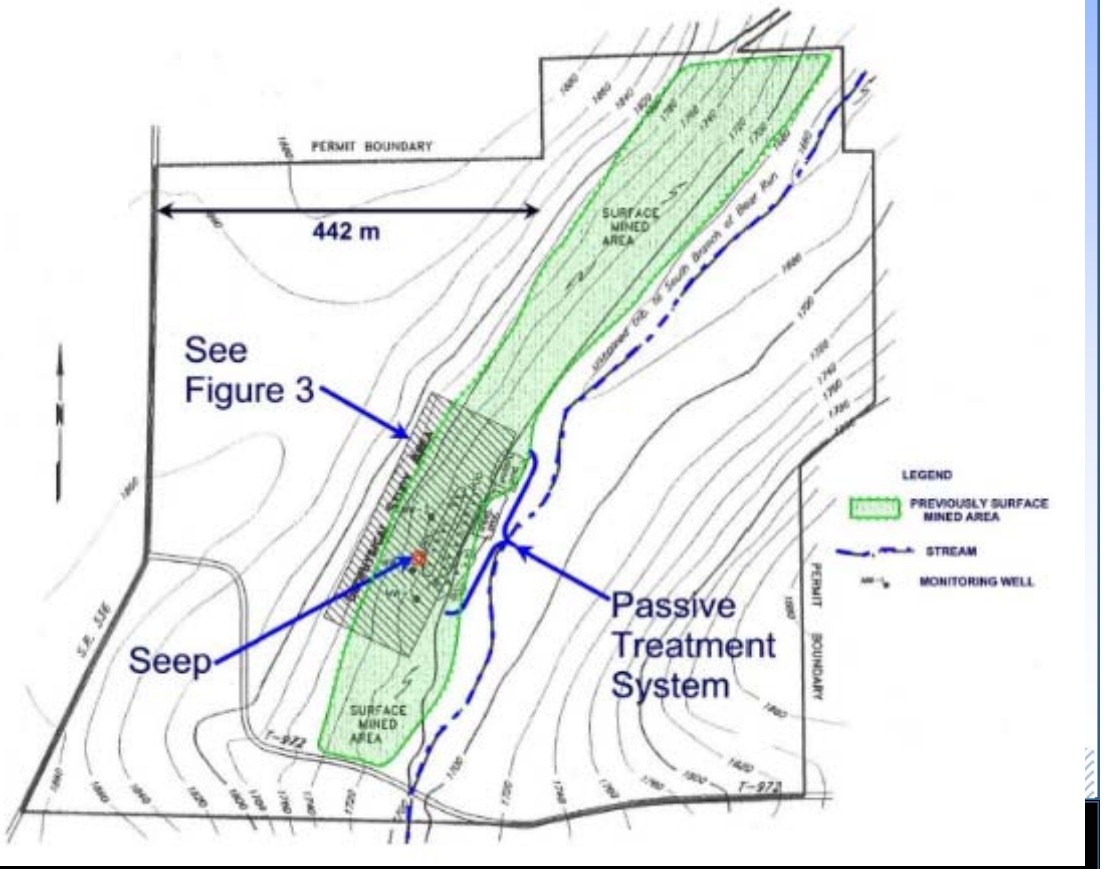
North Fork Coal Mine, VA



Fisher Coal Mine, Indiana County, PA



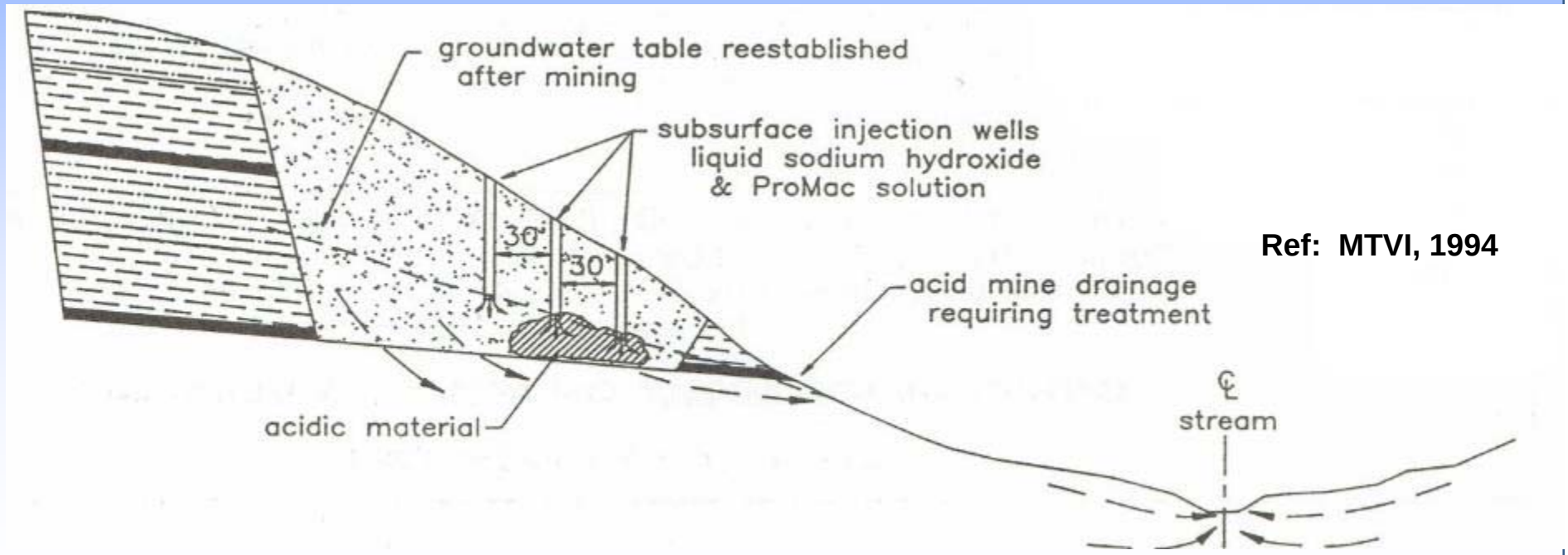
108 km NW of Pittsburgh, Pennsylvania USA



Ref: Gusek & Plocus, 2016 and Plocus & Rastogi, 1997 (ASSMR, Austin, TX)

