SOVEREIGN CONSULTING INC.
AN ENVIRONMENTAL SERVICES FIRM

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

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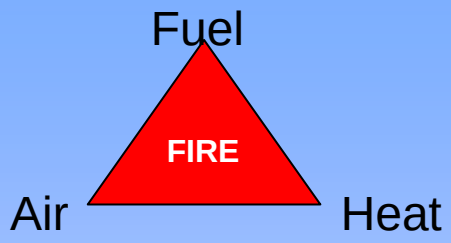
Acid Rock Drainage

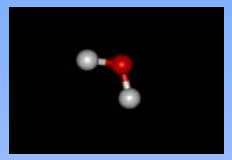
OUTLINE

- **ARD Suppression Background**
  - ARD Tetrahedron
  - History
  - How Bactericides Work
- **Three Case Histories**
- **A Pathway to Walk-Away?**
  - Employ New Technologies
  - **D**ecimate, **O**ut-Compete; **S**ustain [**DOS**]

Acid Rock Drainage Tetrahedron

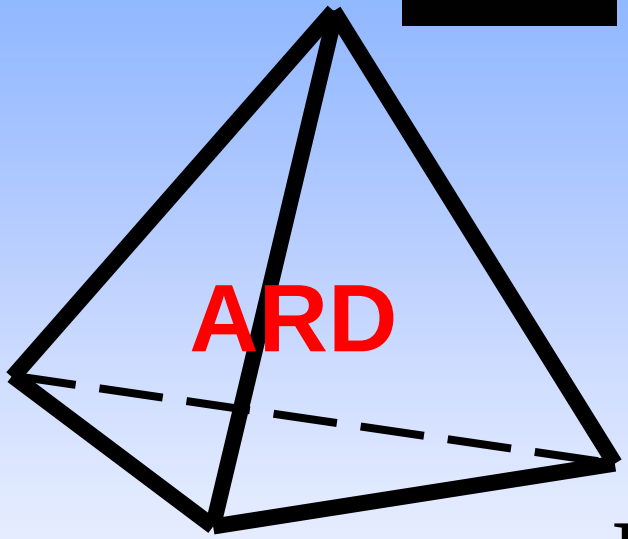


Water



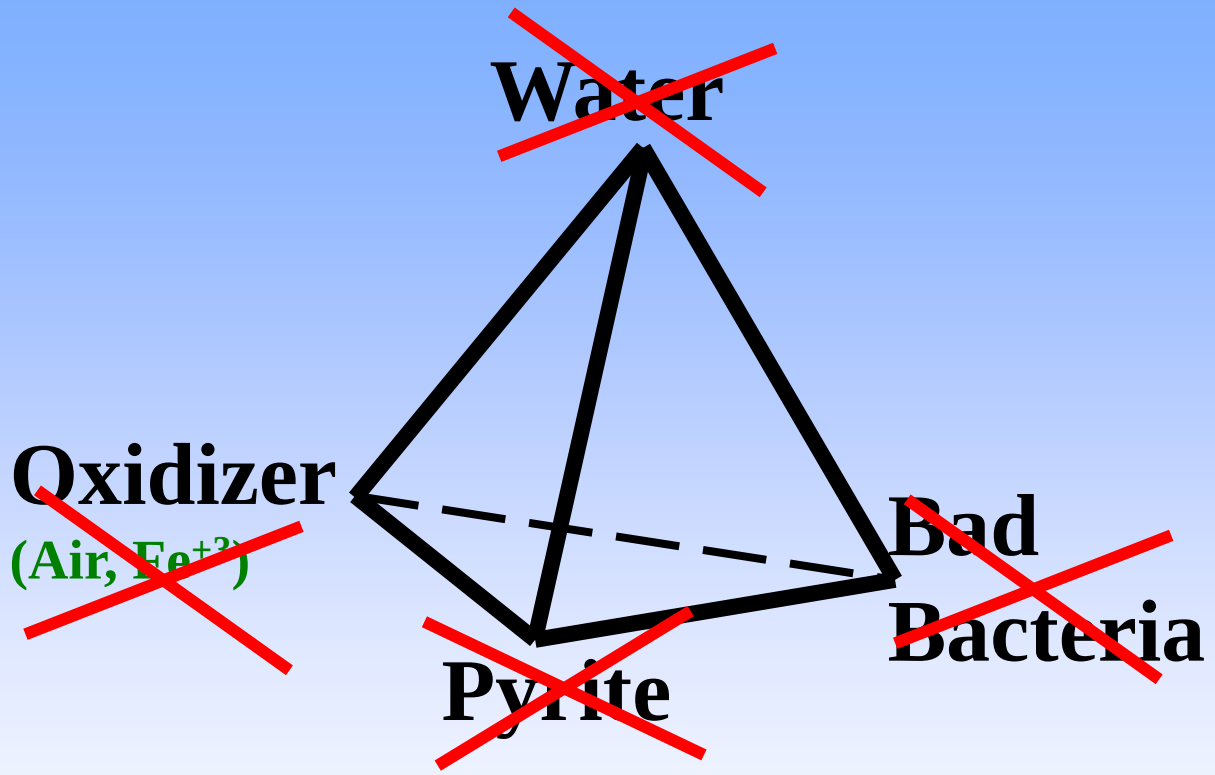
Oxidizer

(Air, Fe^{+3})



Bacteria

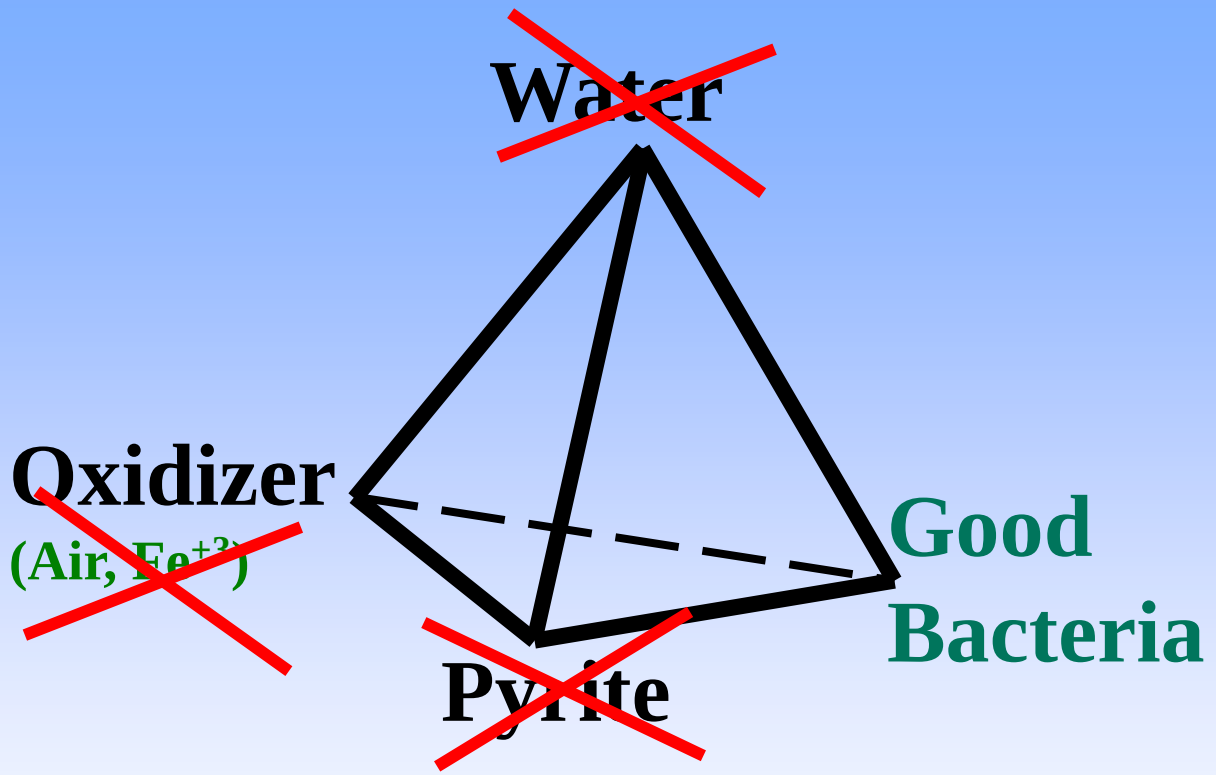
Acid Rock Drainage Tetrahedron



DO NOTHING = **PERPETUAL TREATMENT**

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

Acid Rock Drainage Tetrahedron

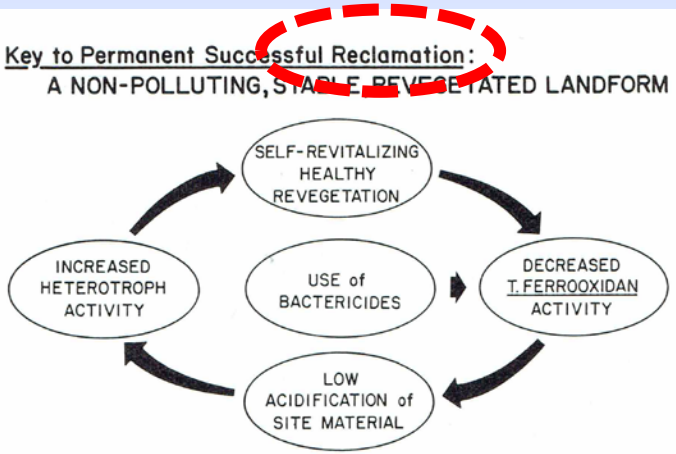


“PROBIOTIC”
PATHWAY TO WALK-AWAY

History

- Bacteria are important (1950)
- Common surfactants are effective bactericides (1980s-1990s)
- Kleinmann & Erickson
  USBM RI 8847 (1983)
- 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)



Kleinmann & Erickson 1983

- ***Thiobacillus ferrooxidans*** dramatically increases rate of pyrite oxidation
- Developed a laboratory procedure to determine application rates
- Case studies : two sites
  - 60% to 95% decrease in acid production
  - 90% to 95% decrease in iron
- Temporary effect: re-apply three times per year

Bohac, et al., 1987

Microbiological Studies of Sites Reclaimed with Bactericides

Proceedings, WV Mine Drainage Task Force

- **Norton Coal Refuse, WV**
- **Route 43, Jefferson County, OH**
- **“Southern OH”**

Known Bactericides

- Sodium lauryl sulfate (SLS)
- Sodium laureth sulfate (SLES)
- Slow release commercial products – ProMac™ (no [illegible] available)
- Alkyl-benzen[illegible]onate (laundry deterge[illegible] cheaper than SLS)
- S[illegible]m Thiocyanate (NaSCN)
- [illegible]Bi-Polar Lipids (patented)

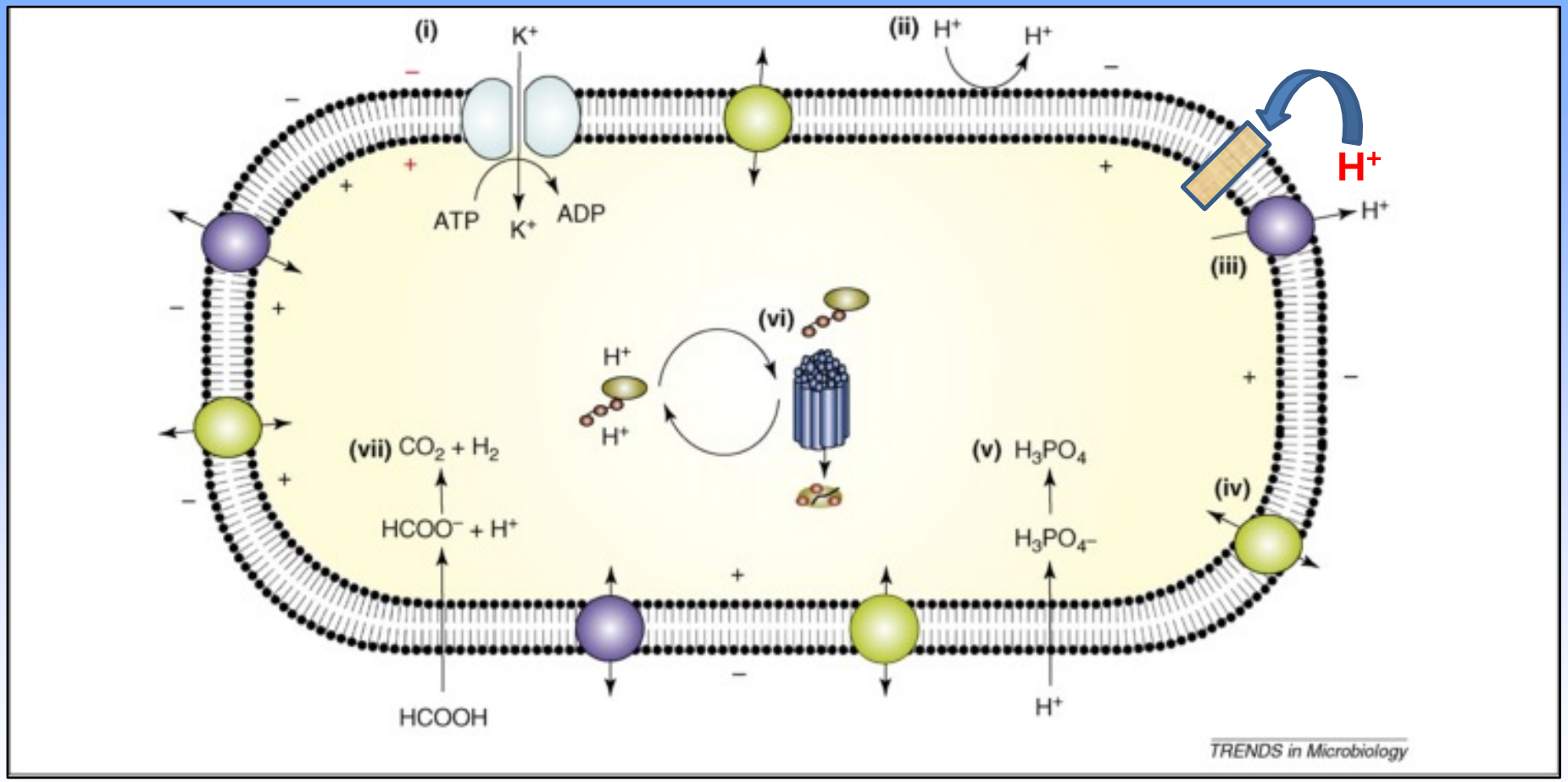
Some of these concepts are 35 years old

Organic Amendments

- Organic acids (Tuttle, et al., 1977)
- 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)**

How Bactericides Work

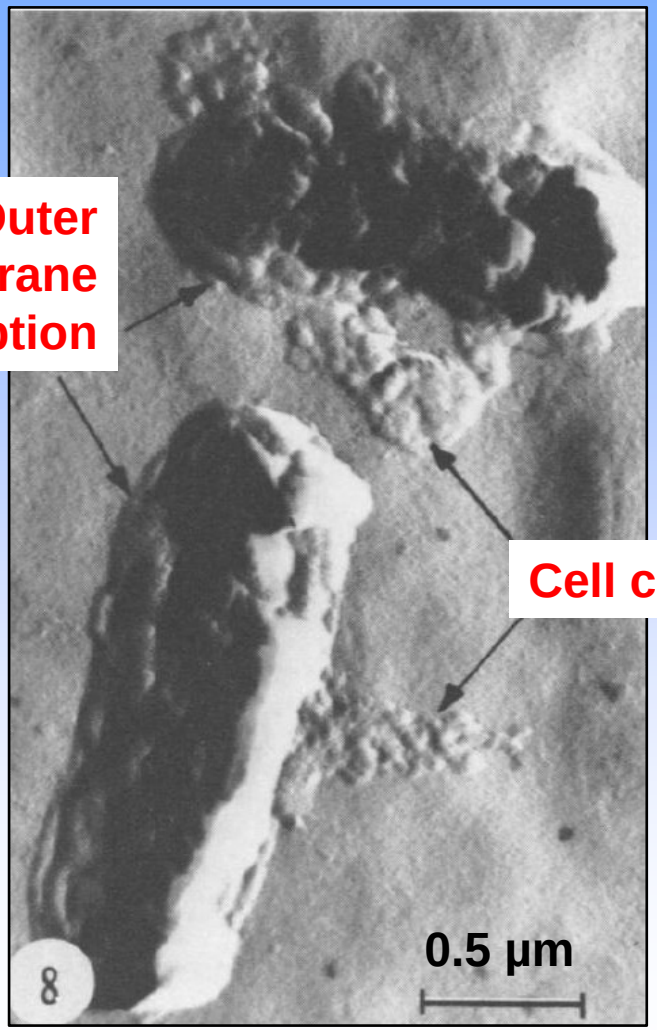
(Anionic Surfactants)



Baker-Austin & Dopson (2007)

How Bactericides Work

(Organic Acids)



Tuttle, et al. 1977

Bactericide Case Histories

1. Route 43, Jefferson County, OH
2. North Fork Coal Mine, Wise County, VA
3. Fisher Coal Mine, Indiana County, PA

DO YOU KNOW OF OTHERS???