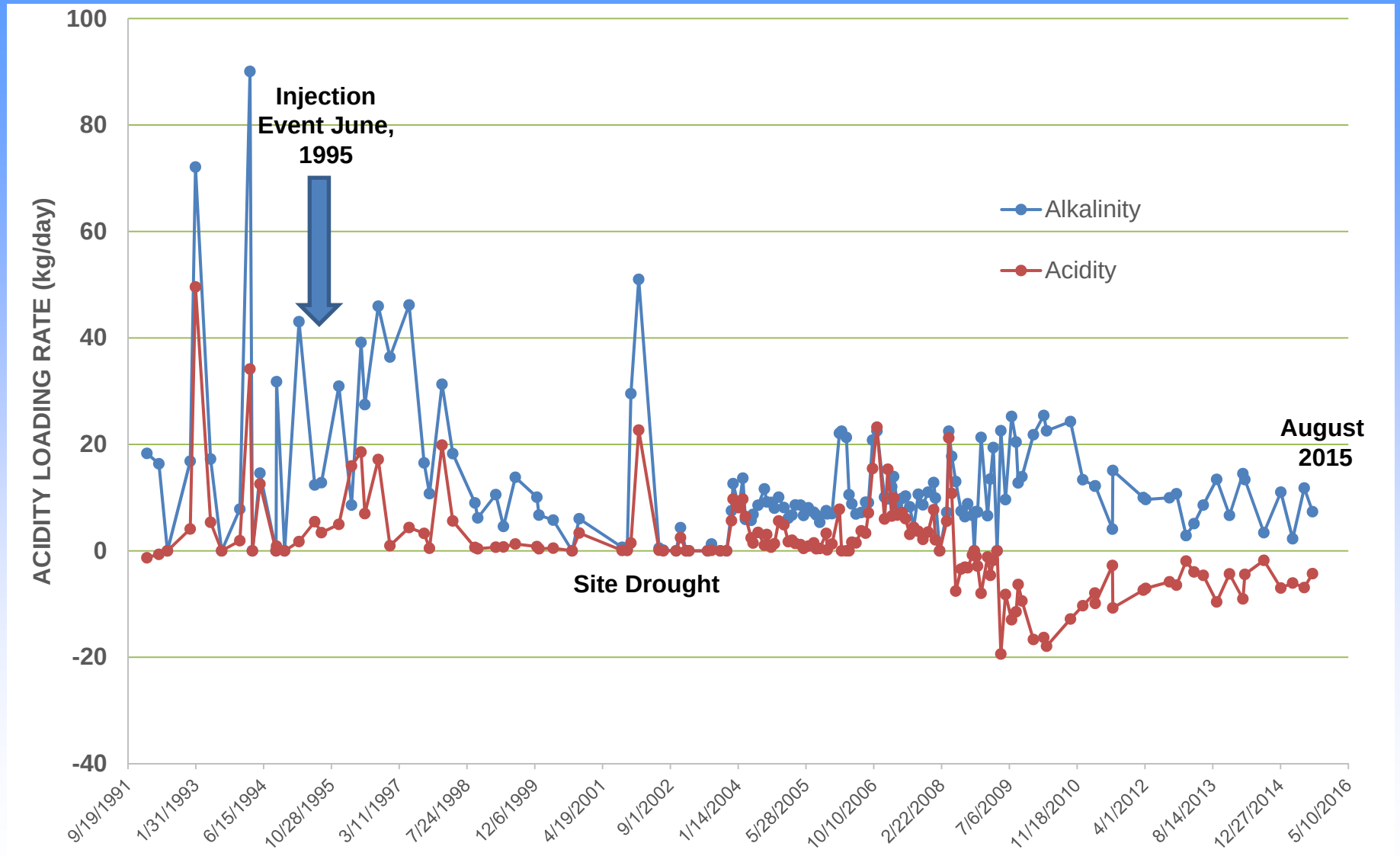
Fisher Coal Mine, Indiana County, PA

- Geophysics targeted three ARD–generating zones
- Multiple injection boreholes on a tight spacing
- Injection of 20% NaOH solution followed by Injection of 2% sodium lauryl sulfate bactericide