IS THIS TOO GOOD TO BE TRUE???

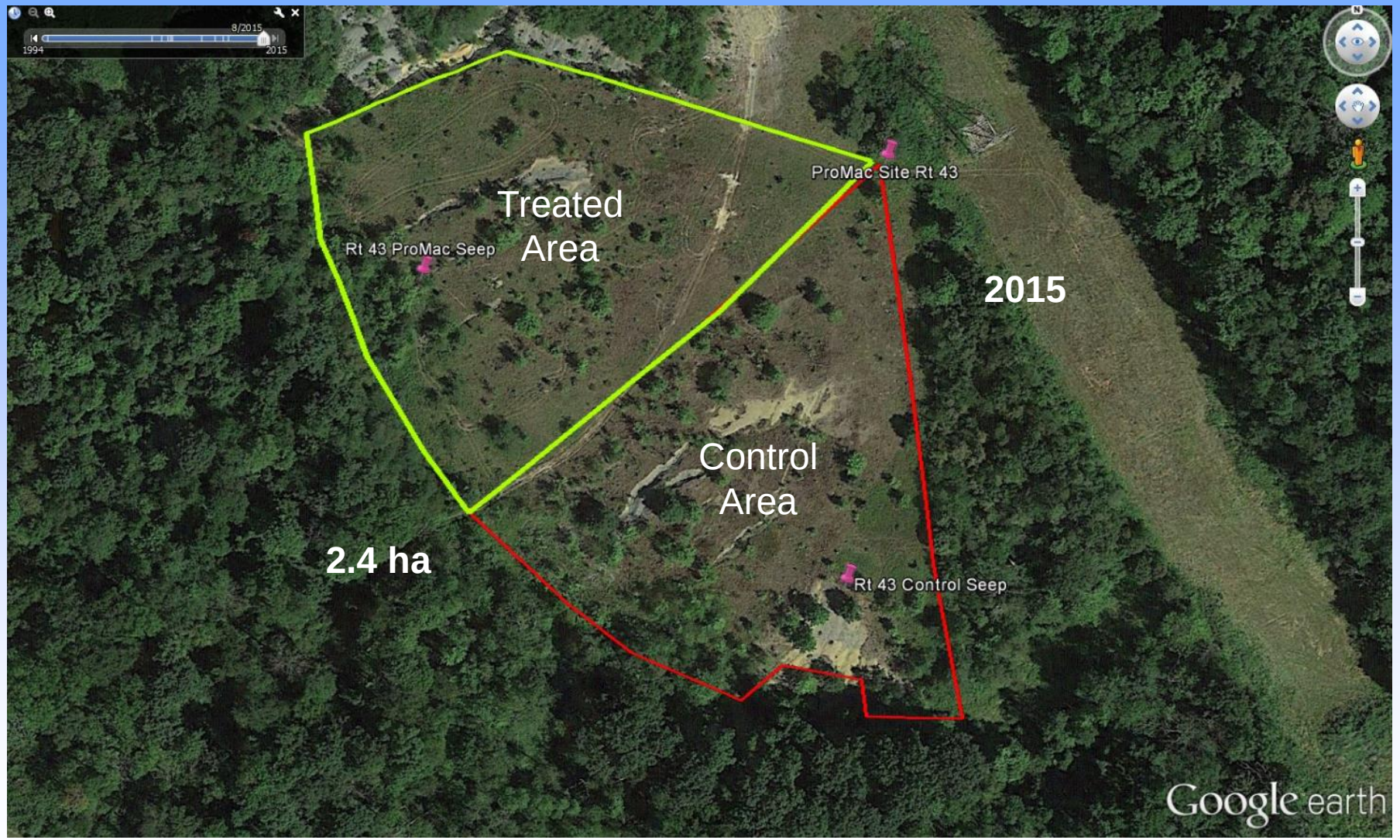
Definition of “Long Term” Success

A. Site exhibited ARD and it received an engineered dose of bactericide or other material intended to disrupt ARD microbial kinetics

B. No evidence of ARD observed in air photo imagery and/or

C. The site has been completely dropped from regulatory sampling programs (nothing to monitor)

1 - Route 43, Jefferson County, OH



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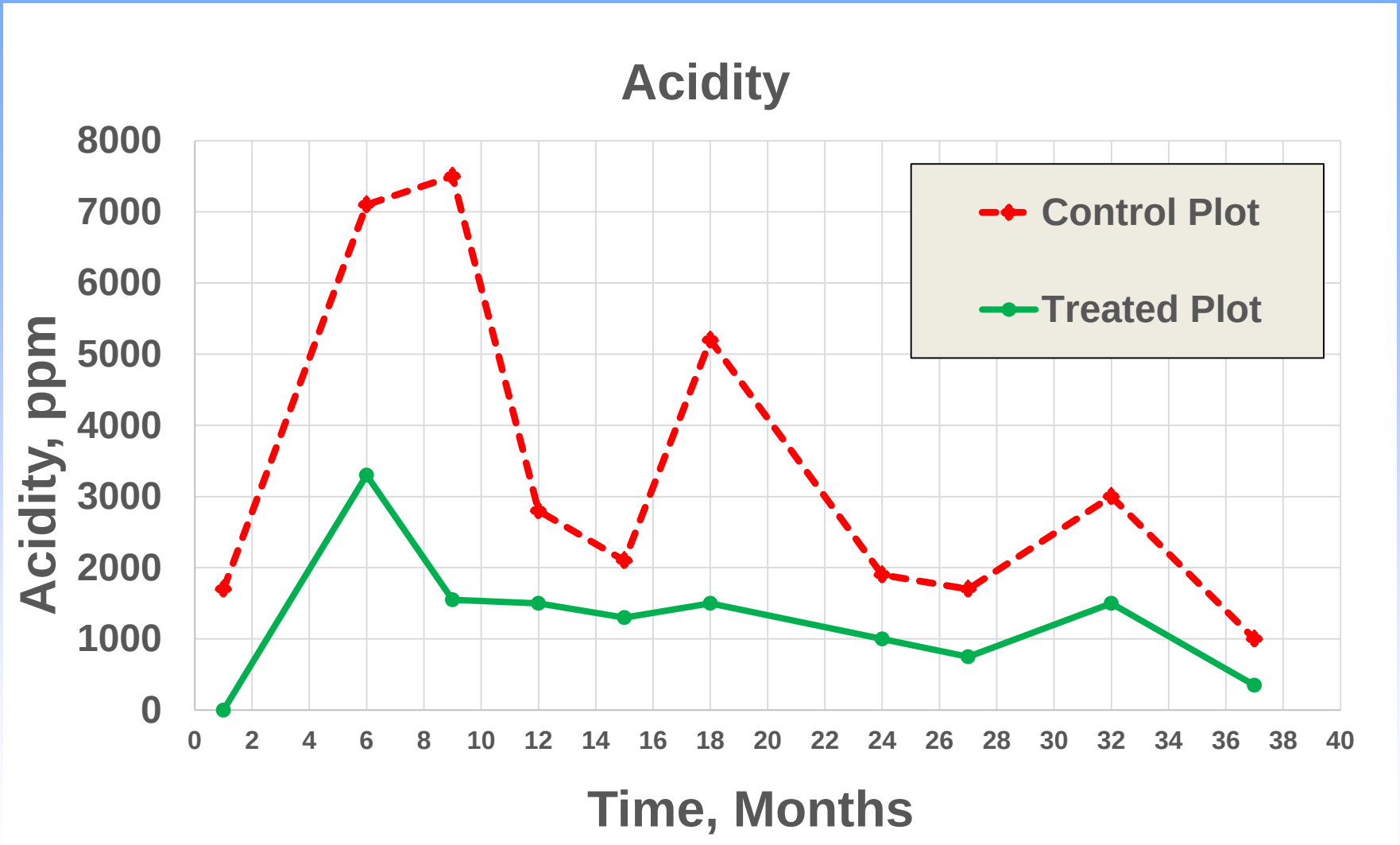
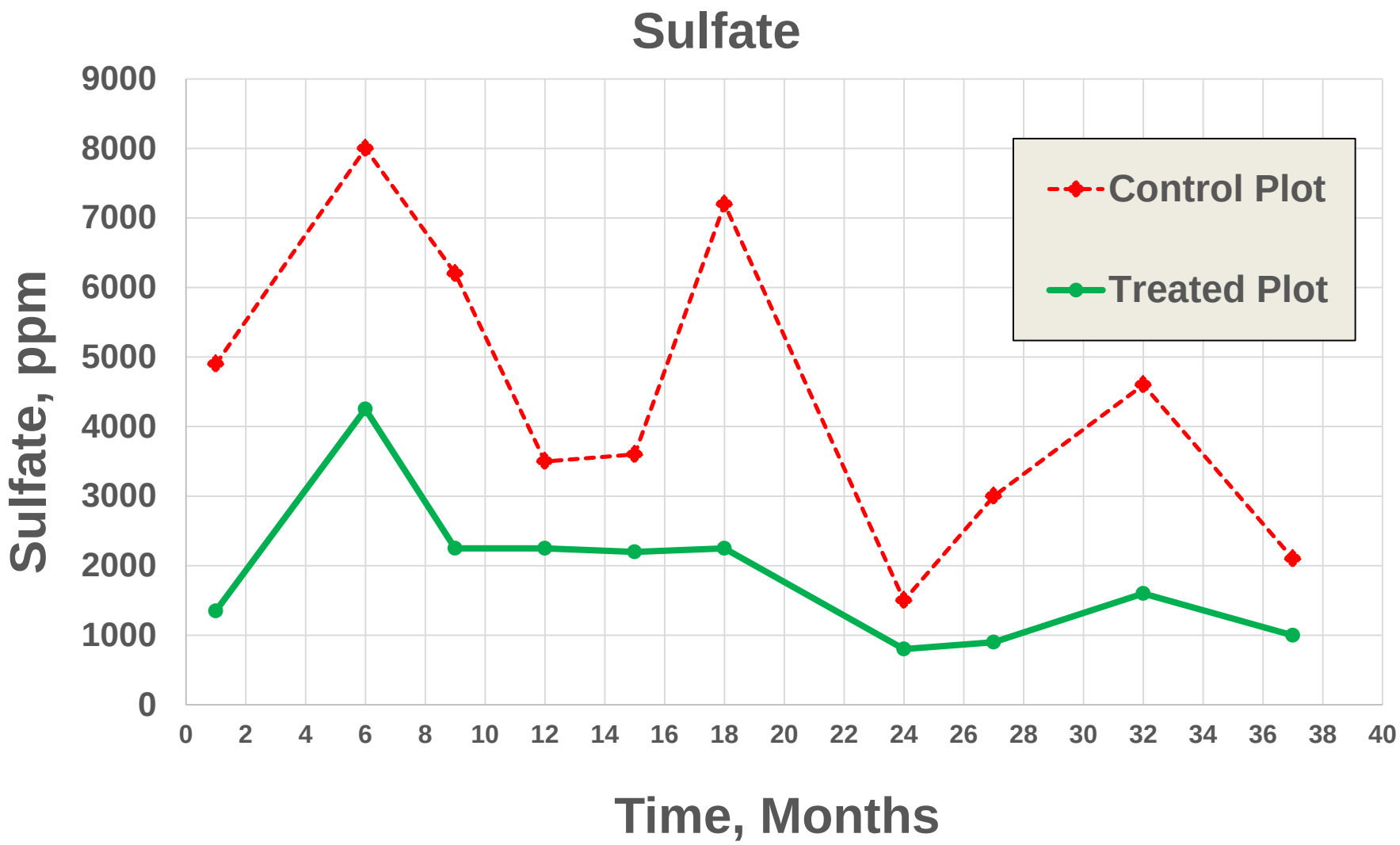