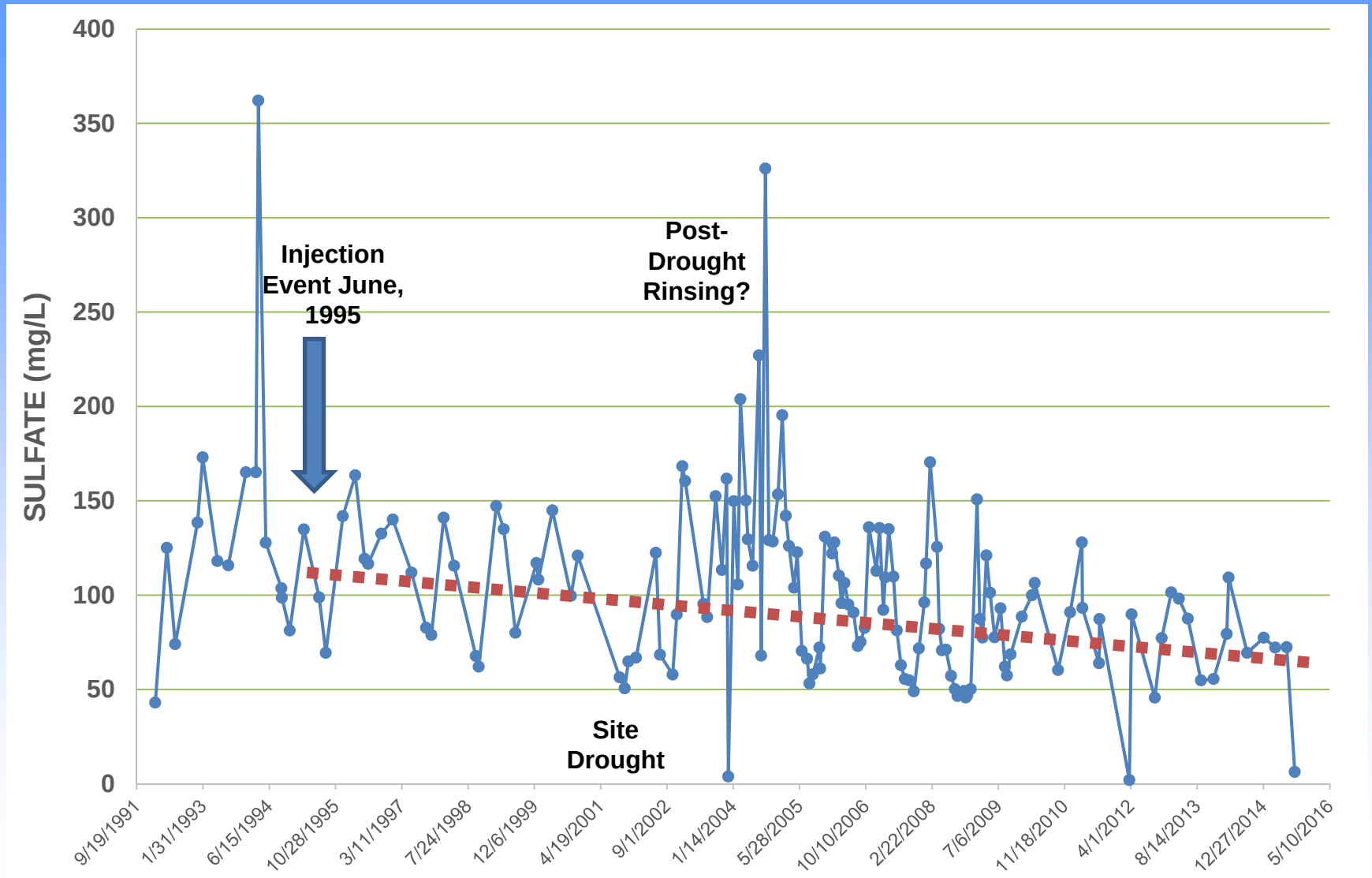
Ref: MTVI, 1994

Acidity Loading



Ref: Gusek & Plocus, 2016

Sulfate Trends

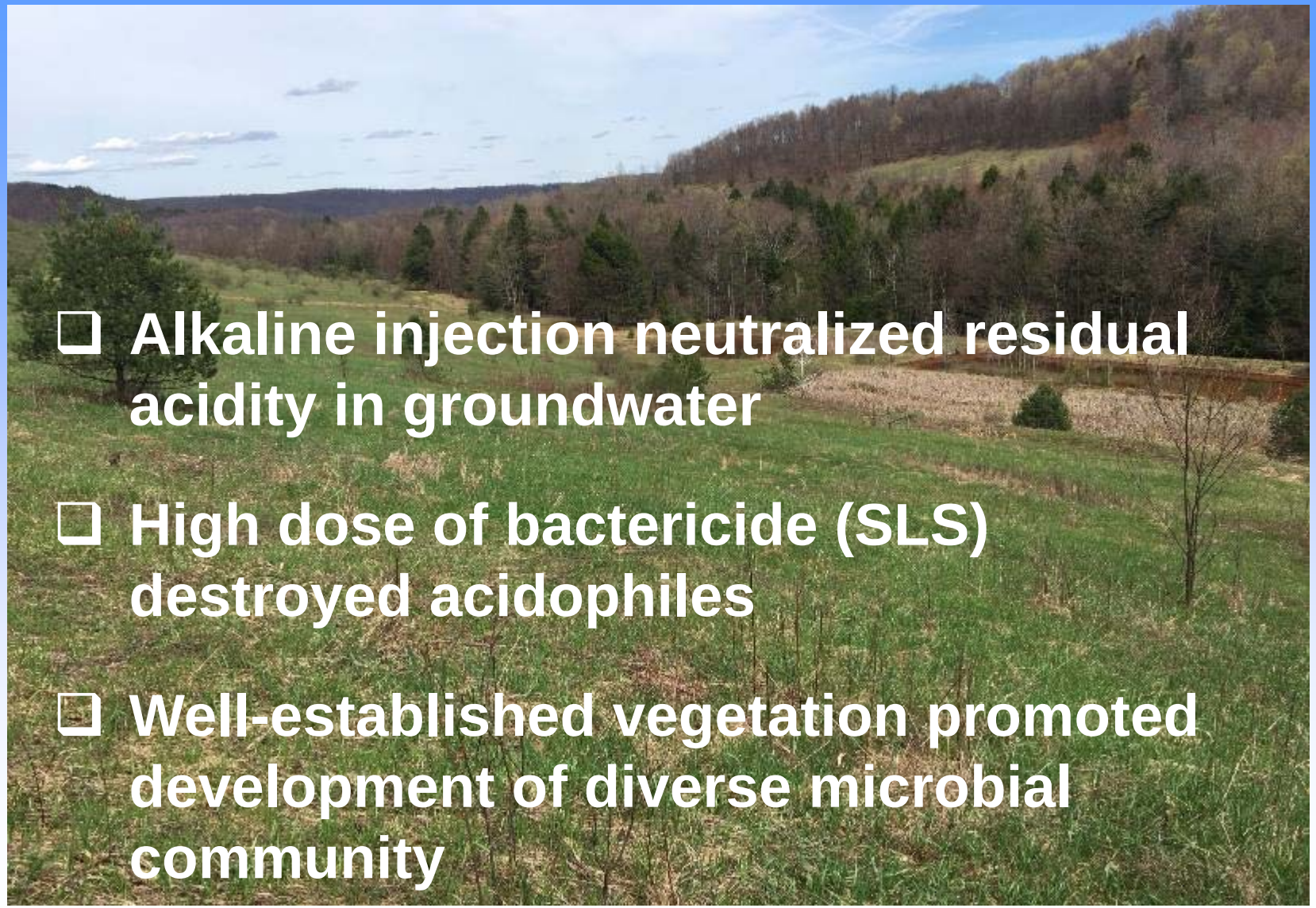


Ref: Gusek & Plocus, 2016

Results

- Cost of reagents: $US 8,400
- After injection, shut down alkaline addition
- Permit conditions now met at seep
- Passive system is not needed
- Seepage is still net alkaline 21 years later
- Bond release is imminent

Why Does It Still Work @ Fisher – 21 Years Later?



- Alkaline injection neutralized residual acidity in groundwater
- High dose of bactericide (SLS) destroyed acidophiles
- Well-established vegetation promoted development of diverse microbial community

Photo courtesy M. Hudock

Why Did the Bactericide Strategy Disappear?

- **Patented product (ProMac)**
  - Used primarily for coal mine–
  - Initial focus was revegetation
  - Miners wanted a “magic bullet”, proven technology
  - Primary proponent was viewed as a “vendor”; his retirement & failure to find a successor was detrimental
- **Narrow application methods (pellets & single dose spray application)**

Why Did the Bactericide Strategy Disappear?

- Concerns with uniformity of application and longevity
- No thorough understanding of process (importance of vegetation and probiotic community in suppressing ARD)
- ***Successes not tracked; remediated sites fell off regulatory radar screens***

What is Sustainable Closure?

The site requires:

1. **Little or no maintenance**
2. **Infrequent inspection**
3. **Little or no long term monitoring**
4. **A final land use that benefits society**

How Can We Get There?