Sobek, et al., 1990

1 - Route 43, Jefferson County, OH



Sobek, et al., 1990

1 - 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

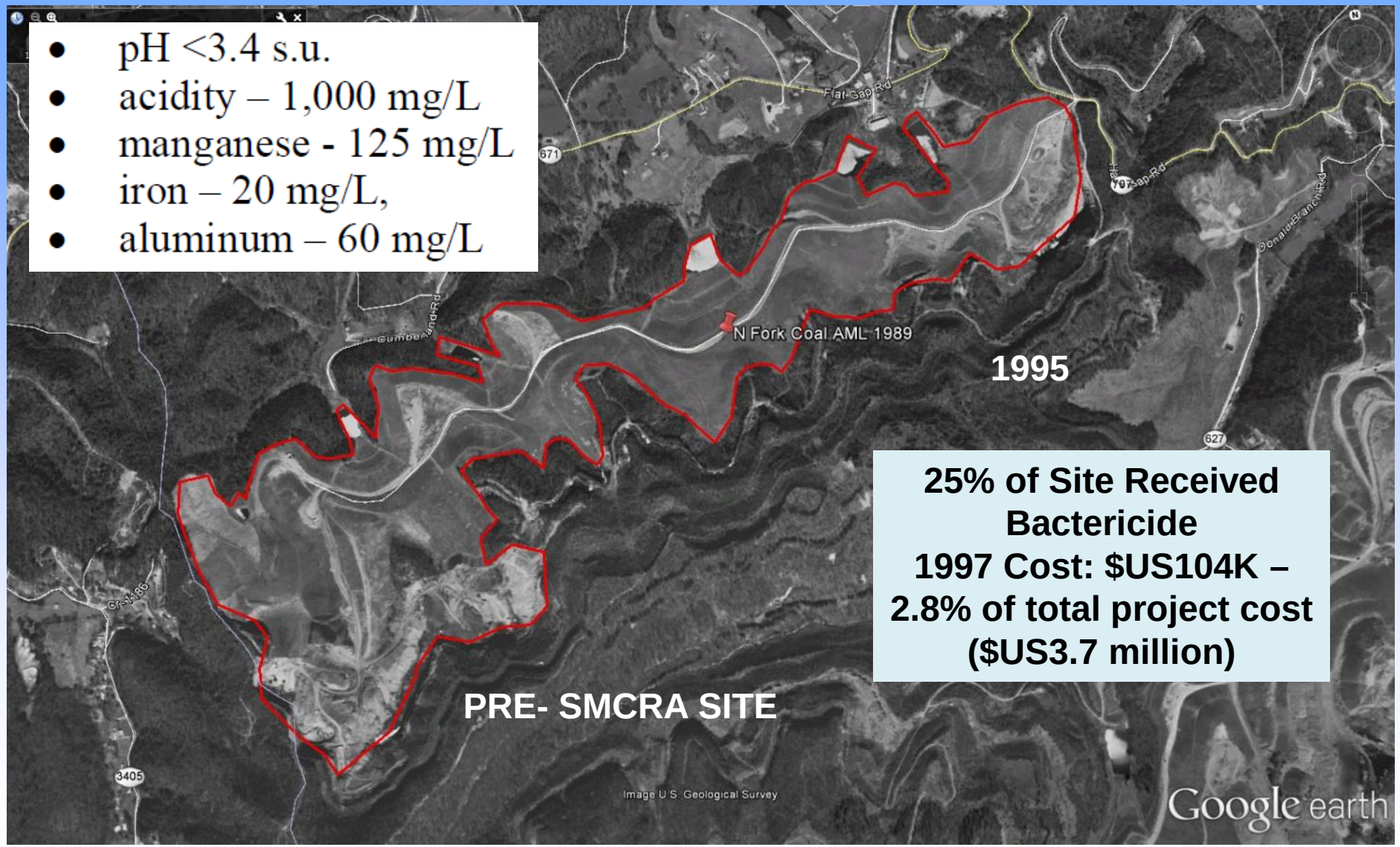
BAD Bugs decimated

GOOD Bugs happy

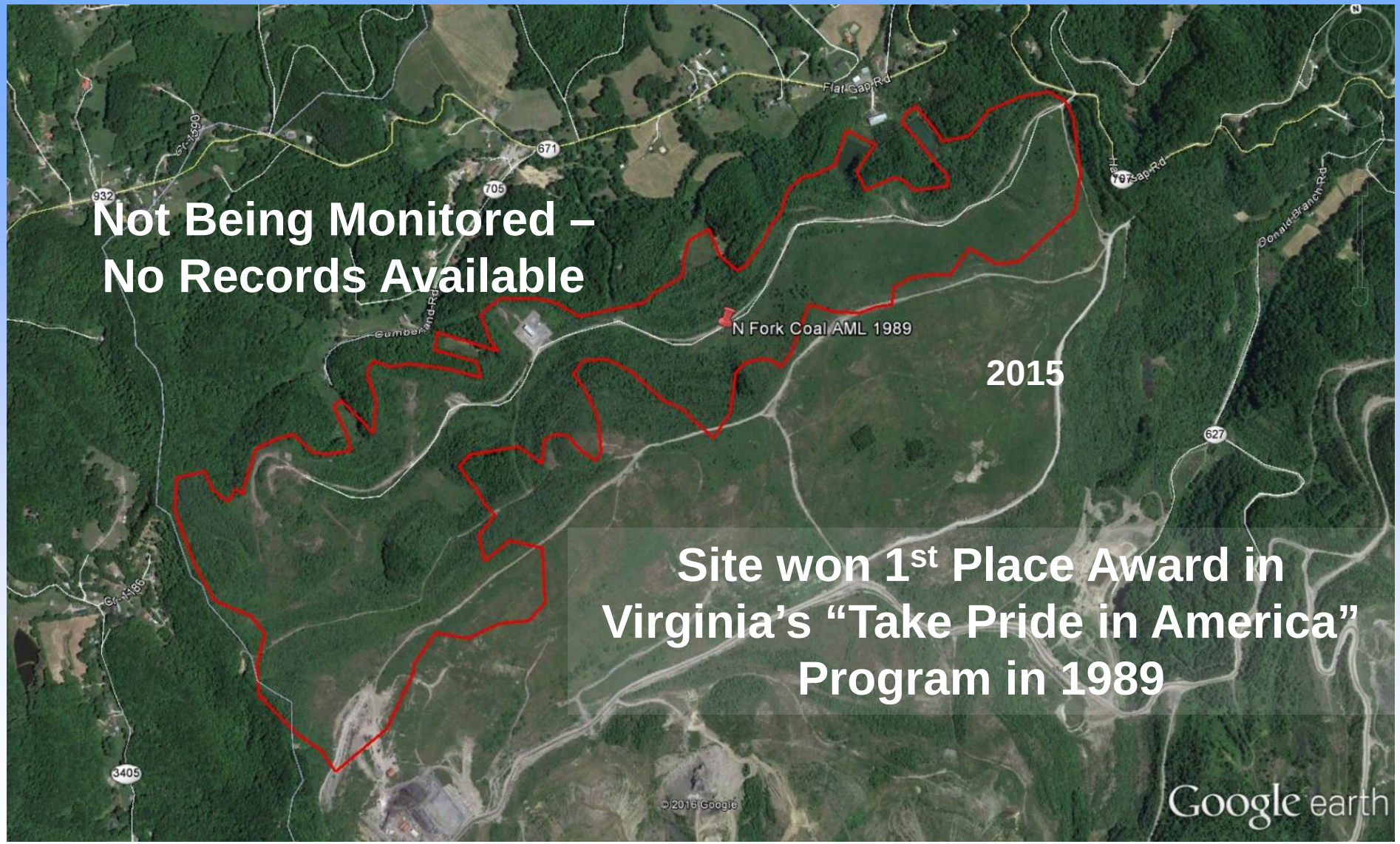
BAD:GOOD Bugs

Maierhofer, 1988

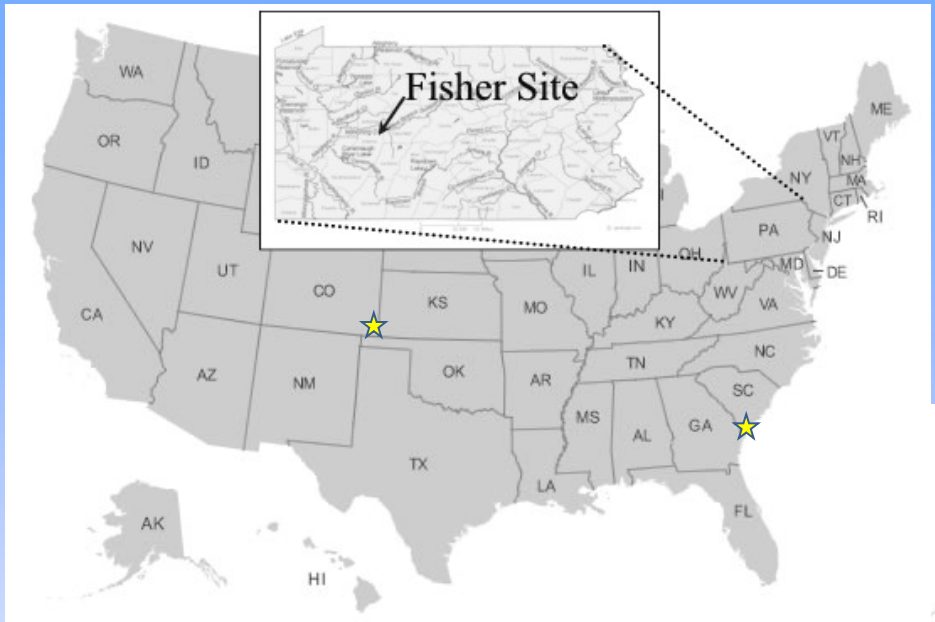
#2 – North Fork Coal Mine, VA



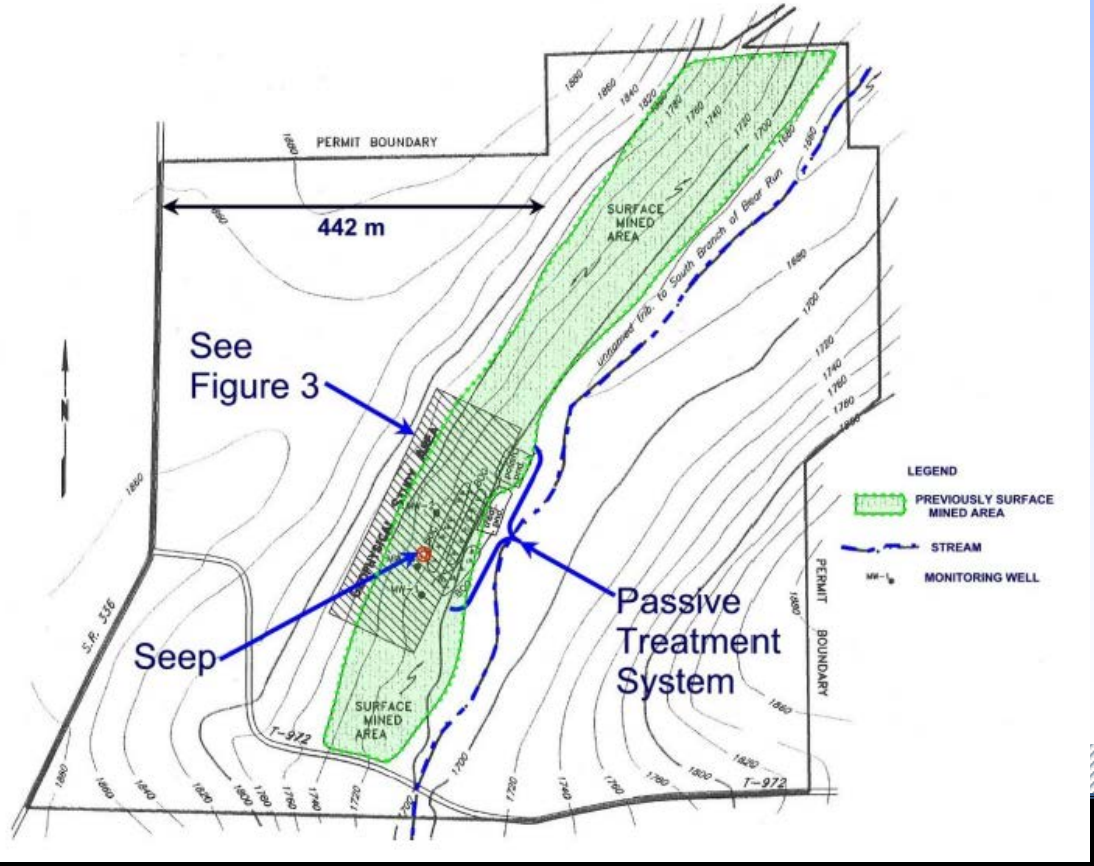
#2 – North Fork Coal Mine, VA



3 Fisher Coal Mine, Indiana County, PA

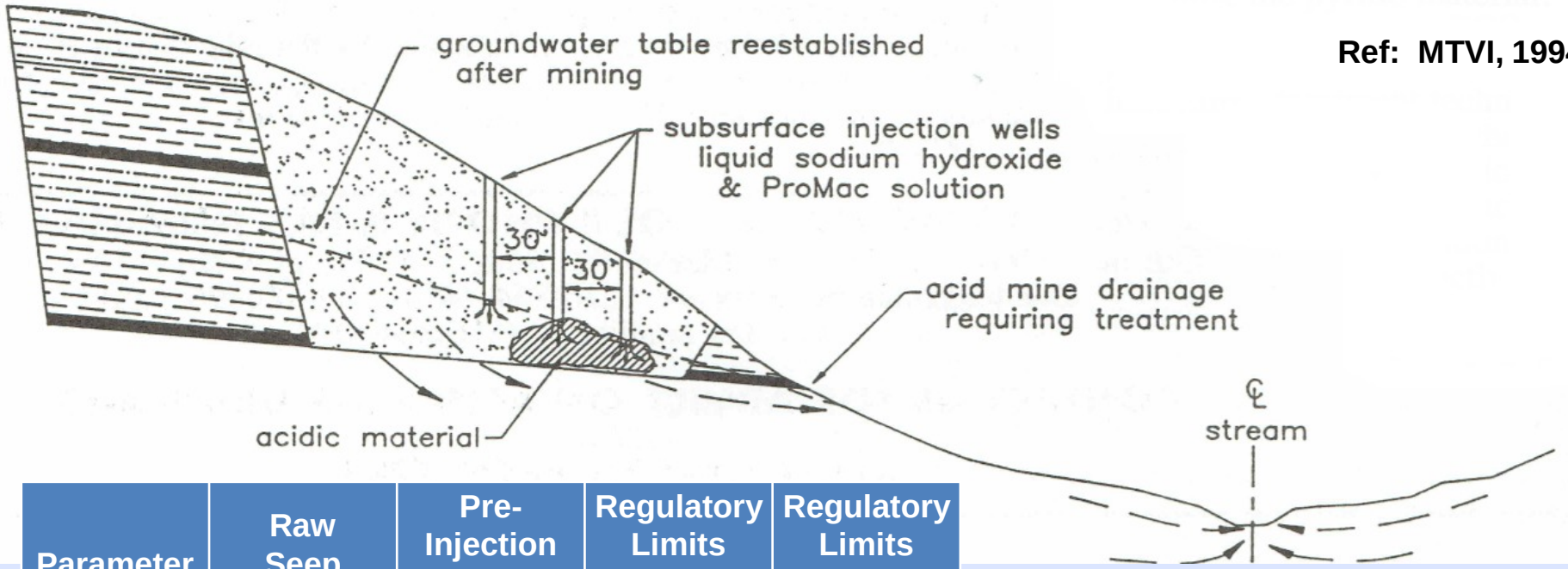


108 km NW of Pittsburgh, Pennsylvania USA



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

3 Fisher Coal Mine, Indiana County, PA



Ref: MTVI, 1994

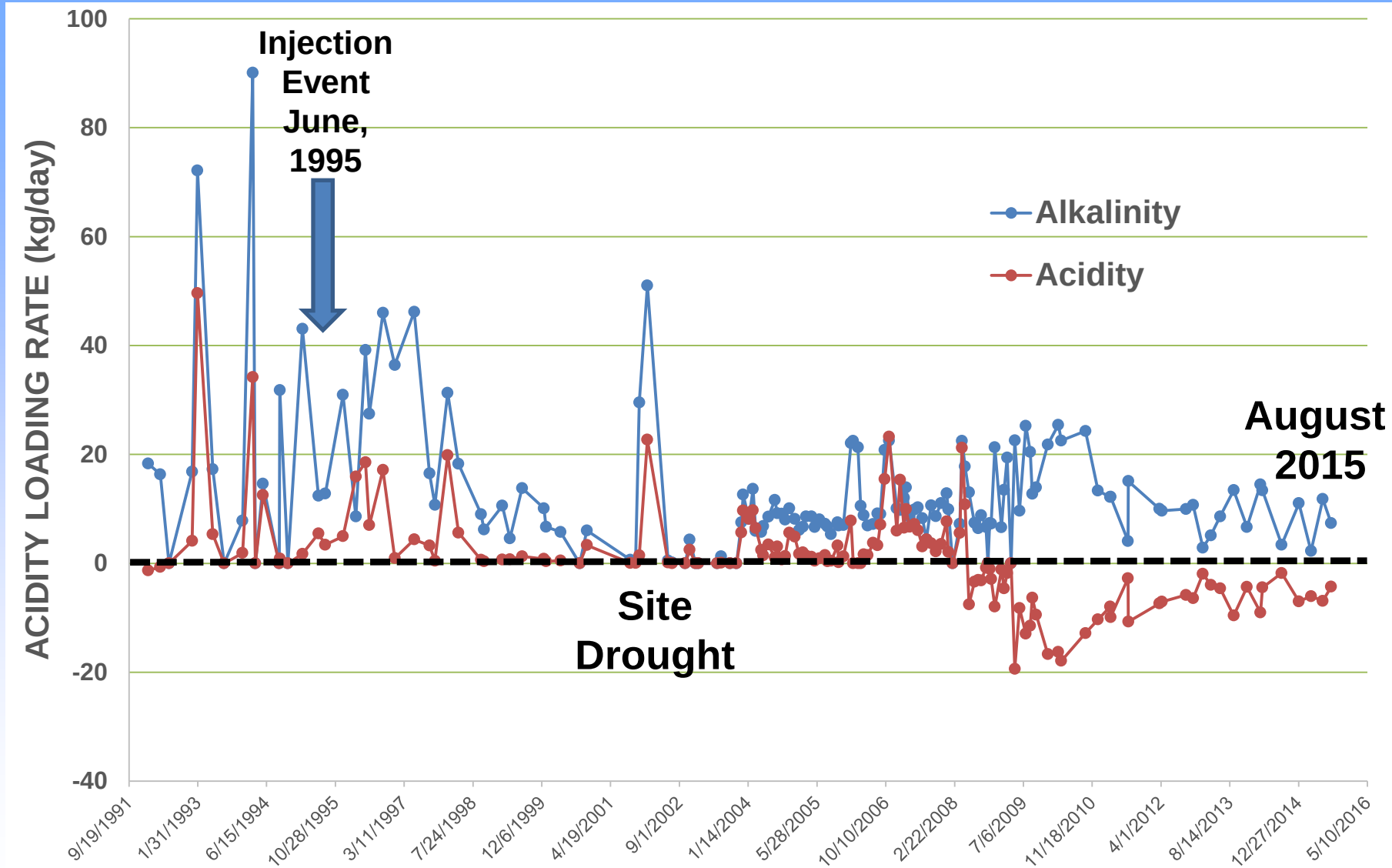
Parameter	Raw Seep Value	Pre-Injection "Bog" Effluent	Regulatory Limits (Monthly avg.)	Regulatory Limits (Instant. Max.)
Iron (mg/L)	8 to 42	17.7	3.0	7.0
Manganese (mg/L)	6 to 12	12.4	2.0	5.0
pH (s.u.)	5 to 6	5.5	6.0 to 9.0	
Acidity (mg/L)	>alkalinity	Est. ~54	<alkalinity	n/a

"Not the worst ARD ever, but out of compliance."