New Technologies

- Drip irrigation technology for ARD suppressant solution delivery
- Use temporarily stable foams to delivery bactericidal reagents (solid, liquid, or gaseous)
- Buffering of reagent solution could lower bactericide concentration & costs
- Advances in revegetation technology (biochar amendments) to accelerate site cover maturity

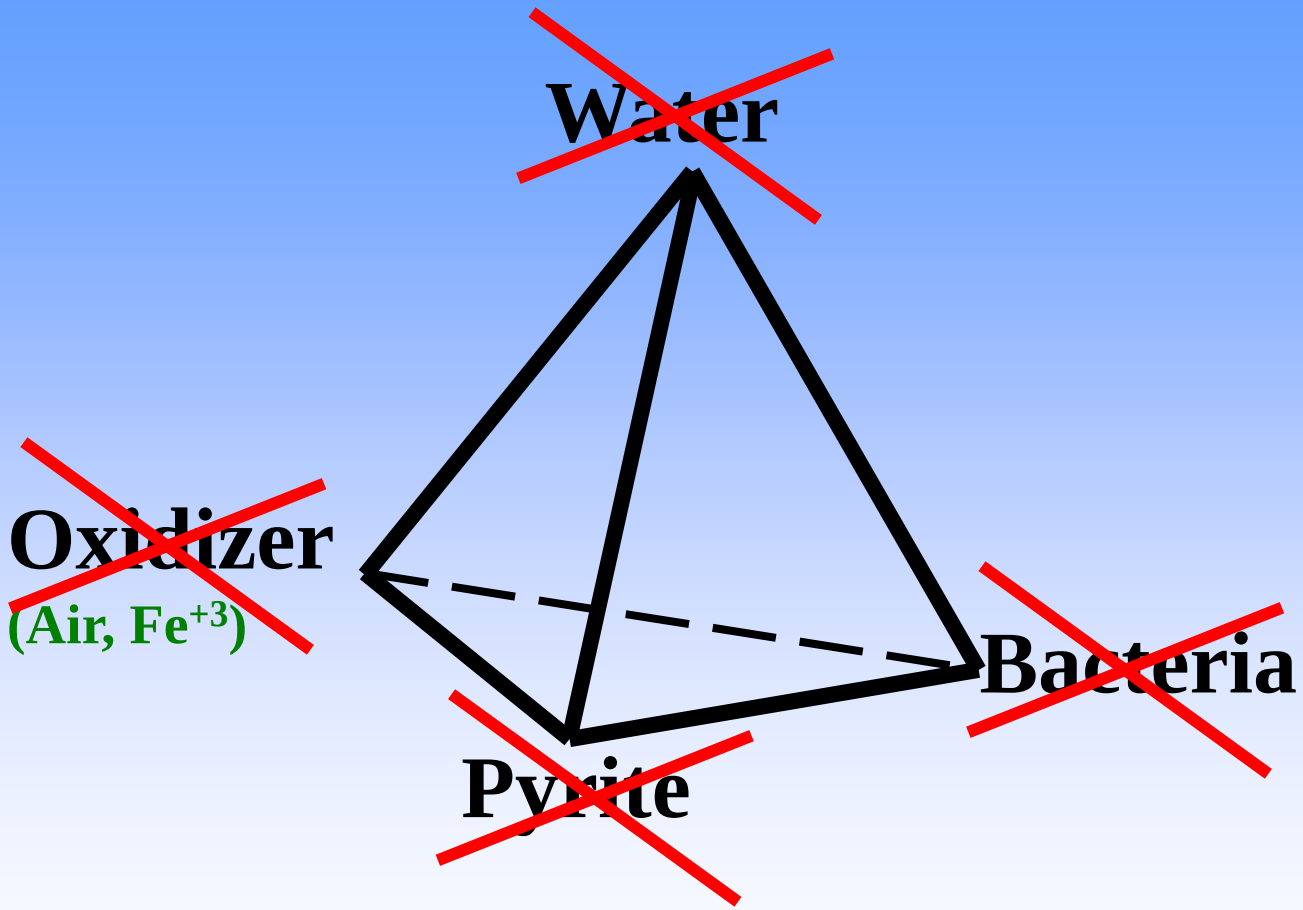
www.aerix.com

www.diynatural.com

Merging Technologies

1. Primary application of SLS to decimate acidophile populations
2. Application of waste milk or other organic (with inoculant) to support competing heterotrophes
3. Establishing a vibrant and sustainable vegetative cover to keep heterotrophic community healthy for decades or <u>longer</u>