1995 Injection Event

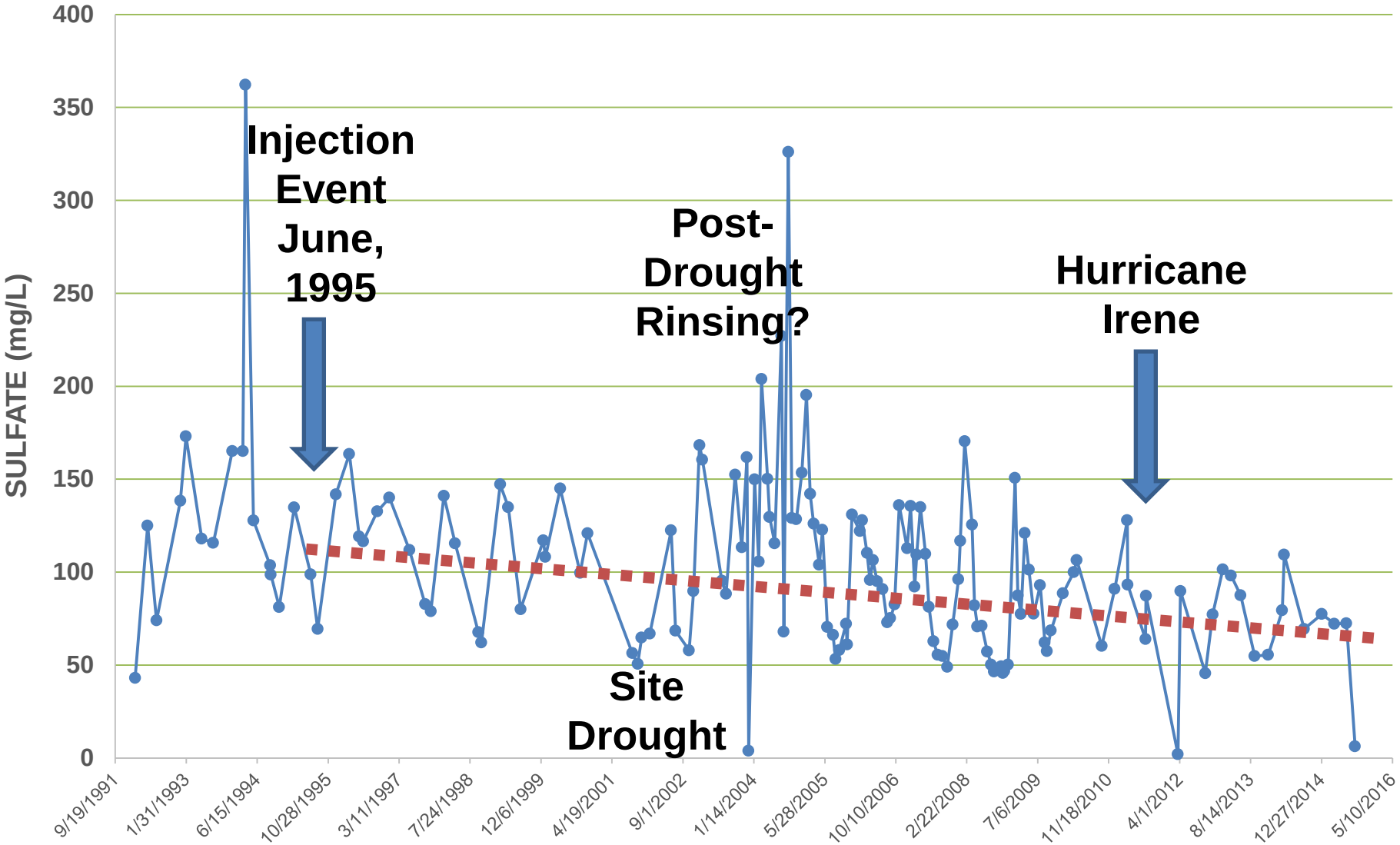
- Seep pH was 5.5; iron 17 mg/L and higher
- Passive treatment alone could not meet discharge limits
- *Geophysics* targeted three ARD–generating zones
- Multiple injection boreholes on a tight spacing
- Injection of 20% NaOH solution simultaneously into 12 shallow (3 m deep) boreholes with packers
- Injection of 2% sodium lauryl sulfate bactericide
- **Cost of reagents: $US8,400**
- **Seepage continues to be net alkaline 21 years later; bond release is under review (State is OK with it).**

Acidity Loading



Ref: Gusek & Plocus, 2016

Sulfate Trends



Ref: Gusek & Plocus, 2016

Why Does It Still Work – 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

Why Did the Bactericide Strategy Disappear?

- **Patented product (ProMac)**
  - Used in coal mining and very few hard rock sites – focus on reveg.
  - 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)**
- **Miners didn’t accept the importance of vegetation and the probiotic community in suppressing ARD**
- ***Successes not tracked; remediated sites fell off regulatory radar screens***
- **“Walk-away” conflicts with consultants’ bu$ine$$ model (lime do$ing plant$ operating in perpetuity)**

What is Walk-Away?

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?