Acid Rock Drainage Tetrahedron - Recap



DO SOMETHING (<u>anything</u>) = Sustainable closure

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Summary

- Source control can be effective
- Requires good site characterization
  - Each site is unique
  - Identify all sources
  - May require several methods
  - Generally requires on-site testing

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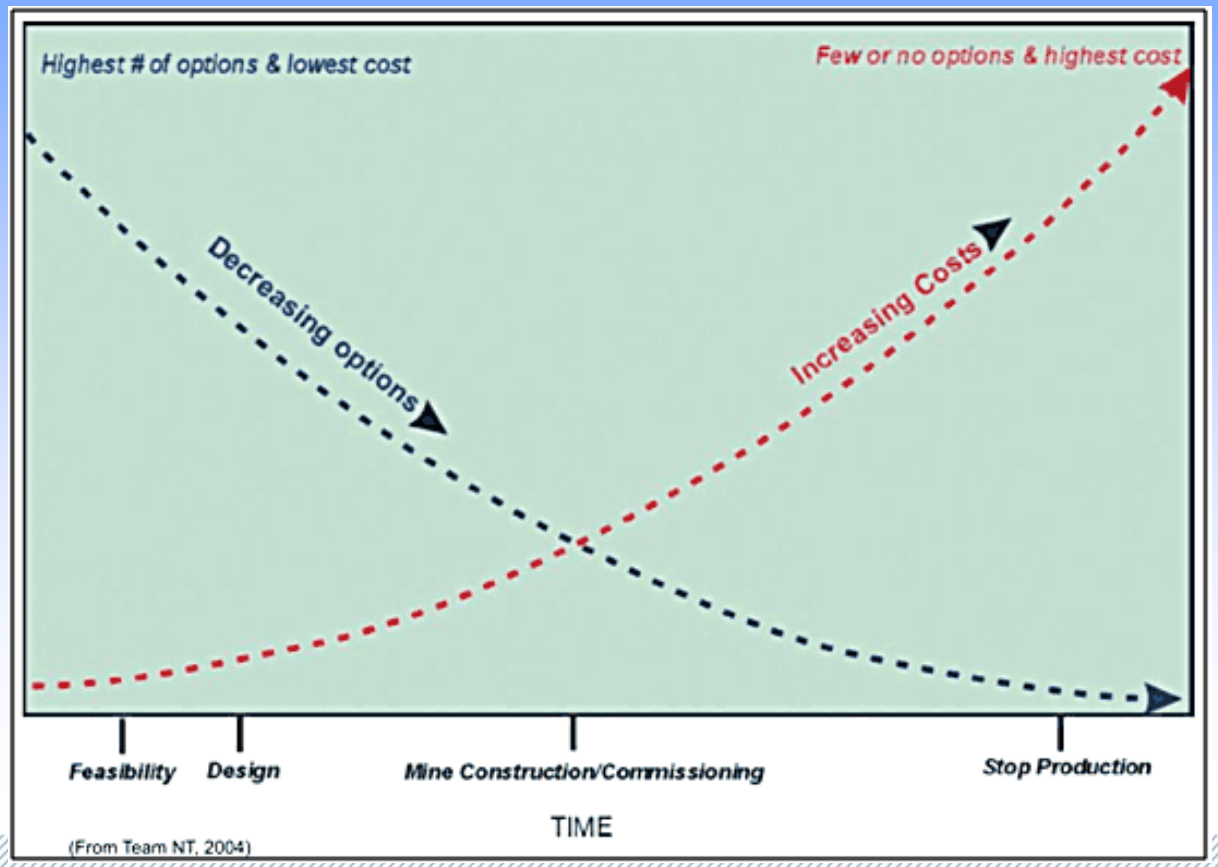
Summary

- New operations
  - More demonstrated options



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Summary

- Existing and Legacy
  - Fewer options
    - Covers
    - Bactericides / Organics

Where do we go from here?

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Next Steps

- Proof of Principle testing
  - Have developed partnership with universities and colleges to help with testing and reduce costs
    - Bactericides
    - Milk
- Field trial
- Partner with site and a problem

Thank You

Questions?

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