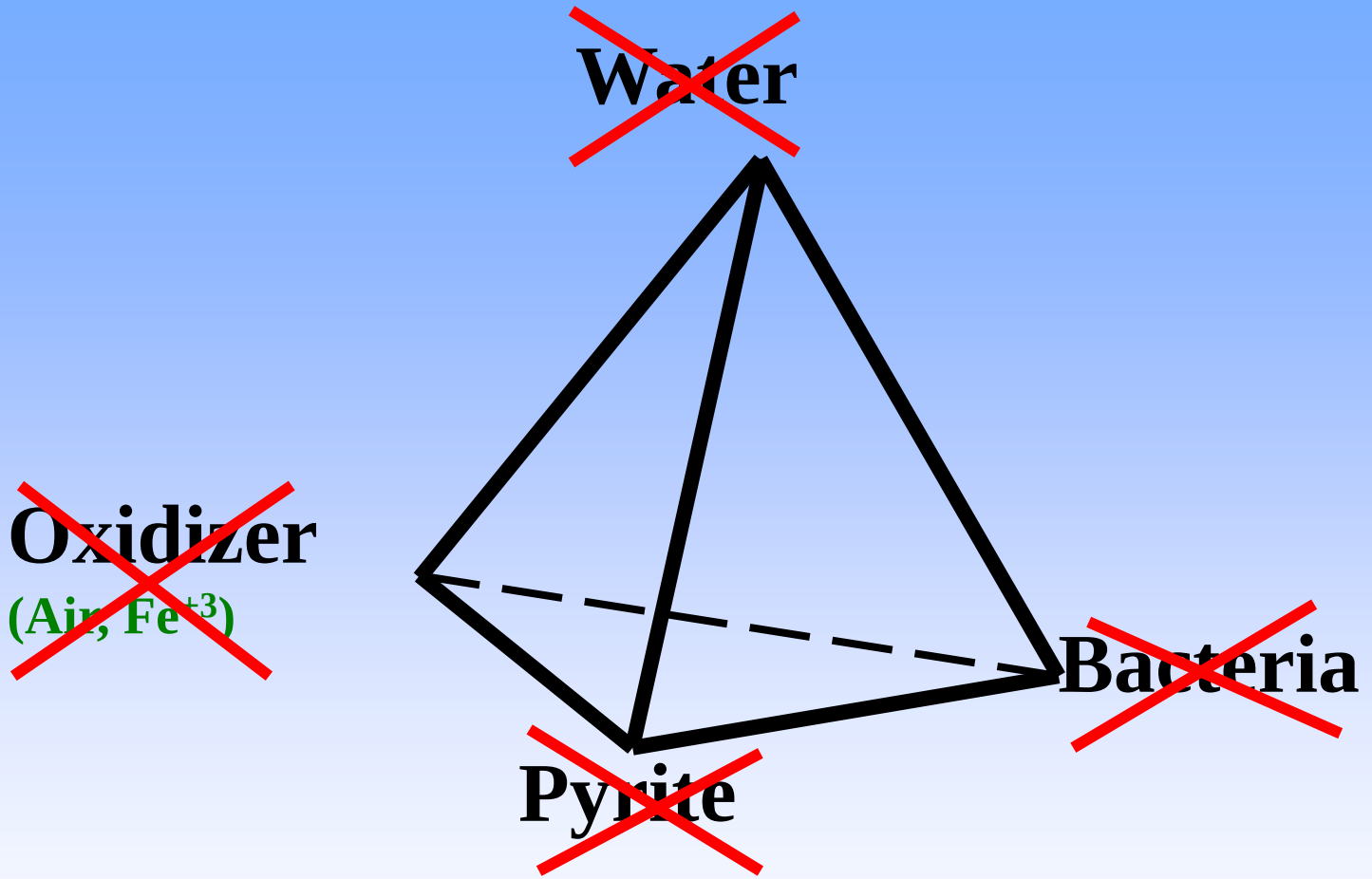
Employ New Technologies

- Drip irrigation technology for ARD suppressant solution delivery
- Use temporary stable foams to deliver 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 & increase productivity

DECIMATE; OUT-COMPETE; SUSTAIN [DOS]

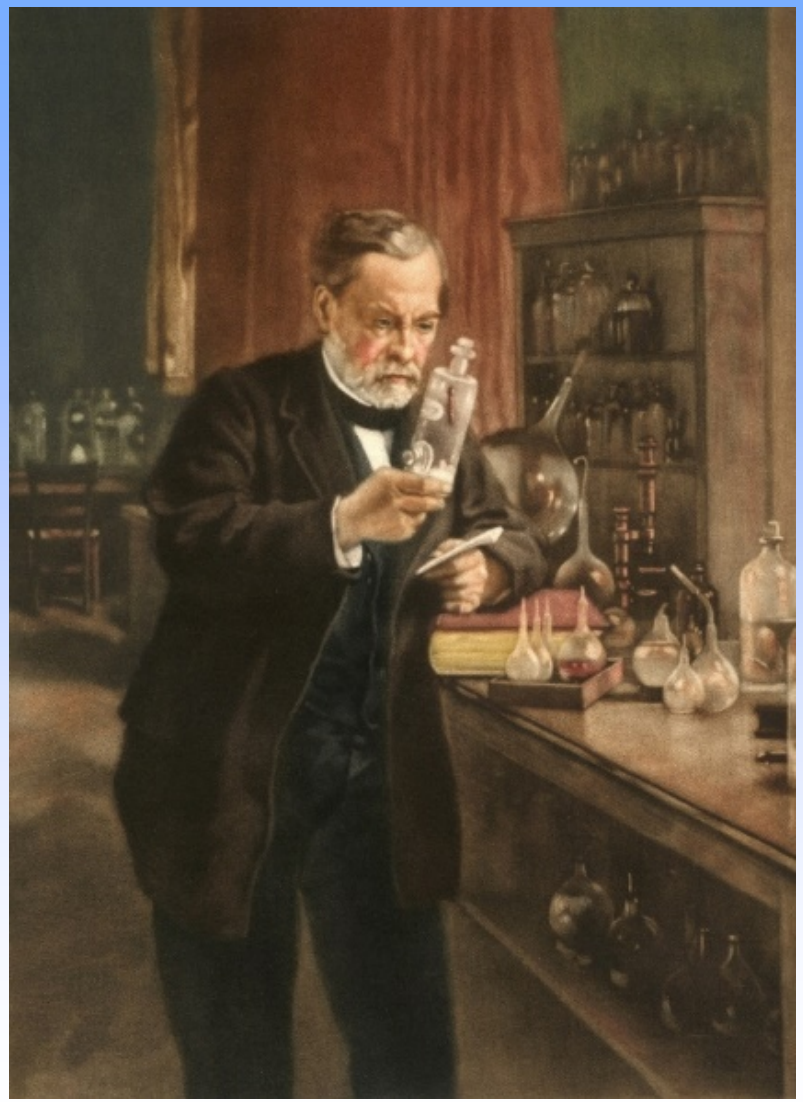
1. Primary application of SLS to **decimate** acid-loving bug populations
2. Application of waste milk or other organic (with inoculant) to make heterotrophic **good bugs** happy & **out-compete** acid-loving bugs
3. Establishing a vibrant and **sustain**able vegetative cover to keep **good bugs** happy for decades or <u>longer</u>

Acid Rock Drainage Tetrahedron



DO SOMETHING (<u>anything</u>) = PATHWAY TO WALK-AWAY

Thank You



Nihil simul inventum est et perfectum

- Latin Proverb

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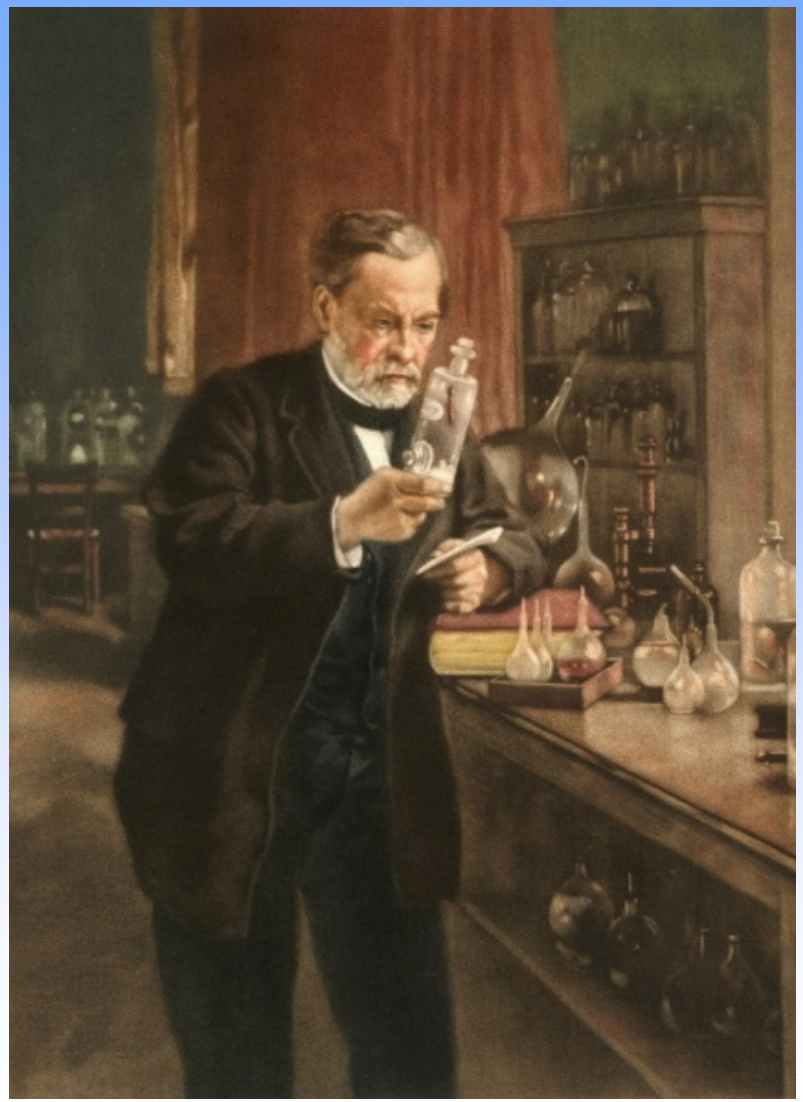
Thank You



Nothing is invented and perfected at the same time.

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